

Sediment Deposition and Occurrence of Selected Nutrients and Other Chemical Constituents in Bottom Sediment, Tuttle Creek Lake, Northeast Kansas, 1962–99

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CONVERSION FACTORS, ABBREVIATIONS, AND DEFINITION

	Multiply	By	To obtain
	acre	0.40468	hectare
	acre	43,560	square foot
	acre	4,047	square meter
	acre	0.001562	square mile
	acre-foot (acre-ft)	43,560	cubic feet
	acre-foot (acre-ft)	1,233	cubic meter
	centimeter (cm)	0.3937	inch
	cubic centimeter (cm ³)	0.06102	cubic inch
	cubic foot (ft ³)	2.296 x 10 ⁻⁵	acre-foot
	cubic foot (ft ³)	0.02832	cubic meter
	foot (ft)	0.3048	meter
	gram (g)	0.03527	ounce
	gram per cubic centimeter (g/cm ³)	62.43	pound per cubic foot
	hectare (ha)	0.003861	square mile
	inch (in.)	2.54	centimeter
	inch per hour (in/hr)	2.54	centimeter per hour
	kilogram (kg)	2.205	pound
	kilogram per cubic meter (kg/m ³)	0.06243	pound per cubic foot
	kilogram per hectare (kg/ha)	571	pound per square mile
	kilogram per hectare per year [(kg/ha)/yr]	571	pound per square mile per year
	kilogram per year (kg/yr)	2.205	pound per year
	meter (m)	3.281	foot
	mile (mi)	1.609	kilometer
	microgram per gram (µg/g)	1.0	milligram per kilogram
	microgram per gram (µg/g)	1.0	part per million
	microgram per kilogram (µg/kg)	0.001	milligram per kilogram
	microgram per kilogram (µg/kg)	1.0	part per billion
	milligram per kilogram (mg/kg)	1.0	part per million
	millimeter (mm)	0.03937	inch
	percent concentration	10,000	milligram per kilogram
	pound (lb)	0.45359	kilogram
	pound per cubic foot (lb/ft ³)	16.02	kilogram per cubic meter
	pound per square mile (lb/mi ²)	0.1751	kilogram per square kilometer
	pound per square mile per year [(lb/mi ²)/yr]	0.1751	kilogram per square kilometer per year
	pound per year (lb/yr)	0.45359	kilogram per year
	square foot (ft ²)	0.09290	square meter
	square mile (mi ²)	259.0	hectare
	square mile (mi ²)	2.590	square kilometer

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

$$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$$

$$^{\circ}\text{F} = 9/5 (^{\circ}\text{C}) + 32$$

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.

Sediment Deposition and Occurrence of Selected Nutrients and Other Chemical Constituents in Bottom Sediment, Tuttle Creek Lake, Northeast Kansas, 1962–99

By Kyle E. Juracek *and* David P. Mau

Abstract

A combination of bathymetric surveying and bottom-sediment coring was used to investigate sediment deposition and the occurrence of selected nutrients (total ammonia plus organic nitrogen and total phosphorus), 44 metals and trace elements, 15 organochlorine compounds, and 1 radionuclide in bottom sediment of Tuttle Creek Lake, northeast Kansas. The total estimated volume and mass of bottom sediment deposited from 1962 through 1999 in the original conservation-pool area of the lake was 6,170 million cubic feet (142,000 acre-feet) and 292,400 million pounds (133,000 million kilograms), respectively. The volume of sediment occupies about 33 percent of the original conservation-pool, water-storage capacity of the lake. Mean annual net sediment deposition since 1962 was estimated to be 7,900 million pounds (3,600 million kilograms). Mean annual net sediment yield from the Tuttle Creek Lake Basin was estimated to be 821,000 pounds per square mile (1,440 kilograms per hectare).

The estimated mean annual net loads of total ammonia plus organic nitrogen and total phosphorus deposited in the bottom sediment of Tuttle Creek Lake were 6,350,000 pounds per year (2,880,000 kilograms per year) and 3,330,000 pounds per year (1,510,000 kilograms per year), respectively. The estimated mean annual net yields of total ammonia plus organic nitrogen and total phosphorus from the Tuttle Creek Lake

Basin were 657 pounds per square mile per year (1.15 kilograms per hectare per year) and 348 pounds per square mile per year (0.61 kilograms per hectare per year), respectively. No statistically significant trend for total phosphorus deposition in the bottom sediment of Tuttle Creek Lake was indicated (trend analysis for total ammonia plus organic nitrogen was not performed).

On the basis of available sediment-quality guidelines, the concentrations of arsenic, chromium, copper, nickel, silver, and zinc in the bottom sediment of Tuttle Creek Lake frequently or typically exceeded the threshold-effects levels established by the U.S. Environmental Protection Agency. Sediment concentrations of metals and trace elements were relatively uniform over time. Organochlorine compounds either were not detected or were detected at concentrations generally less than the threshold-effects levels. Following an initial positive trend, a statistically significant negative depositional trend was indicated for DDE (degradation product of DDT), which was consistent with the history of DDT use. Other organochlorine compounds detected included aldrin, DDD, and dieldrin.

Notable changes in human activity within the basin included a substantial increase in the production of grain corn and soybeans from the 1960s to the 1990s. This increase in production was accompanied by a pronounced increase in the number of irrigated acres. Also, during the same time period, there was an overall increase in hog

production. These changes in human activity have not had a discernible effect on the deposition of chemical constituents in the bottom sediment of Tuttle Creek Lake.

INTRODUCTION

In addition to their importance for flood control, reservoirs in Kansas are a valuable resource as a water supply for various human uses, for recreation, and as habitat for fish and wildlife. Effective resource management requires several types of information including water quality, sedimentation, and sediment quality. Water-quality information is important for determining if water in a reservoir is suitable for the various needs. Also, water-quality trends may be used to describe the overall effect of human activity in a reservoir basin, to indicate the effectiveness of regulatory decisions and changes in land-management practices, and to provide a warning of potential future water-quality problems.

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

Tuttle Creek Lake is a Federal impoundment on the Big Blue River in Riley, Pottawatomie, and Marshall (only at flood pool) Counties, northeast Kansas (fig. 1). Although the reservoir was officially completed in 1962 by the U.S. Army Corps of Engineers (USCOE), water storage actually began in 1959. The reservoir is used for flood control, recreation, water supply, fish and wildlife habitat, water-quality control, and navigation supplementation.

Some early water-quality information for Tuttle Creek Lake is available from USCOE (U.S. Army Corps of Engineers, circa 1966). Additional historical information on water quality and (or) streambed sediment quality for the Big Blue River Basin is available from several sources including Tanner and others (1990), Fallon and McChesney (1993), Frankforter (1994), Stamer and Zelt (1994), Bevans and others (1995), and Jordan and Stamer (1995). From 1996 through 2000, USCOE sampled the water in Tuttle Creek Lake and analyzed it for nutrients (total nitrogen and total phosphorus) and herbicides (alachlor, atrazine, cyanazine, and metolachlor) (U.S. Army Corps of Engineers, 2000).

During a 5-year period from 1993–97, the water in Tuttle Creek Lake was sampled by the Kansas Department of Health and Environment (KDHE) and analyzed for selected organic and inorganic constituents. Detections of the herbicides alachlor and atrazine exceeded water-quality standards (Tom Stiles, Kansas Department of Health and Environment, oral commun., 2000), which resulted in the listing of Tuttle Creek Lake under Section 303(d) of the Federal Clean Water Act of 1972. The 303(d) list is a priority list that identifies water bodies that do not meet water-quality standards developed on the basis of the use of the water bodies. For each impaired water body on the 303(d) list, a State is required by the Clean Water Act to develop a total maximum daily load (TMDL), which is an estimate of the maximum pollutant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality standards (U.S. Environmental Protection Agency, 1991). Other concerns affecting the reservoir, in addition to alachlor and atrazine, were sedimentation, eutrophication, and bacteria (Tom Stiles, Kansas Department of Health and Environment, oral commun., 2000).

A 2-year study by the U.S. Geological Survey (USGS), in cooperation with KDHE, was begun in 1999 to estimate sedimentation in Tuttle Creek Lake as well as to determine the deposition of, and trends in, various chemical constituents. The specific study objectives were to:

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

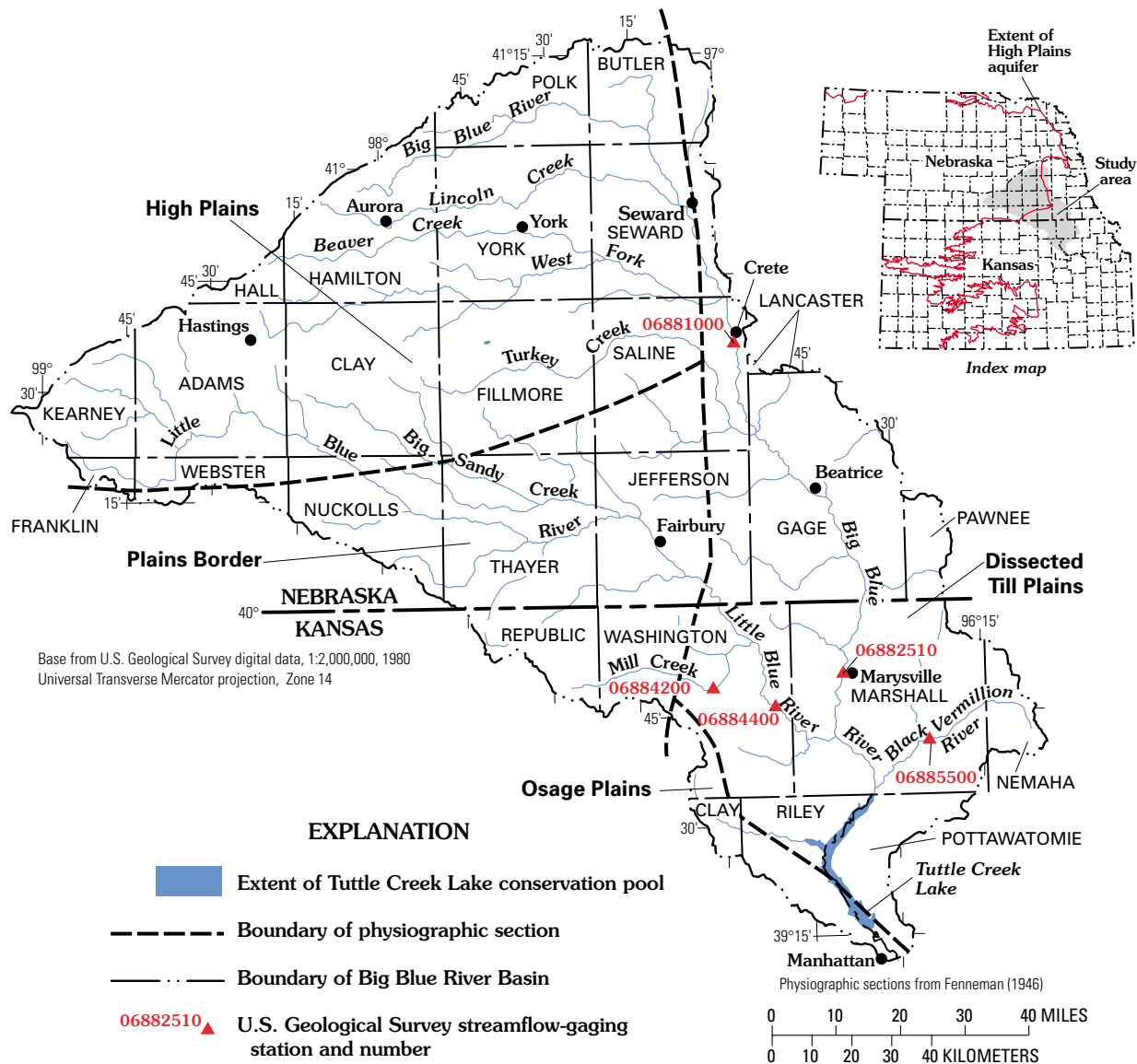


Figure 1. Location of Big Blue River Basin, physiography, streamflow-gaging stations, and Tuttle Creek Lake, northeast Kansas.

USCOE bathymetric survey of Tuttle Creek Lake in 1962;

- (2) Determine the occurrence and mass of, as well as trends in, selected chemical constituents in the bottom sediment;
- (3) Determine the mean annual net load and yield for selected chemical constituents in the bottom sediment;
- (4) Relate, to the extent possible, any observed constituent trends in the bottom sediment to documented historical changes in human activity in the basin; and
- (5) Provide a baseline of information on reservoir conditions with which to compare future conditions

that may represent a response to changes in human activity in the basin.

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

Description of Tuttle Creek Lake Basin

The Tuttle Creek Lake Basin, which is essentially synonymous with the Big Blue River Basin (except for the small area located downstream from the dam), is an area of 9,628 mi² that drains parts of southeast Nebraska and northeast Kansas (fig. 1). About 75 percent of the basin is located in Nebraska. In 2000, the lake had a surface area of about 12,620 acres and a water-storage capacity of about 280,000 acre-ft at the conservation-pool elevation of 1,075 ft above sea level (Phil Snell, U.S. Army Corps of Engineers, written commun., 2000). Originally, the lake had a surface area of about 15,830 acres and a water-storage capacity of about 425,000 acre-ft at the conservation-pool elevation (U.S. Army Corps of Engineers, 1966). The decreases in surface area and storage capacity are due to the effects of ongoing sedimentation. At the flood-control pool elevation of 1,136 ft above sea level, the lake in 2000 had a surface area of about 53,050 acres and a water-storage capacity of about 2,150,000 acre-ft (Phil Snell, U.S. Army Corps of Engineers, written commun., 2000). In addition to the Big Blue River, a number of small tributaries contribute flow directly to Tuttle Creek Lake including Baldwin, Booth, Carnahan, Dry, Fancy, McIntire, Mill, and Tuttle Creeks (fig. 2).

Physiographically, the Big Blue River Basin can be characterized with reference to physical divisions as defined by Fenneman (1946) (fig. 1). The upstream half of the basin is located mostly in the High Plains and Plains Border Sections of the Great Plains Province. The High Plains Section is typified by flat plains with limited stream dissection and little local relief. This section is underlain by fluvial (stream) and eolian (windblown) deposits that consist of sand, gravel, silt, and clay. The Plains Border Section is more dissected than the High Plains Section and thus has greater local relief. This section is underlain by shale, sandstone, and limestone, with minor fluvial and eolian deposits. The downstream half of the basin is located mostly in the Dissected Till Plains Section of the Central Lowland Province. This section is characterized by dissected deposits of glacial till that consist of silt, clay, sand, gravel, and boulders that overlie bedrock of primarily shale and limestone, with some sandstone (Jordan and Stamer, 1995).

Maximum local relief is from 300 to 500 ft in the downstream part of the Big Blue River Basin and generally less than 300 ft elsewhere. Slopes in the basin range from typically less than 3 percent in the High

Plains Section to as much as 10 percent or more elsewhere in the basin (Jordan and Stamer, 1995). Slope, along with soil permeability and land use (discussed in the following paragraphs), are important determinants of storm runoff in a basin. In general, soil erodibility is somewhat higher in the upstream half of the Big Blue River Basin (U.S. Department of Agriculture, 1994).

Depth-weighted, mean soil permeability in the Big Blue River Basin ranges from about 0.3 to 13.0 in/hr with a mean of about 0.9 in/hr. In general, soil permeability is less in the uplands (typically less than 1.0 in/hr) and somewhat greater in the flood plains of the principal rivers and streams (typically between 1.0 and 1.5 in/hr). Isolated areas with much greater soil permeability (4.0 to 13.0 in/hr) mostly are located along the Little Blue River and its tributaries (fig. 3) (U.S. Department of Agriculture, 1994).

Long-term mean annual precipitation in the Big Blue River Basin ranges from about 28 in. at Hastings, Nebraska (period of record 1948–99), in the northwest part of the basin (fig. 1), to about 33 in. at Manhattan, Kansas (period of record 1900–99), in the southeast (High Plains Regional Climate Center, 2000). Most of the annual precipitation is received during the growing season (generally April–September).

Land use (circa 1992) in the Big Blue River Basin is mostly agricultural with cropland accounting for about 66 percent of the basin. Grassland and pasture account for about 29 percent of the basin. Woodland and urban land use cover about 3 and 1 percent of the basin, respectively (fig. 4) (U.S. Geological Survey, 2000).

Acknowledgments

This study was made possible in part by support from the Kansas State Water Plan Fund. The authors gratefully acknowledge the bathymetric information provided by USCOE.

METHODS

The objectives of this study were accomplished using available and newly collected information. Available information included USCOE 1962 bathymetric information for the lake and USGS 1:24,000-scale topographic quadrangles that were used as base maps for the study. New information was

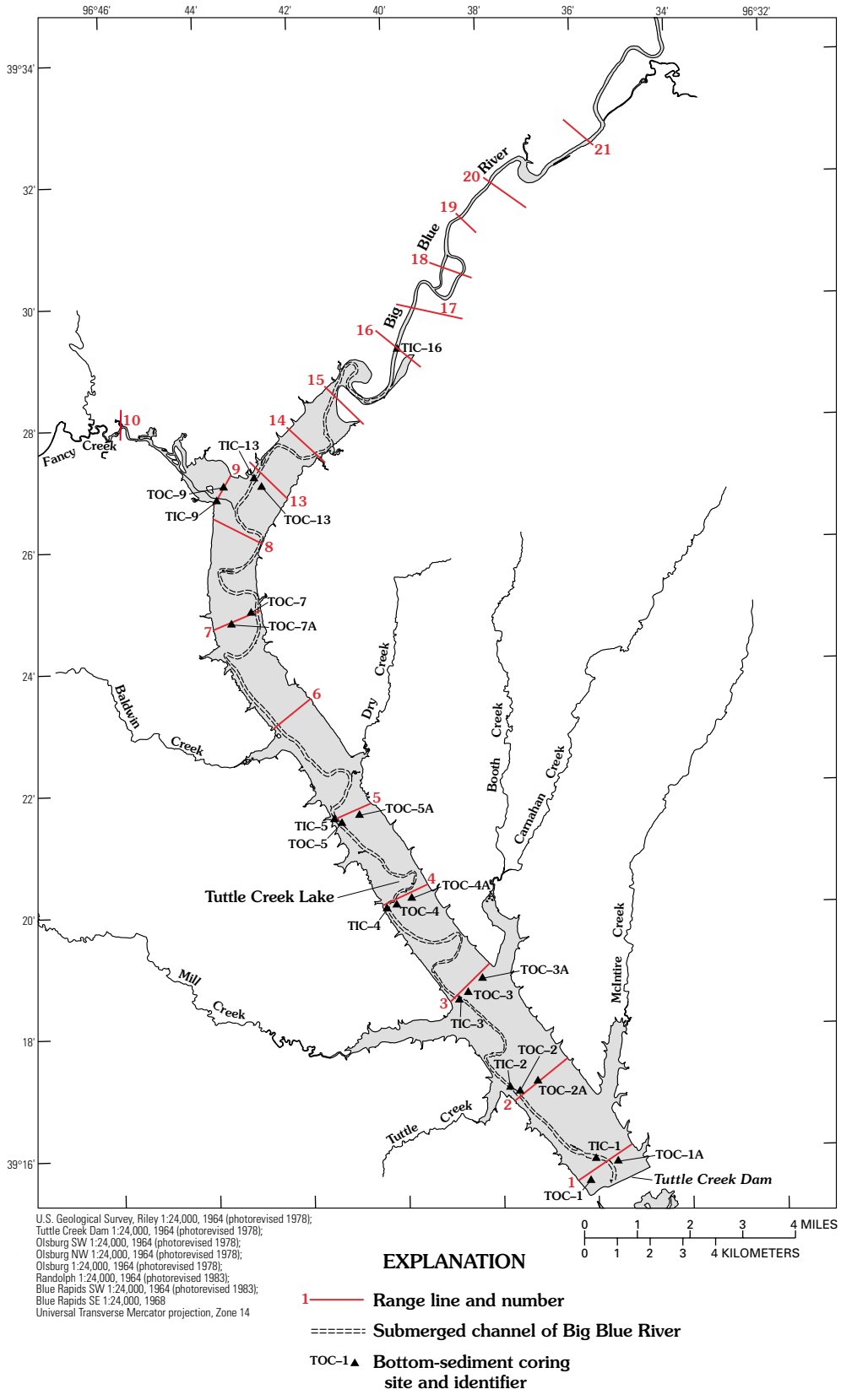


Figure 2. Location of bathymetric range lines and sediment-coring sites in Tuttle Creek Lake.

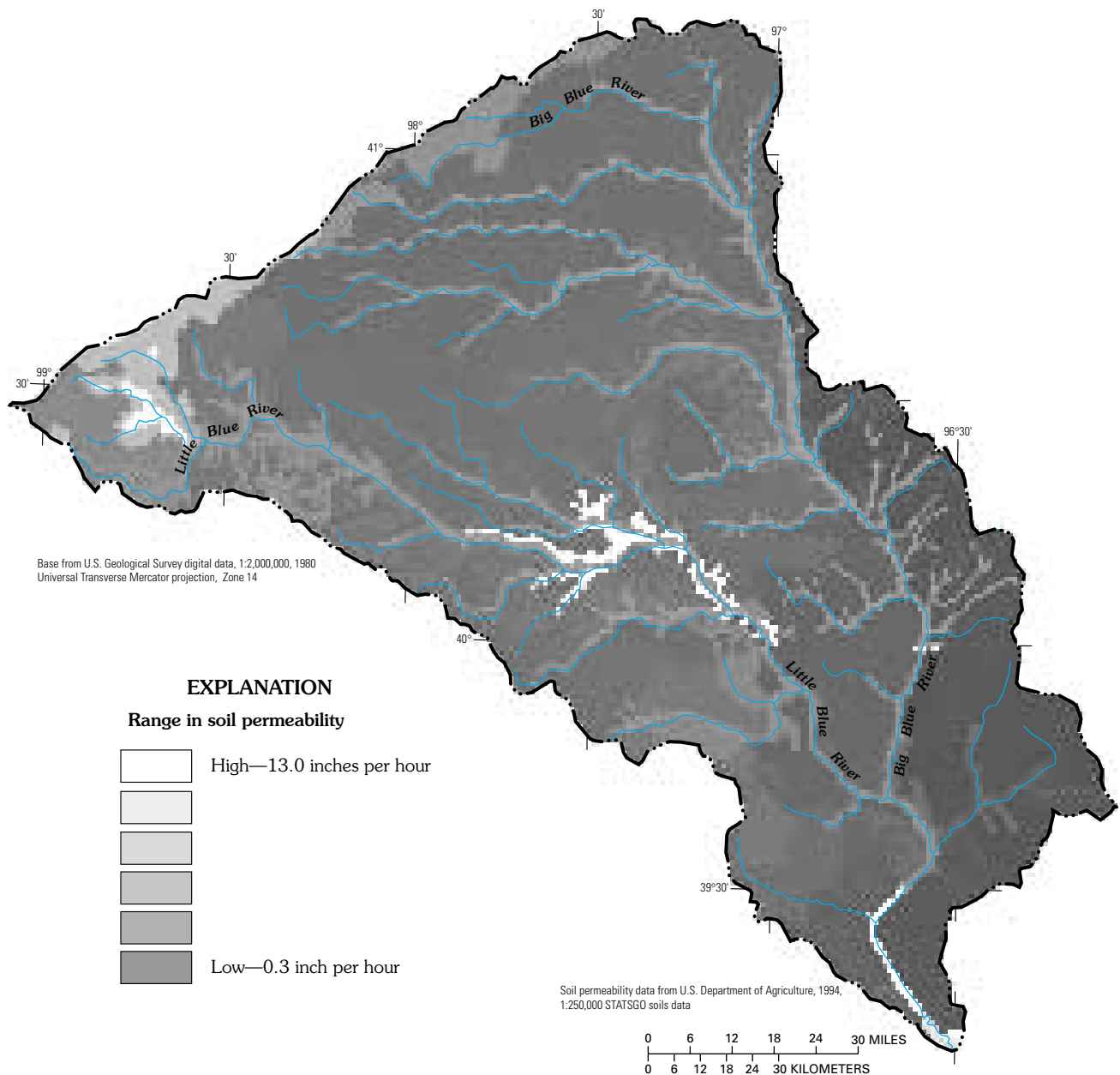


Figure 3. Depth-weighted, mean soil permeability in Big Blue River Basin.

obtained through additional bathymetric surveying and the collection and analysis of bottom-sediment cores.

Bathymetric Survey

To provide the additional information necessary for estimating the volume of bottom sediment in Tuttle Creek Lake, a bathymetric (lake-bed elevation) survey was performed by the USGS during June and July 1999. The bathymetric survey involved the use of global-positioning-system (GPS) technology to

record the geographic location of the boat on the lake and a fathometer system to determine the depth to the sediment/water interface (top of lake bed). The GPS and fathometer data were recorded digitally using a data-logging unit. The bathymetric survey was conducted along 10 range lines (1–9, 13) that were established by USCOE in 1962 (fig. 2; see also figs. 32–41 in the “Supplemental Information” section at the back of this report). The latitude and longitude coordinates for the end points of USCOE range lines used in this study are provided in table 12 in the “Supplemental

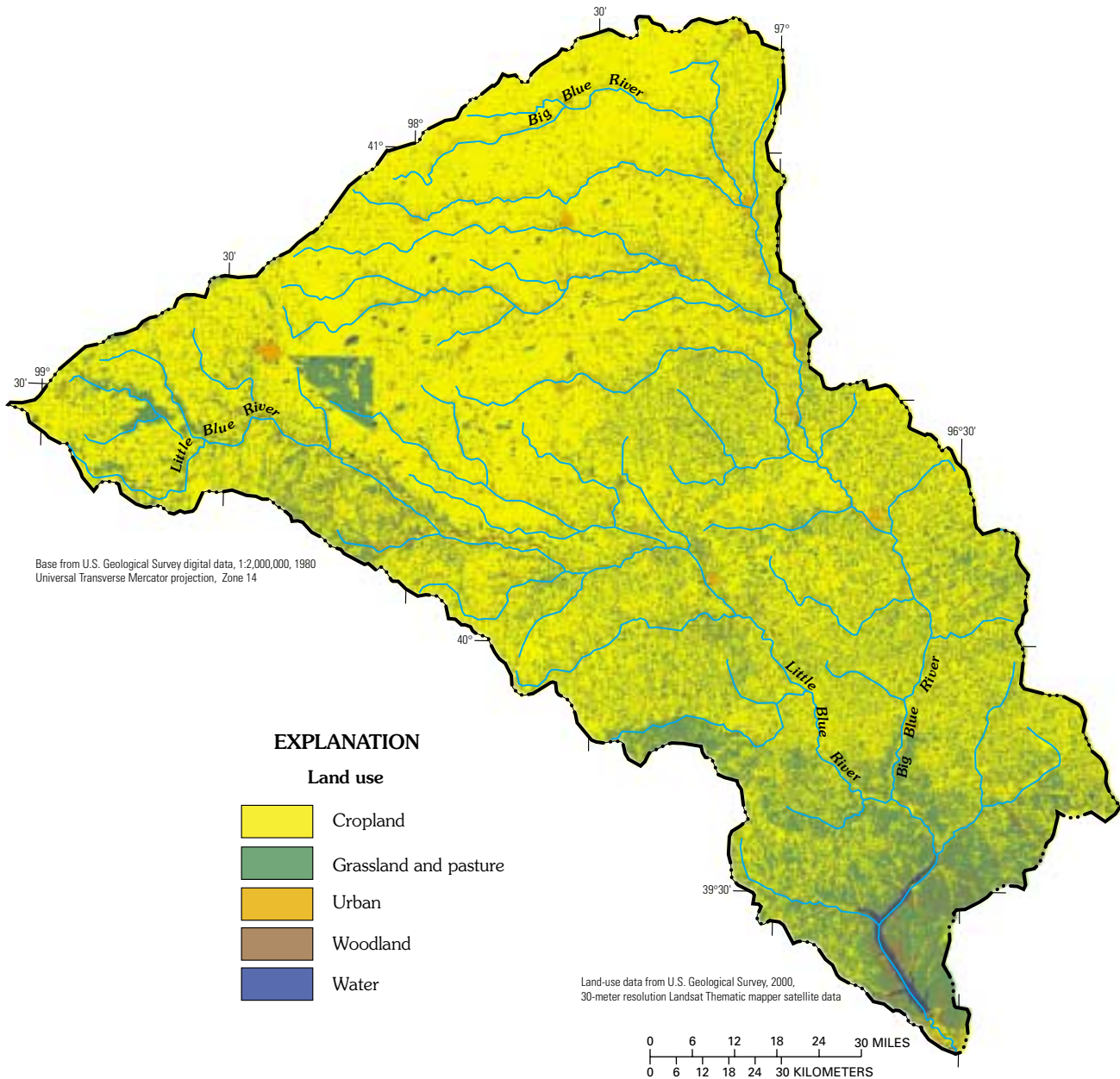


Figure 4. Land use in Big Blue River Basin, circa 1992.

Information” section. The reliability of the fathometer was verified at the start and end of each day (weather conditions permitting) by suspending a metal plate at known depths directly below the transducer. Additional bathymetric data from a USCOE survey of the lake in September 2000 also were used to provide information for nine range lines (10, 14–21) that were not surveyed in 1999 due to insufficient lake levels (fig. 2; see also figs. 42–50 in the “Supplemental

Information” section). Given that 2000 was a very dry year (with minimal sediment inflow to the lake), the 1999 and 2000 bathymetrically derived lake-bed elevations may be considered comparable for the purposes of estimating total sediment deposition within the lake. The upstream limits of the original conservation-pool surface area of the lake were defined approximately by range lines 10 and 21 (fig. 2).

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

Total bottom-sediment volume (sediment plus water and gases) in Tuttle Creek Lake was estimated using a partitioning approach in which the original conservation-pool surface area of the lake (15,830 acres) was divided into segments as determined by the locations where the bathymetric range lines crossed the lake (fig. 2). These segments were divided further into in-channel and out-of-channel components to improve the precision of the bottom-sediment volume estimates. Bottom-sediment volume was computed separately for all components as the total surface area multiplied by the mean thickness of the bottom sediment.

The total conservation-pool surface area for each segment was determined by digitizing the lake boundary and range lines using USGS 1:24,000-scale topographic quadrangles as the source maps. Mean channel widths of the Big Blue River and Fancy Creek were estimated using USCOE 1962 bathymetric information. With two exceptions, the mean channel width for each segment was computed as the average of the channel widths determined using the two range lines that defined the segment. The exceptions were the segments from the dam to range line 1 and from range line 9 to the confluence with the submerged Big Blue River channel (fig. 2), for which the respective channel widths computed for range lines 1 and 9 were used. The main channel length for each segment was estimated by measuring the channel centerline on USGS 1:24,000-scale topographic quadrangles. The surface area for each in-channel component was computed (mean channel width multiplied by channel length) and subtracted from the total surface area for each segment to determine the surface area for each out-of-channel component.

For range lines 1–9 and 13, the mean thickness of the bottom sediment was computed as the difference between the 1999 and 1962 lake-bed elevations (figs. 32–41 at the back of this report). For range lines 10 and 14–21, the mean thickness of the bottom sediment was computed as the difference between the 2000 and 1962 lake-bed elevations (figs. 42–50 at the back of this report). With three exceptions, the mean sediment thickness was computed for each in- and out-of-channel component as the average of the sediment thicknesses determined using the range lines that defined the segment. The in-channel exceptions were the components from the dam to range line 1 and from

range line 9 to the confluence with the submerged Big Blue River channel, for which the respective in-channel sediment thicknesses computed for range lines 1 and 9 were used. The out-of-channel exception was the component from the dam to range line 1, for which the out-of-channel sediment thickness computed for range line 1 was used. The component results then were combined to provide an estimate of the total volume of bottom sediment in the lake.

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

With several exceptions, the representative bulk density for each component was computed as the average of the bulk densities determined for the coring sites located along or near the range lines that defined the reservoir segments. In-channel exceptions included the component from the dam to range line 1 and the components upstream from range lines 9 and 16, for which limited information dictated that the representative bulk density was assigned the value for the nearest coring site for which a bulk density value was available. Likewise, for the out-of-channel components upstream from range lines 9 and 13, limited information dictated that the representative bulk density was assigned the value for the nearest coring site for which a bulk density value was available. Also, for some components, the representative bulk density was determined on the basis of coring site(s) for a single range line. Overall, the approach taken was to assign a bulk density value to each component, using available values outright or averaged, to provide what was believed to be the most representative value in the absence of more complete information. Typically, the bulk densities of reservoir sediment tend to be lowest downstream near the dam where the fine sediment is deposited and highest in the upstream part of the lake where the coarse delta deposits are located (Morris and Fan, 1997).

Because it was not feasible to accurately distinguish annual layers of sediment deposition in the lake,

mean annual sediment deposition was estimated by dividing the total mass of bottom sediment in the lake by the number of years of deposition. Given that the original bathymetric survey was completed in 1962, about 37 years of sediment deposition had occurred in the lake at the time the new bathymetric survey was completed in July 1999. Therefore, mean annual sediment deposition was estimated as the total mass of bottom sediment divided by 37. Mean annual sediment yield from the Tuttle Creek Lake Basin was estimated as the mean annual sediment deposition divided by the area of the basin (9,628 mi²). Because losses are not accounted for (for example, due to reservoir outflow), the computed sediment deposition and yield represent net, rather than total, values.

Sediment-Core Collection, Processing, and Analysis

To determine the occurrence and mass of, as well as trends in, selected chemical constituents, bottom-sediment cores were collected in August and September of 1999 at 22 sites (fig. 2) within Tuttle Creek Lake using a gravity corer. The liner used in the corer was cellulose acetate butyrate transparent tubing with a 2.625-in. inside diameter. The coring sites were located to provide a spatially representative sample of bottom sediment both in and outside of the submerged river and stream channels. A total of 8 in-channel and 14 out-of-channel sites were cored. In most cases, the cores were collected on or near the range lines used in the bathymetric surveys (fig. 2). One to three cores were collected at each site to provide sufficient sediment material for laboratory analyses. The latitude and longitude for each coring site, obtained using GPS technology, are provided in table 13 in the “Supplemental Information” section at the back of this report.

When using a gravity corer, a phenomenon referred to as “core shortening” occurs that results in a recovered sediment core that may be only about one-half of the actual thickness of sediment penetrated (Emery and Hulsemann, 1964). Core shortening is caused by the friction of the sediment against the inner wall of the liner as the gravity corer penetrates the sediment (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979; Blomqvist, 1985; Blomqvist and Bostrom, 1987). In “normal” lake-bottom sediment at Tuttle Creek Lake, which is characterized by uniform texture with decreasing water content at depth, core shortening results in a core sample that provides a

thinned but complete representation of all of the sediment layers that were penetrated (Emery and Hulsemann, 1964; Hongve and Erlandsen, 1979). However, there is some evidence to suggest that the use of a gravity corer may result in the complete loss of some of the uppermost soft surficial sediment on the lake bed (Crusius and Anderson, 1991).

The sediment cores were refrigerated and processed about 1 week after collection at the USGS laboratory in Lawrence, Kansas. The core liners were cut lengthwise in two places 180 degrees apart. The cuts were completed with a 4-in. hand-held circular saw with its blade set at a depth to minimize penetration of the sediment cores. The cores were split in half by pulling a tightly held nylon string through the length of the cores and allowing the halves to separate. Once split, the relatively undisturbed inner parts of the cores were exposed for examination and sampling. On the basis of differences in moisture content, texture, and organic matter content (for example, root hairs, sticks, seed pods, leaves), the boundary between the lake bottom sediment and the underlying original (pre-reservoir) land-surface (or channel-bed) material was determined. Typically, the bottom sediment was characterized by higher moisture content, finer texture, and little if any visible organic matter as compared to the original material. Due to the substantial thickness of the bottom sediment in Tuttle Creek Lake, penetration of the entire thickness of sediment was not achieved for all cores.

The number of samples extracted from each core depended on the length of the core, the intended use of the core, and the amount of material required for chemical analyses. Typically, a core was divided into three or five intervals of equal length. An exception was the in-channel core collected at site TIC-2 (fig. 2), which was divided into 15 intervals of equal length for the purpose of trend analyses. An equal volume of sediment (defined as the space occupied by the sediment particles, water, and gases as measured in cubic units) was extracted lengthwise from both halves of the core for each interval and combined. The combined sediment volume was homogenized and sampled for subsequent chemical analyses. For the in-channel sites, the intervals were sampled and analyzed separately. For the out-of-channel sites, the sediment from all intervals was combined and homogenized to produce a composite for the core that then was sampled and analyzed.

The sediment samples were analyzed for nutrients (total ammonia plus organic nitrogen and total phosphorus), 44 metals and trace elements, 15 organochlorine compounds, and 1 radionuclide. A complete list of the constituents for which analyses were performed is provided in table 1. All constituent analyses of bottom-sediment samples were performed at the USGS National Water-Quality Laboratory in Denver, Colorado. Analyses of sediment samples for total ammonia plus organic nitrogen and total phosphorus concentrations were performed using the methods described by Fishman and Friedman (1989). Analyses for metals and trace elements were performed using the methods described by Arbogast (1996) and Briggs and Meier (1999). Analyses for organochlorine compounds were performed using the methods described by Wershaw and others (1987).

Mean annual load was computed for each constituent that was detected with a sufficient frequency to determine a representative median value for the concentration of that constituent in the bottom sediment of Tuttle Creek Lake. For each constituent, mean annual load was computed as the median concentration multi-

plied by the mean annual mass of sediment deposited in the lake. Because the mean annual loads were computed using constituent concentrations determined from sediment cores collected mostly in the downstream half of the original conservation pool area of the lake (that is, where the percentage of fine sediment, and possibly the associated constituent concentrations, may be greater), the values computed for the entire lake may represent maximum loads from the basin. For all constituents for which a mean annual load was computed, the mean annual yield was estimated by dividing the mean annual load by the area of the Tuttle Creek Lake Basin. Thus, the computed yields also may represent maximum values for the basin. Because losses are not accounted for (for example, due to reservoir outflow), the computed loads and yields represent net, rather than total, values.

Age dating of the bottom sediment at site TIC-2 was accomplished by determining the concentration of cesium-137 (¹³⁷Cs) by gamma-ray spectrometry (American Society for Testing and Materials, 2000). ¹³⁷Cs is a radioactive isotope that is a by-product of nuclear weapons testing. Measurable concentrations of

Table 1. Analyses performed on bottom-sediment samples from Tuttle Creek Lake, northeast Kansas

		Nutrients	
Total ammonia plus organic nitrogen	Total phosphorus		
		Carbon	
Carbon, inorganic	Carbon, organic	Carbon, total	
		Metals and trace elements	
Aluminum	Copper	Mercury	Sulfur
Antimony	Europium	Molybdenum	Tantalum
Arsenic	Gallium	Neodymium	Thallium
Barium	Gold	Nickel	Thorium
Beryllium	Holmium	Niobium	Tin
Bismuth	Iron	Potassium	Titanium
Cadmium	Lanthanum	Scandium	Uranium
Calcium	Lead	Selenium	Vanadium
Cerium	Lithium	Silver	Ytterbium
Chromium	Magnesium	Sodium	Yttrium
Cobalt	Manganese	Strontium	Zinc
		Organochlorine compounds	
Aldrin	DDT	Gross polychlorinated biphenyls (PCBs)	Methoxychlor
Chlordane	Dieldrin	Heptachlor	Mirex
DDD	Endosulfan	Heptachlor epoxide	Toxaphene
DDE	Endrin	Lindane	
		Radionuclide	
		Cesium-137	

this isotope first appeared in the atmosphere in about 1952, peaked during 1963–64, and have since declined. ^{137}Cs is an effective marker for age dating bottom sediment in reservoirs constructed before 1963–64 (Van Metre and others, 1997). It also can be used to demonstrate that the sediment is relatively undisturbed if a generally uniform, exponential decrease in ^{137}Cs concentrations follows the 1963–64 peak. As shown in figure 5, the ^{137}Cs profile for site TIC-2 indicated that the sediment is relatively undisturbed. Thus, trend analyses performed for this site may be considered meaningful.

The sediment cores also were analyzed to determine bulk density. For this purpose, each core was divided into 3 to 10 intervals of equal length depending on the length of the core. From each interval a 1-in. thick sediment sample was extracted, weighed to the nearest 0.10 g, oven dried at about 45 °C for 96 hours, and reweighed. Oven drying of the sample continued as it was reweighed on a daily basis until no additional moisture loss was observed.

Bulk density was computed as follows:

$$D_b = m/v, \quad (1)$$

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

$$v = h(\pi d^2/4), \quad (2)$$

where v is the volume of the core sample (in cubic centimeters), h is the height (length) of the core sample (in centimeters), and d is the diameter of the core sample (in centimeters) (Gordon and others, 1992). The bulk densities then were converted to pounds per cubic foot for use in subsequent computations. Analyses of sediment samples for bulk density were performed at the USGS laboratory in Lawrence, Kansas.

For the in-channel cores, bulk densities were computed separately for each interval. The results then were averaged to estimate a representative mean bulk density for the site. For the out-of-channel cores, the sediment samples for all intervals were combined and homogenized. The homogenized material then was

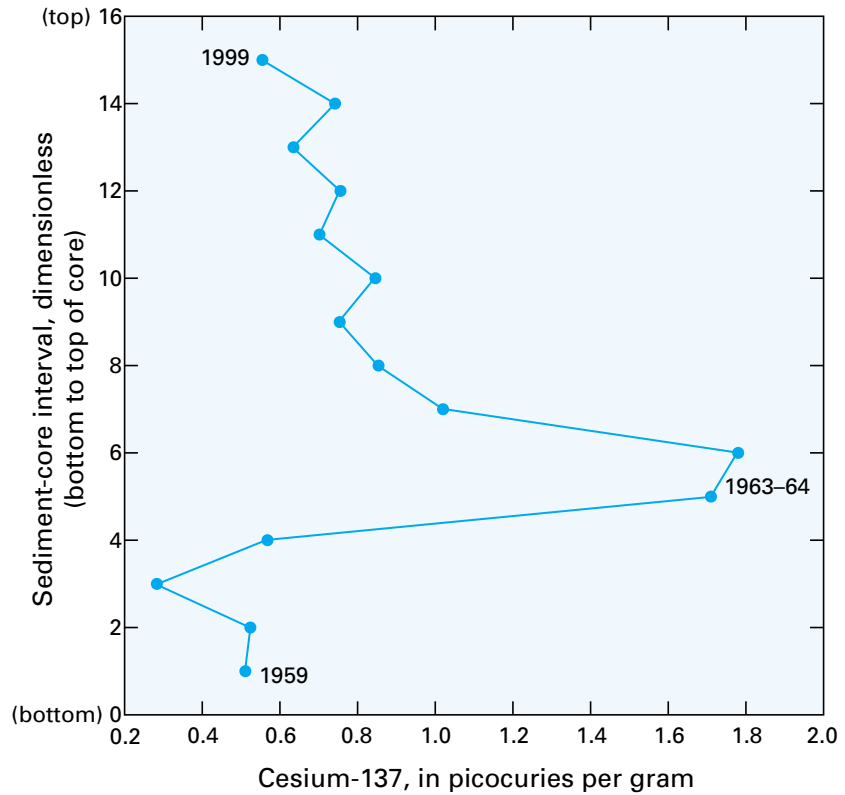


Figure 5. Variation in cesium-137 concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999. Location of site shown in figure 2.

weighed, and a representative volume of material was extracted that was equal to the total weight of the material divided by the number of intervals sampled. The bulk density determined for this sample provided the representative mean value for the site.

A particle-size analysis was performed to determine the percentage of sand (that is, particles larger than 0.062 mm in diameter) and silt and (or) clay (that is, particles smaller than 0.062 mm in diameter) in the sediment cores. The particle-size analyses were completed at the USGS sediment laboratory in Iowa City, Iowa, according to the methods presented in Guy (1969).

Quality Control

Quality control was provided by an evaluation of within-site and analytical variability. At selected sampling sites during this study, multiple sediment cores 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

among cores). Within-site variability was evaluated through the collection and analysis of sequential replicate sediment cores at three sites (TOC-1A, TOC-3A, and TOC-7A) (fig. 2). For each core a composite sample was prepared, as described previously, and analyzed for the various constituents. For each pair of cores, the relative percentage differences between the replicate sample concentrations were computed as the quotient of the absolute value of the difference in the replicate concentrations divided by the summation of the replicate concentrations, multiplied by 100.

Results indicated that, with the exception of total ammonia plus organic nitrogen, total phosphorus, and inorganic carbon, within-site variability was minimal with mean relative percentage differences less than 8 percent. Total ammonia plus organic nitrogen, total phosphorus, and inorganic carbon had mean relative percentage differences of 29.0, 34.2, and 12.0 percent, respectively. The mean relative percentage differences computed for all constituents detected in the sequential replicate cores are provided in table 2.

Analytical variability was evaluated through the collection and analysis of split replicate samples from an individual core at three sites (TOC-2A, TOC-4A, and TOC-5A) (fig. 2). Two composite samples were prepared for each core and analyzed for the various constituents. The relative percentage differences between the split replicate sample concentrations were computed as previously described. Results indicated that, with the exception of total ammonia plus organic nitrogen, total phosphorus, and tantalum, analytical variability was minimal with mean relative percentage differences generally less than 5 percent. Total ammonia plus organic nitrogen, total phosphorus, and tantalum had mean relative percentage differences of 33.8, 10.0, and 16.7 percent, respectively. The mean relative percentage differences computed for all constituents detected in the split replicate samples are provided in table 3. On the basis of these results, most of the within-site variability determined for total ammonia plus organic nitrogen and some of the within-site variability determined for total phosphorus may be due to analytical variability. Analytical variability can be attributed to sample preparation and, to a lesser degree, instrument variability.

Trend Analysis

The in-channel core collected at site TIC-2 (fig. 2), which was divided into 15 sample intervals,

was used for the purpose of trend analyses. Site TIC-2 was selected because it is in relatively deep water near the dam where the sediment was least likely to be disturbed. Trends in constituent concentrations were examined by computing a nonparametric Spearman's rho correlation coefficient. An advantage of Spearman's rho is that, because it is based on ranks, it is more resistant to outlier effects than the more commonly used Pearson's r correlation coefficient (Helsel and Hirsch, 1992). Trends were considered to be significantly positive (constituent concentration increased with decreasing depth in the sediment core) or negative (constituent concentration decreased with decreasing depth in the sediment core) if the probability (two-sided p-value) of rejecting a correct hypothesis (in this case, no trend) was less than or equal to 0.05. Rho was not computed for any constituent having more than five samples with concentrations less than the detection limit.

SEDIMENT DEPOSITION IN TUTTLE CREEK LAKE

The total volume of bottom sediment in Tuttle Creek Lake was estimated by partitioning the original conservation-pool surface area of the lake into in- and out-of-channel components (as segmented by the bathymetric range lines), computing bottom-sediment volume separately for each component, and then summing all component results. The total in- and out-of-channel bottom-sediment volumes were 1,600 and 4,570 million ft³, respectively. Therefore, the total estimated volume of bottom sediment in the original conservation-pool area of the lake was 6,170 million ft³ or about 142,000 acre-ft. In comparison, the USCOE bathymetry-based estimate of the total volume of bottom sediment in 2000 was 145,000 acre-ft (Phil Snell, U.S. Army Corps of Engineers, written commun., 2000). The 142,000 acre-ft of sediment occupies about 33 percent of the lake's original water-storage capacity of 425,000 acre-ft at conservation pool. Within the present (2000) conservation pool area of the lake, the upstream limits of which are approximately indicated by range lines 9 and 13 (fig. 2), the total estimated volume of bottom sediment was 3,640 million ft³ or about 83,600 acre-ft. Table 4 provides the estimated channel length, mean channel width, mean bottom-sediment thickness, and computed bottom-sediment volume for each in-channel component. Table 5 provides the estimated surface area, mean bottom-sediment thickness, and

Table 2. Mean relative percentage differences for constituent concentrations in sequential replicate samples of bottom sediment from coring sites TOC-1A, TOC-3A, and TOC-7A in Tuttle Creek Lake, northeast Kansas, August and September 1999

[--, not calculated]

Constituent	Mean relative percentage difference	Constituent	Mean relative percentage difference
Nutrients		Metals and trace elements—Continued	
Total ammonia plus organic nitrogen	29.0	Potassium	.8
Total phosphorus	34.2	Scandium	1.1
Carbon		Selenium	2.3
Carbon, inorganic	12.0	Silver	4.7
Carbon, organic	2.0	Sodium	3.7
Carbon, total	.4		
Metals and trace elements		Strontium	0
Aluminum	1.4	Sulfur	5.7
Antimony	1.6	Tantalum	2.2
Arsenic	2.7	Thallium	--
Barium	3.4	Thorium	1.1
Beryllium	7.1		
		Tin	2.0
Bismuth	--	Titanium	1.8
Cadmium	4.2	Uranium	3.2
Calcium	2.0	Vanadium	2.5
Cerium	1.7	Ytterbium	.6
Chromium	1.3		
		Yttrium	2.4
Cobalt	2.7	Zinc	2.7
Copper	1.5	Organochlorine compounds	
Europium	3.1	Aldrin	--
Gallium	1.7	Chlordane	--
Gold	--	DDD	--
		DDE ¹	5.1
Holmium	3.0	DDT	--
Iron	2.7		
Lanthanum	1.1	Dieldrin ¹	4.7
Lead	3.6	Endosulfan	--
Lithium	1.0	Endrin	--
		Gross polychlorinated biphenyls (PCBs)	--
Magnesium	0	Heptachlor	--
Manganese	3.6		
Mercury	0	Heptachlor epoxide	--
Molybdenum	6.5	Lindane	--
Neodymium	2.3	Methoxychlor	--
		Mirex	--
Nickel	.9	Toxaphene	--
Niobium	3.7		

¹Mean relative percentage difference calculated on the basis of two sites.

Table 3. Mean relative percentage differences for constituent concentrations in split replicate samples of bottom sediment from coring sites TOC-2A, TOC-4A, and TOC-5A in Tuttle Creek Lake, northeast Kansas, August and September 1999

[--, not calculated]

Constituent	Mean relative percentage difference	Constituent	Mean relative percentage difference
Nutrients		Metals and trace elements—Continued	
Total ammonia plus organic nitrogen	33.8	Potassium	0
Total phosphorus	10.0	Scandium	2.1
Carbon		Selenium	1.7
Carbon, inorganic	1.2	Silver	5.5
Carbon, organic	1.1	Sodium	.7
Carbon, total	.9		
Metals and trace elements		Strontium	0
Aluminum	.2	Sulfur	3.0
Antimony	0	Tantalum	16.7
Arsenic	3.4	Thallium ¹	0
Barium	1.3	Thorium	3.0
Beryllium	3.3		
		Tin	3.4
Bismuth	--	Titanium	.8
Cadmium	1.8	Uranium	2.6
Calcium	1.1	Vanadium	2.1
Cerium	2.0	Ytterbium	1.8
Chromium	0		
		Yttrium	1.1
Cobalt	1.2	Zinc	0
Copper	3.9		
Europium	2.9	Organochlorine compounds	
Gallium	.8	Aldrin	--
Gold	--	Chlordane	--
		DDD	--
Holmium	2.9	DDE	--
Iron	.6	DDT	--
Lanthanum	.7		
Lead	1.3	Dieldrin	--
Lithium	.7	Endosulfan	--
		Endrin	--
Magnesium	1.2	Gross polychlorinated biphenyls (PCBs)	--
Manganese	1.1	Heptachlor	--
Mercury	0		
Molybdenum	0	Heptachlor epoxide	--
Neodymium	1.3	Lindane	--
		Methoxychlor	--
Nickel	.8	Mirex	--
Niobium	0	Toxaphene	--

¹ Mean relative percentage difference calculated on the basis of two sites.

Table 4. Estimated channel length, mean channel width, mean bottom-sediment thickness, and computed bottom-sediment volume in submerged in-channel components of Tuttle Creek Lake, northeast Kansas, 1999

[all values rounded to two or three significant figures]

In-channel lake component (fig. 2)	Estimated channel length (feet)	Mean channel width (feet)	Mean bottom- sediment thickness (feet)	Computed bottom- sediment volume ¹ (cubic feet)
Big Blue River				
Dam to range line 1	1,940	320	2.1	1,300,000
Range lines 1 to 2	10,400	335	10.1	35,200,000
Range lines 2 to 3	16,300	375	16.3	99,600,000
Range lines 3 to 4	17,600	330	15.9	92,300,000
Range lines 4 to 5	15,400	290	18.3	81,700,000
Range lines 5 to 6	14,100	330	20.6	95,900,000
Range lines 6 to 7	16,300	360	25.8	151,000,000
Range lines 7 to 8	11,900	315	33.2	124,000,000
Range lines 8 to 13	8,590	295	36.7	93,000,000
Range lines 13 to 14	7,350	320	35.4	83,300,000
Range lines 14 to 15	7,430	340	34.8	87,900,000
Range lines 15 to 16	15,400	350	29.5	159,000,000
Range lines 16 to 17	3,940	350	22.6	31,200,000
Range lines 17 to 18	9,210	375	25.9	89,500,000
Range lines 18 to 19	6,310	440	25.9	71,900,000
Range lines 19 to 20	6,010	400	20.9	50,200,000
Range lines 20 to 21	11,900	350	18.0	75,000,000
Fancy Creek				
Confluence with Big Blue River to range line 9	5,130	320	32.1	52,700,000
Range lines 9 to 10	18,000	310	21.9	122,000,000
Total for lake				1,600,000,000

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

computed bottom-sediment volume for each out-of-channel component. Longitudinal views of in-channel and out-of-channel sediment deposition in Tuttle Creek Lake are provided in figures 6 and 7, respectively.

Bottom-sediment mass was estimated as the bottom-sediment volume multiplied by the representative bulk density of the sediment. Bulk densities were estimated at all 8 in-channel and all 14 out-of-channel sites in the lake (table 6, fig. 2). Estimated bulk densities ranged from a mean of 18.7 lb/ft³ for core samples from site TOC-2A (out-of-channel site) to 64.3 lb/ft³ for core samples from site TOC-13 (out-of-channel site) with an overall mean of 38.2 lb/ft³. The particle-size composition of the bottom sediment in

Tuttle Creek Lake was very uniform. At virtually every site and sampling depth, the silt and (or) clay content of the sediment was 98 percent or greater.

The total in-channel mass of bottom sediment in the lake, estimated as the sum of the sediment mass computed for the individual channel components (fig. 2), was 80,400 million lb. Total out-of-channel sediment mass, estimated as the sum of the sediment mass computed for the individual out-of-channel components (fig. 2), was 212,000 million lb. Therefore, the total estimated mass of bottom sediment in the original conservation-pool surface area of the lake was 292,400 million lb or about 133,000 million kg. Tables 7 and 8 detail the bottom-sediment mass esti-

Table 5. Estimated surface area, mean bottom-sediment thickness, and computed bottom-sediment volume in out-of-channel components of Tuttle Creek Lake, northeast Kansas, 1999

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

Out-of-channel lake component (fig. 2)	Estimated surface area (square feet)	Mean bottom-sediment thickness (feet)	Computed bottom-sediment volume ¹ (cubic feet)
Big Blue River			
Dam to range line 1	11,900,000	1.7	20,200,000
Range lines 1 to 2	75,600,000	2.7	204,000,000
Range lines 2 to 3	121,000,000	3.3	399,000,000
Range lines 3 to 4	51,200,000	3.9	200,000,000
Range lines 4 to 5	46,100,000	4.9	226,000,000
Range lines 5 to 6	53,500,000	5.4	289,000,000
Range lines 6 to 7	50,000,000	8.6	430,000,000
Range lines 7 to 8	37,300,000	15.0	560,000,000
Range lines 8 to 9 to 13	31,200,000	15.1	471,000,000
Range lines 13 to 14	19,000,000	14.7	279,000,000
Range lines 14 to 15	23,100,000	14.2	328,000,000
Range lines 15 to 16	30,400,000	11.2	340,000,000
Range lines 16 to 17	19,100,000	11.8	225,000,000
Range lines 17 to 18	18,300,000	12.3	225,000,000
Range lines 18 to 19	8,040,000	9.9	79,600,000
Range lines 19 to 20	4,160,000	11.0	45,800,000
Range lines 20 to 21	5,140,000	12.5	64,300,000
Fancy Creek			
Range lines 9 to 10	14,200,000	12.9	183,000,000
Total for lake			4,570,000,000

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

mated for the in- and out-of-channel lake components, respectively.

Annual net sediment deposition was estimated by dividing the total mass of bottom sediment in the lake by the number of years of deposition (that is, 37). The mean annual net sediment deposition was estimated to be 7,900 million lb or 3,600 million kg. Mean annual net sediment yield from the Tuttle Creek Lake Basin, computed as the mean annual net sediment deposition divided by the area of the basin (9,628 mi²), was estimated to be 821,000 lb/mi² or 1,440 kg/ha.

CONCENTRATIONS AND TRENDS IN SELECTED CHEMICAL CONSTITUENTS

The U.S. Environmental Protection Agency (USEPA) has established sediment-quality guidelines

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

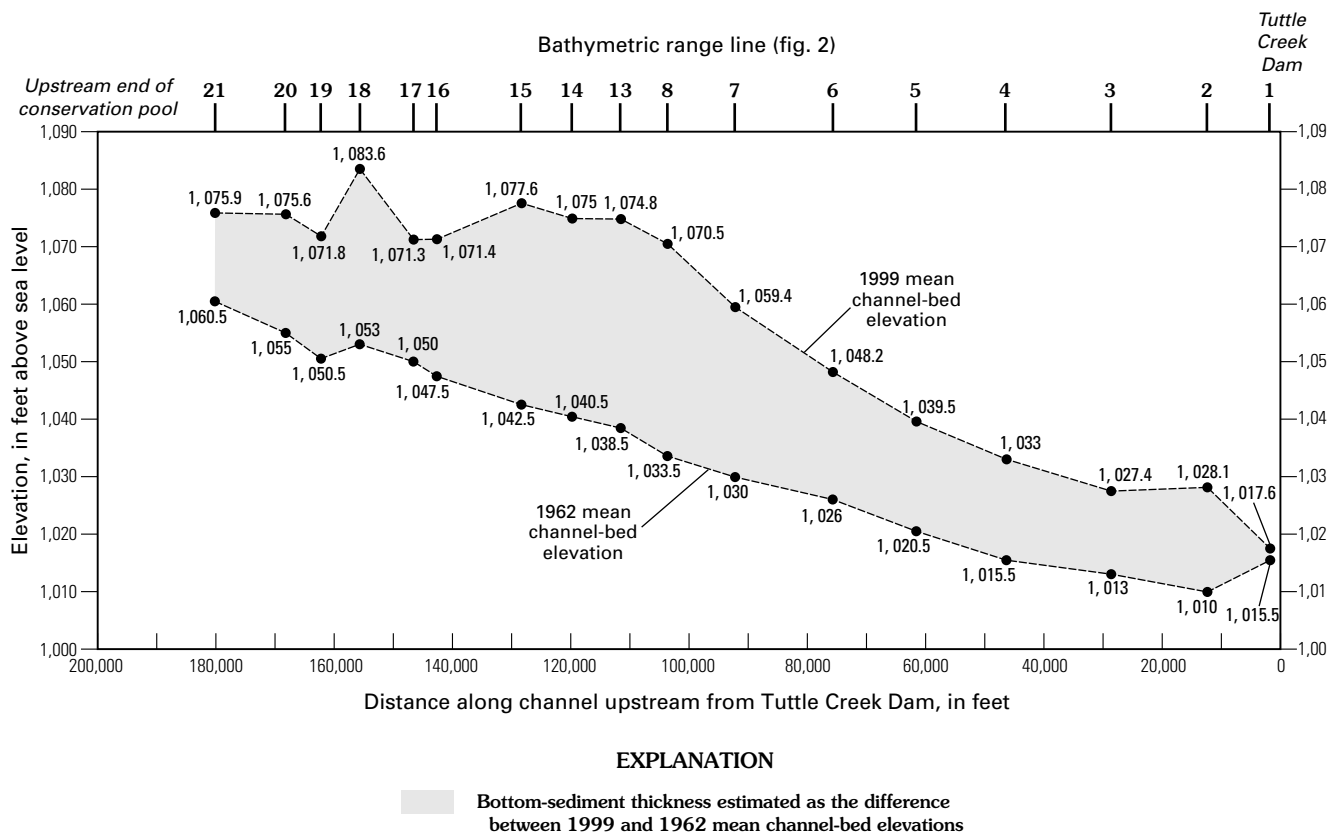


Figure 6. Estimated bottom-sediment thickness in submerged Big Blue River channel of Tuttle Creek Lake, 1999.

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

In this report, discussion of constituent concentrations with respect to sediment-quality guidelines is limited to the nine trace elements and six organochlorine compounds for which guidelines are available.

Nutrients and Total Organic Carbon

Nutrients, such as nitrogen and phosphorus, are necessary for growth and reproduction of plants. In

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

Total organic carbon (TOC), an approximate determination of total organic material in a sediment sample, is important because various organic solutes can form complexes, which in turn affect metal solubilities (Hem, 1992). The organic carbon content of sediment also is important because many contaminants (for example, organochlorine compounds) specifically sorb to the organic material in sediment (Karickhoff, 1984). Sediment-quality guidelines for TOC have not been established by USEPA.

Total ammonia plus organic nitrogen concentrations in the bottom-sediment samples collected from

Tuttle Creek Lake ranged from 600 to 5,200 mg/kg with a median concentration of 800 mg/kg (table 9). Of the 26 samples analyzed, concentrations of total ammonia plus organic nitrogen in 24 were in the range of 600 to 1,100 mg/kg. Because total ammonia plus organic nitrogen was not analyzed in the sediment core from site TIC-2 (fig. 2), a trend analysis was not performed. Total ammonia plus organic nitrogen concentrations were determined for several other sites; however, none of the cores analyzed for total ammonia plus organic nitrogen were divided into a sufficient number of intervals to enable trend analysis. Mean concentrations of total ammonia plus organic nitrogen in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 8.

The estimated mean annual net load of total ammonia plus organic nitrogen deposited in the bottom sediment was 6,350,000 lb/yr (2,880,000 kg/yr). The estimated mean annual net yield of total ammonia plus organic nitrogen from the Tuttle Creek Lake Basin was 657 (lb/mi²)/yr [1.15 (kg/ha)/yr] (table 10).

Total phosphorus concentrations ranged from 198 to 952 mg/kg with a median concentration of 419 mg/kg (table 9). No statistically significant trend in total phosphorus deposition was indicated (table 11, fig. 9). Mean concentrations of total phosphorus in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 10. The estimated mean annual net load of total phosphorus deposited in the bottom sediment was 3,330,000 lb/yr (1,510,000 kg/yr). The estimated mean annual net yield of total phosphorus from the Tuttle Creek Lake Basin was 348 (lb/mi²)/yr [0.61 (kg/ha)/yr] (table 10).

TOC concentrations ranged from 0.84 to 2.0 percent with a median concentration of 1.7 percent

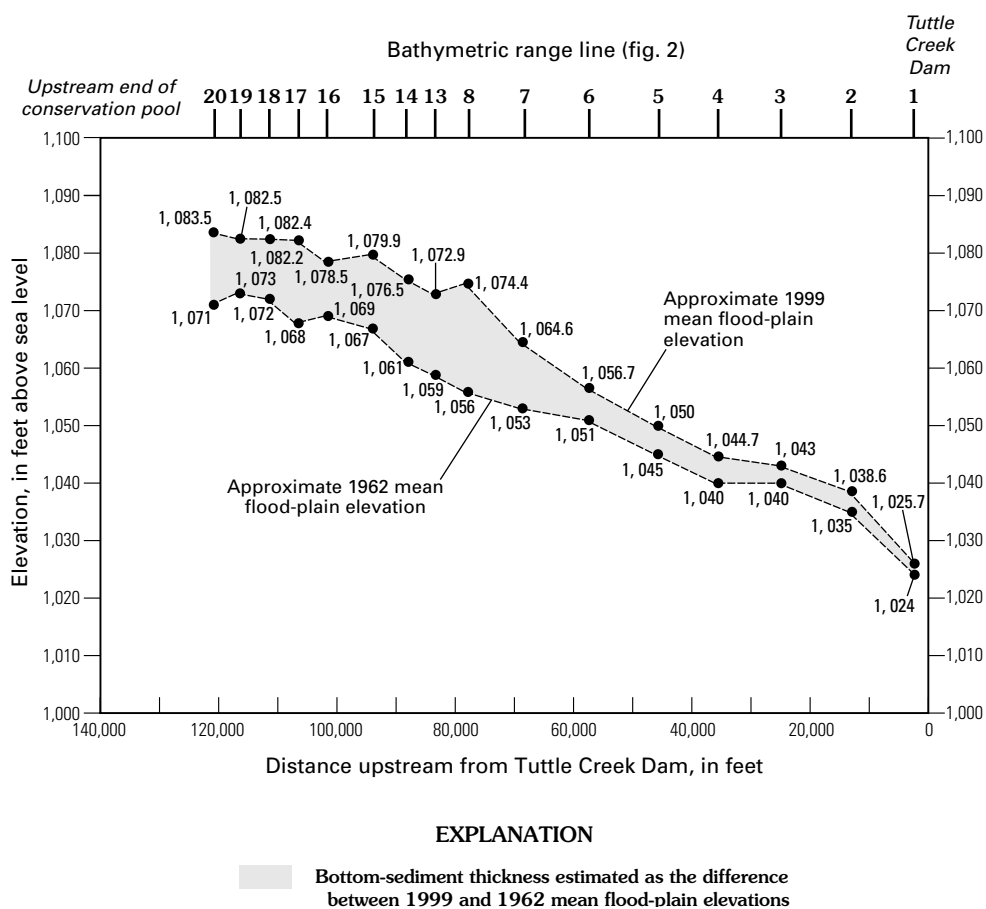


Figure 7. Estimated bottom-sediment thickness on submerged Big Blue River flood plain in Tuttle Creek Lake, 1999.

(table 9). No statistically significant trend in TOC deposition was indicated (table 11, fig. 11). Mean concentrations of TOC in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 12. The estimated mean annual net load of TOC deposited in the bottom sediment was 138,000,000 lb/yr (62,600,000 kg/yr). The estimated mean annual net yield of TOC from the Tuttle Creek Lake Basin was 14,300 (lb/mi²)/yr [25.1 (kg/ha)/yr] (table 10).

Metals and Trace Elements

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

Table 6. Estimated mean bulk density of bottom sediment at in- and out-of-channel coring sites in Tuttle Creek Lake, northeast Kansas, 1999

[bulk-density values rounded to three significant figures]

Site number (fig. 2)	Mean bulk density (pounds per cubic foot)
In-channel sites	
TIC-1	36.6
TIC-2	38.0
TIC-3	40.2
TIC-4	32.0
TIC-5	37.7
TIC-9	57.9
TIC-13	54.9
TIC-16	60.8
Out-of-channel sites	
TOC-1	32.5
TOC-1A	27.8
TOC-2	41.8
TOC-2A	18.7
TOC-3	23.1
TOC-3A	23.7
TOC-4	31.2
TOC-4A	26.8
TOC-5	38.1
TOC-5A	25.0
TOC-7	35.0
TOC-7A	37.5
TOC-9	56.8
TOC-13	64.3
Mean	38.2

which are some of the abundant rock-forming elements, include aluminum, calcium, iron, magnesium, potassium, and sodium (Adriano, 1986).

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

The health of living organisms is dependent on a sufficient intake of various metals and trace elements. Many elements, such as calcium, cobalt, copper, iron,

magnesium, manganese, and zinc, are essential for plants, animals, and humans. Other elements, such as arsenic and chromium, are required by animals and humans but are not essential for plants. Nonessential elements for plants, animals, and humans include cadmium, mercury, and lead (Adriano, 1986; Lide, 1993; Pais and Jones, 1997).

Toxicity is a function of several factors including the type of organism, availability of a metal or trace element in the environment, and its potential to bioaccumulate once in the food chain. The daily intake of metals and trace elements by animals and humans may be classified as deficient, optimal, or toxic. Most, if not all, metals and trace elements may be toxic in animals and humans if the concentrations are sufficiently large (Pais and Jones, 1997). Information on the bioaccumulation index for most of the metals and trace elements that were analyzed in this study is provided in table 10.

Of the 44 elements analyzed, 40 were detected in all or virtually all of the sediment samples analyzed and at all or virtually all sites for which the analyses were performed (sites TOC-1, TOC-1A, TOC-2, TOC-2A, TOC-3, TOC-3A, TOC-4, TOC-4A, TOC-5, TOC-5A, TOC-7, TOC-7A, TOC-9, TOC-13, TIC-2, TIC-9, and TIC-13; fig. 2). The exceptions included bismuth and gold, which were not detected in any of the 41 sediment samples analyzed. Sulfur and thallium were detected in 16 of 41 and 15 of 41 samples analyzed, respectively (table 9).

Trend analyses, with a significance level of 0.05, indicated a statistically significant positive depositional trend (constituent concentration increased with decreasing depth in the sediment core) for chromium, cobalt, gallium, iron, lithium, magnesium, mercury, molybdenum, nickel, scandium, selenium, tantalum, tin, and zinc (table 11, figs. 13-16). However, despite the statistical significance, the indicated trends may not be representative of actual conditions for two reasons. First, an assessment of the trends with respect to analytical variance (defined here as the mean element concentration for the core plus or minus 10 percent) indicated that many of the trends may be due to analytical variance. This conclusion was based on the fact that, for most of the elements for which a positive trend was indicated, the majority of the concentrations were within 10 percent of the mean value. Second, visual inspection of the vertical profiles (figs. 13-16) indicated that most of the constituents for which a positive trend was indicated actually had a bimodal distribution rather than a trend. An exception was mercury for which the indication of a positive trend was due to

Table 7. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in submerged in-channel components of Tuttle Creek Lake, northeast Kansas, 1999

[all values rounded to three significant figures]

In-channel lake component (fig. 2)	Estimated bottom-sediment volume (cubic feet)	Representative bulk density (pounds per cubic foot)	Computed bottom-sediment mass ¹ (pounds)
Big Blue River			
Dam to range line 1	1,300,000	36.6	47,600,000
Range lines 1 to 2	35,200,000	37.3	1,310,000,000
Range lines 2 to 3	99,600,000	39.1	3,890,000,000
Range lines 3 to 4	92,300,000	36.1	3,330,000,000
Range lines 4 to 5	81,700,000	34.9	2,850,000,000
Range lines 5 to 6	95,900,000	37.7	3,620,000,000
Range lines 6 to 7	151,000,000	46.3	6,990,000,000
Range lines 7 to 8	124,000,000	46.3	5,740,000,000
Range lines 8 to 13	93,000,000	46.3	4,310,000,000
Range lines 13 to 14	83,300,000	54.9	4,570,000,000
Range lines 14 to 15	87,900,000	57.9	5,090,000,000
Range lines 15 to 16	159,000,000	57.9	9,210,000,000
Range lines 16 to 17	31,200,000	60.8	1,900,000,000
Range lines 17 to 18	89,500,000	60.8	5,440,000,000
Range lines 18 to 19	71,900,000	60.8	4,370,000,000
Range lines 19 to 20	50,200,000	60.8	3,050,000,000
Range lines 20 to 21	75,000,000	60.8	4,560,000,000
Fancy Creek			
Confluence with Big Blue River to range line 9	52,700,000	57.9	3,050,000,000
Range lines 9 to 10	122,000,000	57.9	7,060,000,000
Total for lake			80,400,000,000

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

the effect of a single, anomalously large value (fig. 14).

In general, the bimodal distribution was characterized by relatively small concentrations in the bottom one-fifth of the core and relatively large and uniform concentrations in the upper four-fifths of the core. Examples of the bimodal distribution include the vertical profiles for chromium (fig. 13), lithium (fig. 14), nickel (fig. 15), scandium (fig. 15), and zinc (fig. 16). A possible explanation for the smaller concentrations at the bottom of the core may be disturbance of the Big Blue River flood plain during construction of the dam coupled with a mobilization and redeposition of flood-plain and channel-bank materials during the initial filling of the reservoir. Such locally derived sediment

may be chemically different from sediment originating elsewhere in the basin.

The vertical profiles of element concentrations for the sediment core from site TIC-2 (fig. 2) indicated the possibility of unusual conditions during the deposition of sediment at core intervals 3 and 11. For interval 3, 25 elements had notably smaller concentrations (for example, see figs. 13–16). For interval 11, anomalously large concentrations were detected for antimony, barium, chromium (fig. 13), mercury (fig. 14), molybdenum (fig. 14), nickel (fig. 15), selenium (fig. 15), sodium, and strontium. Conversely, anomalously small concentrations were detected for cerium, holmium, lanthanum, neodymium, niobium, silver, tantalum (fig. 15), tin (fig. 16), ytterbium, and yttrium.

Table 8. Estimated bottom-sediment volume, representative bulk density, and computed bottom-sediment mass in out-of-channel components of Tuttle Creek Lake, northeast Kansas, 1999

[all values rounded to three significant figures]

Out-of-channel lake component (fig. 2)	Estimated bottom-sediment volume (cubic feet)	Representative bulk density (pounds per cubic foot)	Computed bottom-sediment mass ¹ (pounds)
Big Blue River			
Dam to range line 1	20,200,000	30.2	610,000,000
Range lines 1 to 2	204,000,000	30.2	6,160,000,000
Range lines 2 to 3	399,000,000	26.8	10,700,000,000
Range lines 3 to 4	200,000,000	26.2	5,240,000,000
Range lines 4 to 5	226,000,000	30.3	6,850,000,000
Range lines 5 to 6	289,000,000	31.6	9,130,000,000
Range lines 6 to 7	430,000,000	33.9	14,600,000,000
Range lines 7 to 8	560,000,000	36.3	20,300,000,000
Range lines 8 to 9 to 13	471,000,000	48.4	22,800,000,000
Range lines 13 to 14	279,000,000	64.3	17,900,000,000
Range lines 14 to 15	328,000,000	64.3	21,100,000,000
Range lines 15 to 16	340,000,000	64.3	21,900,000,000
Range lines 16 to 17	225,000,000	64.3	14,500,000,000
Range lines 17 to 18	225,000,000	64.3	14,500,000,000
Range lines 18 to 19	79,600,000	64.3	5,120,000,000
Range lines 19 to 20	45,800,000	64.3	2,940,000,000
Range lines 20 to 21	116,000,000	64.3	7,460,000,000
Fancy Creek			
Range lines 9 to 10	183,000,000	56.8	10,400,000,000
Total for lake			212,000,000,000

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

Several other elements also exhibited larger or smaller concentrations for interval 11 but to a lesser degree. One possible explanation for the divergent concentrations observed for intervals 3 and 11 may be floods. During floods, different processes and sediment sources may have been activated that would account for the anomalous concentrations. Noteworthy was the fact that the organic carbon concentrations for intervals 3 and 11 were much less than the other intervals in the core (fig. 11). Moody and others (2000), in a study of the effects of the 1993 flood on bed sediment in the upper Mississippi River, found that decreased organic carbon concentrations were attributable to an increase in the deposition of coarser sediment during the flood.

Because of uncertainty as to whether or not the statistically significant positive depositional trends

determined may be due, in part, to the anomalous values of intervals 3 and 11, the trend analyses for the sediment core from site TIC-2 were repeated with the data for intervals 3 and 11 excluded. Results indicated that, with the exception of mercury (for which no trend was indicated), all elements for which a statistically significant positive depositional trend was originally indicated also had a statistically significant positive depositional trend when data from intervals 3 and 11 were excluded. Also, the repeated analyses indicated a statistically significant negative depositional trend for sodium and statistically significant positive depositional trends for thorium and vanadium (table 11). USEPA has not established sediment-quality guidelines for thorium or vanadium. However, for the reasons stated earlier, the indicated trends may not be representative of actual changes.

Table 9. Statistical summary of concentrations, and comparison to sediment-quality guidelines, for selected constituents in bottom-sediment samples from Tuttle Creek Lake, northeast Kansas, August and September 1999

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

Constituent and unit of measurement	Number of detections/ number of analyses	Concentration			Sediment-quality guidelines ¹	
		Minimum	Median	Maximum	TEL	PEL
Nutrients						
Total ammonia plus organic nitrogen, mg/kg	26/26	600	800	5,200	--	--
Total phosphorus, mg/kg	59/59	198	419	952	--	--
Carbon						
Carbon (inorganic), %	41/41	.06	.20	.58	--	--
Carbon (organic), %	41/41	.84	1.7	2.0	--	--
Carbon (total), %	41/41	.93	2.0	2.2	--	--
Metals and trace elements						
Aluminum, %	41/41	5.4	8.6	10	--	--
Antimony, µg/g	41/41	.79	1.2	7.1	--	--
Arsenic, µg/g	41/41	6.9	14	18	7.24	41.6
Barium, µg/g	41/41	570	660	980	--	--
Beryllium, µg/g	41/41	1.5	2.6	3.5	--	--
Bismuth, µg/g	0/41	<1.0	<1.0	<1.0	--	--
Cadmium, µg/g	41/41	.26	.44	.61	.676	4.21
Calcium, %	41/41	.98	1.4	2.3	--	--
Cerium, µg/g	41/41	48	80	92	--	--
Chromium, µg/g	41/41	48	81	120	52.3	160
Cobalt, µg/g	41/41	8.4	12	14	--	--
Copper, µg/g	41/41	20	34	44	18.7	108
Europium, µg/g	41/41	1.0	1.5	1.8	--	--
Gallium, µg/g	41/41	13	20	23	--	--
Gold, µg/g	0/41	<1.0	<1.0	<1.0	--	--
Holmium, µg/g	35/41	<1.0	1.1	1.3	--	--
Iron, %	41/41	2.2	4.9	5.7	--	--
Lanthanum, µg/g	41/41	27	44	51	--	--
Lead, µg/g	41/41	16	25	160	30.2	112
Lithium, µg/g	41/41	29	52	57	--	--
Magnesium, %	41/41	.67	1.2	1.4	--	--
Manganese, µg/g	41/41	440	710	1,100	--	--
Mercury, µg/g	40/41	< .02	.04	1.4	.130	.696
Molybdenum, µg/g	41/41	.58	1.1	1.9	--	--
Neodymium, µg/g	41/41	21	37	41	--	--
Nickel, µg/g	41/41	19	38	77	15.9	42.8
Niobium, µg/g	41/41	8.8	17	20	--	--
Potassium, %	41/41	1.8	2.1	2.3	--	--
Scandium, µg/g	41/41	6.5	13	17	--	--
Selenium, µg/g	41/41	.34	.81	1.5	--	--

Table 9. Statistical summary of concentrations, and comparison to sediment-quality guidelines, for selected constituents in bottom-sediment samples from Tuttle Creek Lake, northeast Kansas, August and September 1999—Continued

Constituent and unit of measurement	Number of detections/ number of analyses	Concentration			Sediment-quality guidelines ¹	
		Minimum	Median	Maximum	TEL	PEL
Metals and trace elements—Continued						
Silver, µg/g	41/41	0.40	0.73	1.2	0.733	1.77
Sodium, %	41/41	.19	.32	1.1	--	--
Strontium, µg/g	41/41	120	140	250	--	--
Sulfur, %	16/41	<.05	<.05	.10	--	--
Tantalum, µg/g	39/41	<1.0	1.6	3.3	--	--
Thallium, µg/g	15/41	<.1	<.1	1.0	--	--
Thorium, µg/g	41/41	10	15	17	--	--
Tin, µg/g	41/41	2.0	3.5	7.7	--	--
Titanium, %	41/41	.28	.36	.41	--	--
Uranium, µg/g	41/41	2.5	3.1	3.5	--	--
Vanadium, µg/g	41/41	73	140	160	--	--
Ytterbium, µg/g	41/41	1.7	2.7	6.3	--	--
Yttrium, µg/g	41/41	18	28	33	--	--
Zinc, µg/g	41/41	65	120	150	124	271
Organochlorine compounds						
Aldrin, µg/kg	2/34	<.2	<.2	.6	--	--
Chlordane, µg/kg	0/34	<3	<3	<3	2.26	4.79
DDD, µg/kg	10/34	<.5	<.5	1.4	1.22	7.81
DDE, µg/kg	30/34	<.2	.4	5.2	2.07	374
DDT, µg/kg	0/34	<.5	<.5	<.5	1.19	4.77
Dieldrin, µg/kg	10/34	<.2	<.2	.4	.715	4.30
Endosulfan, µg/kg	0/34	<.2	<.2	<.2	--	--
Endrin, µg/kg	0/34	<.2	<.2	<.2	--	--
Gross polychlorinated biphenyls (PCBs), µg/kg	0/34	<5	<5	<5	21.6	189
Heptachlor, µg/kg	0/34	<.2	<.2	<.2	--	--
Heptachlor epoxide, µg/kg	0/34	<.2	<.2	<.2	--	--
Lindane, µg/kg	0/34	<.2	<.2	<.2	--	--
Methoxychlor, µg/kg	0/34	<2.5	<2.5	<2.5	--	--
Mirex, µg/kg	0/34	<.2	<.2	<.2	--	--
Toxaphene, µg/kg	0/34	<50	<50	<50	--	--

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

Sediment-quality guidelines have been established by USEPA for arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc (table 9). Arsenic concentrations in the bottom sediment of Tuttle Creek Lake ranged from 6.9 to 18 µg/g with a median concentration of 14 µg/g (table 9). Of the 41 detections, 2 were less than the TEL (7.24 µg/g), and 39 exceeded the TEL but were less than the PEL (41.6 µg/g). Mean concentrations of arsenic in

bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 17.

Cadmium concentrations ranged from 0.26 to 0.61 µg/g with a median concentration of 0.44 µg/g (table 9). All detections of cadmium were less than the TEL (0.676 µg/g).

Chromium concentrations ranged from 48 to 120 µg/g with a median concentration of 81 µg/g (table 9). In general, the concentrations exceeded

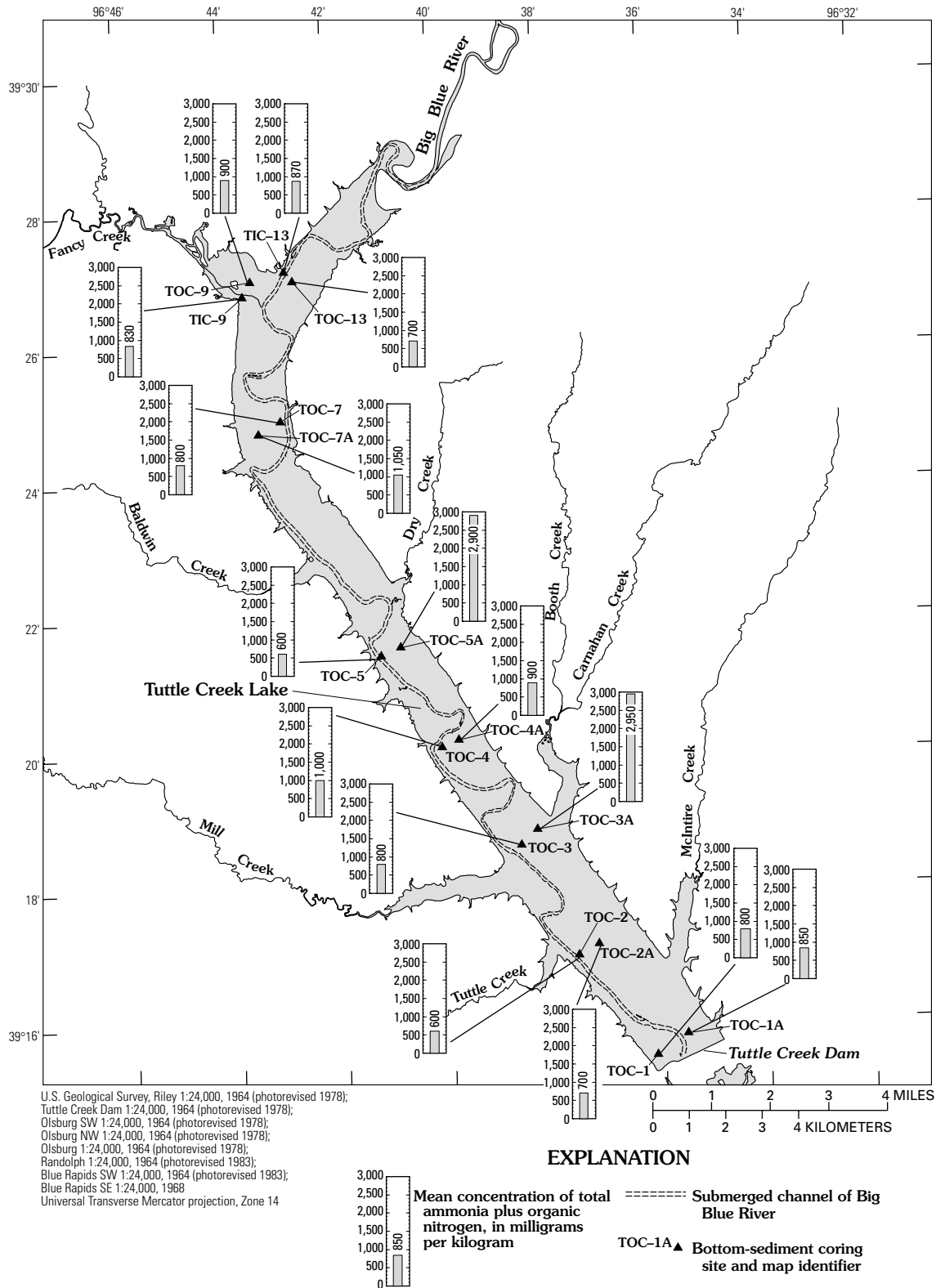


Figure 8. Mean concentrations of total ammonia plus organic nitrogen in bottom-sediment cores collected from Tuttle Creek Lake, 1999.

Table 10. Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Tuttle Creek Lake, northeast Kansas

[Mean annual net loads and yields have been rounded to three significant figures. mg/kg, milligrams per kilogram; kg/yr, kilograms per year; (kg/ha)/yr, kilograms per hectare per year; (lb/mi²)/yr, pounds per square mile per year; <, less than; --, not calculated or not available]

Constituent	Median concentration (mg/kg)	Mean annual net load ¹ (kg/yr)	Mean annual net yield ²		Bioaccumulation index ³
			[(kg/ha)/yr]	[(lb/mi ²)/yr]	
Nutrients					
Total ammonia plus organic nitrogen	800	2,880,000	1.15	657	--
Total phosphorus	419	1,510,000	.61	348	--
Carbon					
Carbon (inorganic)	2,000	7,200,000	2.89	1,650	--
Carbon (organic)	17,400	62,600,000	25.1	14,300	--
Carbon (total)	20,000	72,000,000	28.9	16,500	--
Metals and trace elements					
Aluminum	86,000	310,000,000	124	71,000	--
Antimony	1.2	4,320	.002	1.14	moderate
Arsenic	14	50,400	.02	11.4	moderate
Barium	660	2,380,000	.95	542	low
Beryllium	2.6	9,360	.004	2.28	low
Bismuth	<1.0	--	--	--	low
Cadmium	.44	1,580	.0006	.34	moderate
Calcium	14,000	50,400,000	20.2	11,500	--
Cerium	80	288,000	.12	68.5	--
Chromium	81	292,000	.12	68.5	moderate
Cobalt	12	43,200	.02	11.4	high
Copper	34	122,000	.05	28.6	high
Europium	1.5	5,400	.002	1.14	--
Gallium	20	72,000	.03	17.1	low
Gold	<1.0	--	--	--	low
Holmium	1.1	3,960	.002	1.14	--
Iron	49,000	176,000,000	70.6	40,300	low
Lanthanum	44	158,000	.06	34.3	--
Lead	25	90,000	.04	22.8	moderate
Lithium	52	187,000	.07	40.0	slight
Magnesium	12,000	43,200,000	17.3	9,880	--
Manganese	710	2,560,000	1.03	588	low
Mercury	.04	144	.00006	.034	high
Molybdenum	1.1	3,960	.002	1.14	high
Neodymium	37	133,000	.05	28.6	--
Nickel	38	137,000	.05	28.6	moderate
Niobium	17	61,200	.02	11.4	--
Potassium	21,000	75,600,000	30.3	17,300	--
Scandium	13	46,800	.02	11.4	--
Selenium	.81	2,920	.001	.571	high
Silver	.73	2,630	.001	.571	moderate
Sodium	3,200	11,500,000	4.61	2,630	--

Table 10. Estimated mean annual net loads and yields of constituents deposited in bottom sediment of Tuttle Creek Lake, northeast Kansas—Continued

Constituent	Median concentration (mg/kg)	Mean annual net load ¹ (kg/yr)	Mean annual net yield ²		Bioaccumulation index ³
			[(kg/ha)/yr]	[(lb/mi ²)/yr]	
Metals and trace elements—Continued					
Strontium	140	504,000	0.20	114	moderate
Sulfur	< 500	--	--	--	--
Tantalum	1.6	5,760	.002	1.14	--
Thallium	< .1	--	--	--	low
Thorium	15	54,000	.02	11.4	--
Tin	3.5	12,600	.005	2.86	--
Titanium	3,600	13,000,000	5.21	2,970	moderate
Uranium	3.1	11,200	.004	2.28	--
Vanadium	140	504,000	.20	114	low
Ytterbium	2.7	9,720	.004	2.28	--
Yttrium	28	101,000	.04	22.8	--
Zinc	120	432,000	.17	97.1	high
Organochlorine compounds					
Aldrin	< 0.0002	--	--	--	--
Chlordane	< .003	--	--	--	--
DDD	< .0005	--	--	--	--
DDE	.0004	1.44	.0000006	.0003	--
DDT	< .0005	--	--	--	--
Dieldrin	< .0002	--	--	--	--
Endosulfan	< .0002	--	--	--	--
Endrin	< .0002	--	--	--	--
Gross polychlorinated biphenyls (PCBs)	< .005	--	--	--	--
Heptachlor	< .0002	--	--	--	--
Heptachlor epoxide	< .0002	--	--	--	--
Lindane	< .0002	--	--	--	--
Methoxychlor	< .0025	--	--	--	--
Mirex	< .0002	--	--	--	--
Toxaphene	< .05	--	--	--	--

¹Mean annual net load was computed as median concentration multiplied by the mean annual sediment load deposited in Tuttle Creek Lake (3,600 million kilograms) divided by 1 million.

²Mean annual net yield in kilograms per hectare per year was computed as the mean annual net load divided by the area of the Tuttle Creek Lake Basin (2,493,652 hectares). Mean annual net yield in pounds per square mile per year was computed as the mean annual net yield in kilograms per hectare per year multiplied by 571.

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

the TEL (52.3 µg/g) but were less than the PEL (160 µg/g). Figure 13 shows the variation in chromium concentrations with sediment depth at coring site TIC-2 (fig. 2). Mean concentrations of chromium in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 18.

Copper concentrations ranged from 20 to 44 µg/g with a median concentration of 34 µg/g (table 9). All

detections exceeded the TEL (18.7 µg/g) but were less than the PEL (108 µg/g). Mean concentrations of copper in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 19.

Lead concentrations ranged from 16 to 160 µg/g with a median concentration of 25 µg/g (table 9). Aside from the 160-µg/g value, which was measured for interval 5 of the core collected from site TIC-2

Table 11. Results of trend tests on concentrations of selected constituents in bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, northeast Kansas, September 1999

[--, not calculated]

Constituent	Spearman's rho		Trend test at a 0.05 level of significance	
	All sample intervals	Sample intervals 3 and 11 excluded	All sample intervals	Sample intervals 3 and 11 excluded
Nutrients				
Total ammonia plus organic nitrogen	--	--	--	--
Total phosphorus	0.28	0.30	no trend	no trend
Carbon				
Carbon (inorganic)	-.29	-.28	no trend	no trend
Carbon (organic)	.36	.42	no trend	no trend
Carbon (total)	.15	.13	no trend	no trend
Metals and trace elements				
Aluminum	.44	.51	no trend	no trend
Antimony	.21	0	no trend	no trend
Arsenic	.38	.25	no trend	no trend
Barium	-.42	-.51	no trend	no trend
Beryllium	.47	.37	no trend	no trend
Bismuth	--	--	--	--
Cadmium	.27	.20	no trend	no trend
Calcium	.28	.26	no trend	no trend
Cerium	.08	.03	no trend	no trend
Chromium	.73	.72	positive trend	positive trend
Cobalt	.70	.64	positive trend	positive trend
Copper	.39	.31	no trend	no trend
Europium	-.06	-.13	no trend	no trend
Gallium	.62	.75	positive trend	positive trend
Gold	--	--	--	--
Holmium	.31	.34	no trend	no trend
Iron	.66	.75	positive trend	positive trend
Lanthanum	.09	.06	no trend	no trend
Lead	.20	.18	no trend	no trend
Lithium	.74	.73	positive trend	positive trend
Magnesium	.71	.69	positive trend	positive trend
Manganese	.44	.49	no trend	no trend
Mercury	.58	.51	positive trend	no trend
Molybdenum	.64	.59	positive trend	positive trend
Neodymium	-.08	-.17	no trend	no trend
Nickel	.78	.78	positive trend	positive trend
Niobium	.30	.36	no trend	no trend
Potassium	-.12	-.13	no trend	no trend
Scandium	.55	.56	positive trend	positive trend
Selenium	.64	.59	positive trend	positive trend
Silver	-.06	-.15	no trend	no trend
Sodium	-.51	-.64	no trend	negative trend
Strontium	-.39	-.46	no trend	no trend

Table 11. Results of trend tests on concentrations of selected constituents in bottom-sediment samples collected from coring site TIC-2 in Tuttle Creek Lake, northeast Kansas, September 1999—Continued

Constituent	Spearman's rho		Trend test at a 0.05 level of significance	
	All sample intervals	Sample intervals 3 and 11 excluded	All sample intervals	Sample intervals 3 and 11 excluded
Metals and trace elements—Continued				
Sulfur	--	--	--	--
Tantalum	0.55	0.67	positive trend	positive trend
Thallium	--	--	--	--
Thorium	.49	.57	no trend	positive trend
Tin	.53	.63	positive trend	positive trend
Titanium	.18	.16	no trend	no trend
Uranium	.19	.05	no trend	no trend
Vanadium	.45	.66	no trend	positive trend
Ytterbium	.08	.03	no trend	no trend
Yttrium	.29	.32	no trend	no trend
Zinc	.64	.70	positive trend	positive trend
Organochlorine compounds				
Aldrin	--	--	--	--
Chlordane	--	--	--	--
DDD	--	--	--	--
DDE	-.26	-.40	no trend	no trend
DDT	--	--	--	--
Dieldrin	--	--	--	--
Endosulfan	--	--	--	--
Endrin	--	--	--	--
Gross polychlorinated biphenyls (PCBs)	--	--	--	--
Heptachlor	--	--	--	--
Heptachlor epoxide	--	--	--	--
Lindane	--	--	--	--
Methoxychlor	--	--	--	--
Mirex	--	--	--	--
Toxaphene	--	--	--	--

(fig. 2), all other detections ranged between 16 and 34 $\mu\text{g/g}$. Of the 41 detections, 33 were less than the TEL (30.2 $\mu\text{g/g}$), 7 exceeded the TEL but were less than the PEL (112 $\mu\text{g/g}$), and 1 exceeded the PEL.

Mercury is a very toxic element for plants, animals, and humans. Once in the food chain it can readily bioaccumulate (Forstner and Wittman, 1981; Adriano, 1986; Pais and Jones, 1997). With the exception of the anomalously large concentration (1.4 $\mu\text{g/g}$) determined for interval 11 of the core collected from site TIC-2 (fig. 2), mercury concentrations at the site appeared stable over time and were consistently in the range of 0.02 to 0.05 $\mu\text{g/g}$ (fig. 14). Overall, mercury concentrations in bottom sediment from

Tuttle Creek Lake ranged from less than 0.02 to 1.4 $\mu\text{g/g}$ with a median concentration of 0.04 $\mu\text{g/g}$ (table 9). Aside from the 1.4- $\mu\text{g/g}$ value, all other detections measured 0.07 $\mu\text{g/g}$ or less. With the exception of the 1.4- $\mu\text{g/g}$ value, which exceeded the PEL (0.696 $\mu\text{g/g}$), all other detections were less than the TEL (0.13 $\mu\text{g/g}$).

Nickel concentrations ranged from 19 to 77 $\mu\text{g/g}$ with a median concentration of 38 $\mu\text{g/g}$ (table 9). Aside from the 77- $\mu\text{g/g}$ value, which was measured for interval 11 of the core collected from site TIC-2 (fig. 2), all other detections ranged between 19 and 43 $\mu\text{g/g}$. The 77- $\mu\text{g/g}$ value exceeded the PEL (42.8 $\mu\text{g/g}$). All other detections exceeded the TEL

(15.9 $\mu\text{g/g}$) with several values at or near the PEL. Figure 15 shows the variation in nickel concentrations with sediment depth at coring site TIC-2 (fig. 2). Mean concentrations of nickel in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 20.

Silver concentrations ranged from 0.4 to 1.2 $\mu\text{g/g}$ with a median concentration of 0.73 $\mu\text{g/g}$ (table 9). Of the 41 detections, 21 were less than the TEL (0.733 $\mu\text{g/g}$), and 20 exceeded the TEL but were less than the PEL (1.77 $\mu\text{g/g}$). Mean concentrations of silver in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 21.

Zinc concentrations ranged from 65 to 150 $\mu\text{g/g}$ with a median concentration of 120 $\mu\text{g/g}$ (table 9). Of the 41 detections, 21 were less than the TEL (124 $\mu\text{g/g}$), and 20 exceeded the TEL but were less than the PEL (271 $\mu\text{g/g}$).

Figure 16 shows the variation in zinc concentrations with sediment depth at coring site TIC-2 (fig. 2). Mean concentrations of zinc in bottom-sediment cores collected from Tuttle Creek Lake are shown in figure 22.

USEPA has not established sediment-quality guidelines for selenium. However, concentrations equal to or greater than 4.0 $\mu\text{g/g}$ in sediment are a concern for fish and wildlife because of the potential for bioaccumulation (Lemly and Smith, 1987). Concentrations in bottom-sediment cores collected from Tuttle Creek Lake ranged from 0.34 to 1.5 $\mu\text{g/g}$ with a median concentration of 0.81 $\mu\text{g/g}$ (table 9). Figure 15 shows the variation in selenium concentrations with sediment depth at coring site TIC-2 (fig. 2).

The estimated mean annual net loads and yields for most of the metals and trace elements are provided in table 10.

Organochlorine Compounds

Historically, organochlorine compounds have been manufactured and used extensively for a variety of urban, agricultural, and industrial applications. The use of organochlorine insecticides in agriculture in the United States began in the 1940s and increased to peak levels during the 1950s and 1960s. Then, because of their persistence in the environment, a tendency to bio-

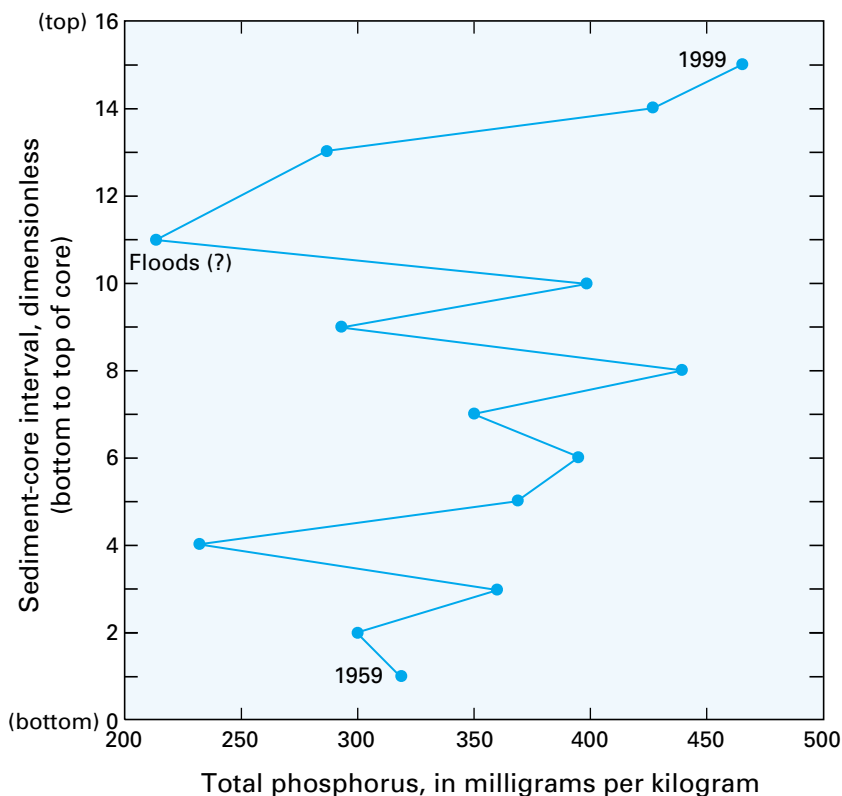


Figure 9. Variation in total phosphorus concentration with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999. Location of site shown in figure 2.

accumulate, and potential effects on wildlife and human health, most of the organochlorine insecticides were banned or severely restricted during the 1970s (Nowell and others, 1999). For example, in the United States the use of DDT was banned in 1972 (Manahan, 2000) followed by bans of aldrin and dieldrin in 1983 (Alloway and Ayres, 1997).

Polychlorinated biphenyls (PCBs), organochlorine compounds that were first produced industrially in 1929, were used for a variety of applications including ink and paint additives, plasticizers, and coolant-insulation fluids in transformers and capacitors (Alloway and Ayres, 1997; Manahan, 2000). PCBs were identified as environmental pollutants in 1966 with toxic effects similar to those of DDT. By 1977, worldwide production of PCBs had practically ceased (Alloway and Ayres, 1997). However, because of their persistence, PCBs remain widespread in the environment.

Of the 15 organochlorine compounds analyzed in this study (14 insecticides and PCBs), only 4 were detected in the bottom sediment of Tuttle Creek Lake. Aldrin was detected in 2 of 34 sediment samples analyzed (table 9). Both detections, with concentrations of

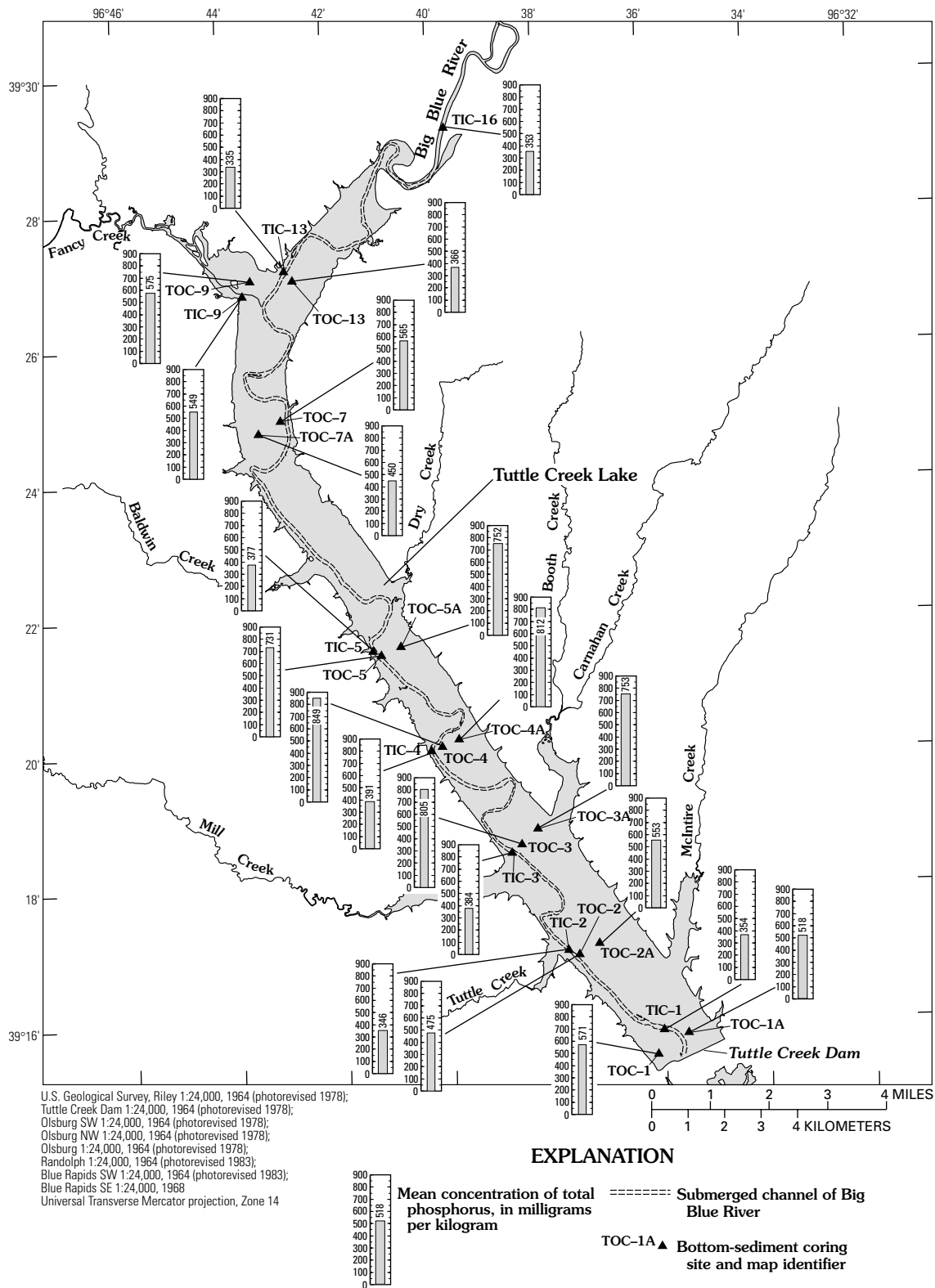


Figure 10. Mean concentrations of total phosphorus in bottom-sediment cores collected from Tuttle Creek Lake, 1999.

0.6 and 0.3 $\mu\text{g}/\text{kg}$, were from coring site TIC-2 (fig. 2). No sediment-quality guidelines have been established for aldrin.

DDT was not detected in any of the 34 sediment samples analyzed. However, its degradation products DDD and DDE were detected at several sites. DDD was detected in 10 of 34 sediment samples analyzed (table 9) and at 3 of 10 sites for which the analysis was performed (sites TOC-1A, TIC-2, and TIC-9; fig. 2). Detectable concentrations of DDD ranged from 0.6 to 1.4 $\mu\text{g}/\text{kg}$. The median concentration of DDD was less than the detection limit of 0.5 $\mu\text{g}/\text{kg}$. Because DDD was not detected in 8 of 15 intervals of the sediment core from site TIC-2, a trend analysis was not performed. With one exception, the detectable concentrations of DDD were less than the TEL of 1.22 $\mu\text{g}/\text{kg}$.

The pattern of DDE deposition (fig. 23) was consistent with the history of DDT usage. DDT was used extensively in agriculture during the 1950s and 1960s. Then, with the ban of DDT in 1972, its use declined (Manahan, 2000). DDE was detected in 30 of 34 sediment samples analyzed (table 9) and at all 10 sites for which the analysis was performed (sites TOC-1A, TOC-2A, TOC-3A, TOC-4A, TOC-5A, TOC-7A, TIC-2, TIC-5, TIC-9, and TIC-13; fig. 2). Concentrations of DDE ranged from less than the detection limit of 0.2 to 5.2 $\mu\text{g}/\text{kg}$ with a median concentration of 0.4 $\mu\text{g}/\text{kg}$. Overall, no significant trend was indicated for DDE (table 11, fig. 23). However, when the intervals for the sediment core from site TIC-2 were grouped and analyzed for trend separately, a different result was indicated. For intervals 1-5 (that is, the oldest sediment in the core), a Spearman's rho of 0.70 was computed. Thus, a positive trend was indicated in which DDE concentrations increased with decreasing depth in the sediment core. However, this trend was not significant at the 0.05 level. For intervals 5-15 (that is, the youngest sediment in the core), a Spearman's rho of -0.90 was computed. Thus, a negative trend, which was significant at the 0.001 level, was indicated in which DDE concentrations decreased with decreasing depth

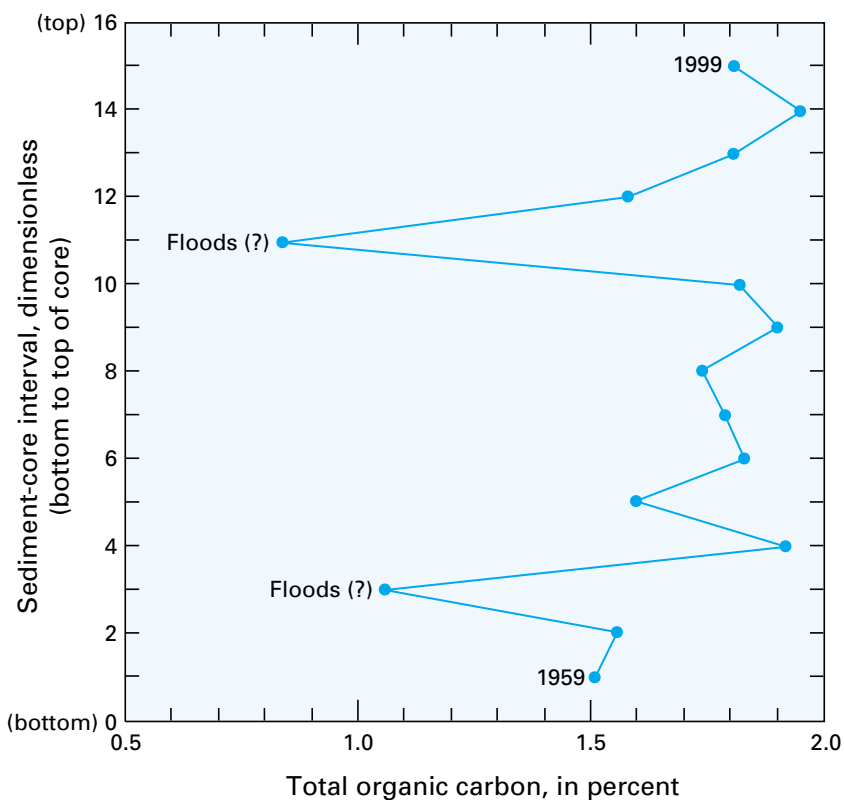


Figure 11. Variation in total organic carbon concentration with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999. Location of site shown in figure 2.

(fig. 23). These results indicated that, over the life of the lake, a reversal in the trend of DDE deposition occurred. With one exception, the detectable concentrations of DDE were less than the TEL of 2.07 $\mu\text{g}/\text{kg}$. The estimated mean annual net load of DDE deposited in the bottom sediment was 3.18 lb/yr (1.44 kg/yr). The estimated mean annual net yield of DDE from the Tuttle Creek Lake Basin was 0.0003 (lb/mi²)/yr [0.0000006 (kg/ha)/yr] (table 10).

Dieldrin was detected in 10 of 34 sediment samples analyzed (table 9) and in samples from 6 of 10 sites for which the analysis was performed (sites TOC-1A, TOC-4A, TOC-5A, TIC-2, TIC-9, and TIC-13; fig. 2). Detectable concentrations of dieldrin ranged from 0.2 to 0.4 $\mu\text{g}/\text{kg}$. The median concentration of dieldrin was less than the detection limit of 0.2 $\mu\text{g}/\text{kg}$. Because dieldrin was not detected in 10 of 15 intervals for the sediment core from site TIC-2, a trend analysis was not performed. In all cases, concentrations of dieldrin were less than the TEL of 0.715 $\mu\text{g}/\text{kg}$.

PCBs were not detected in any of the 34 sediment samples analyzed. Because PCBs are associated with

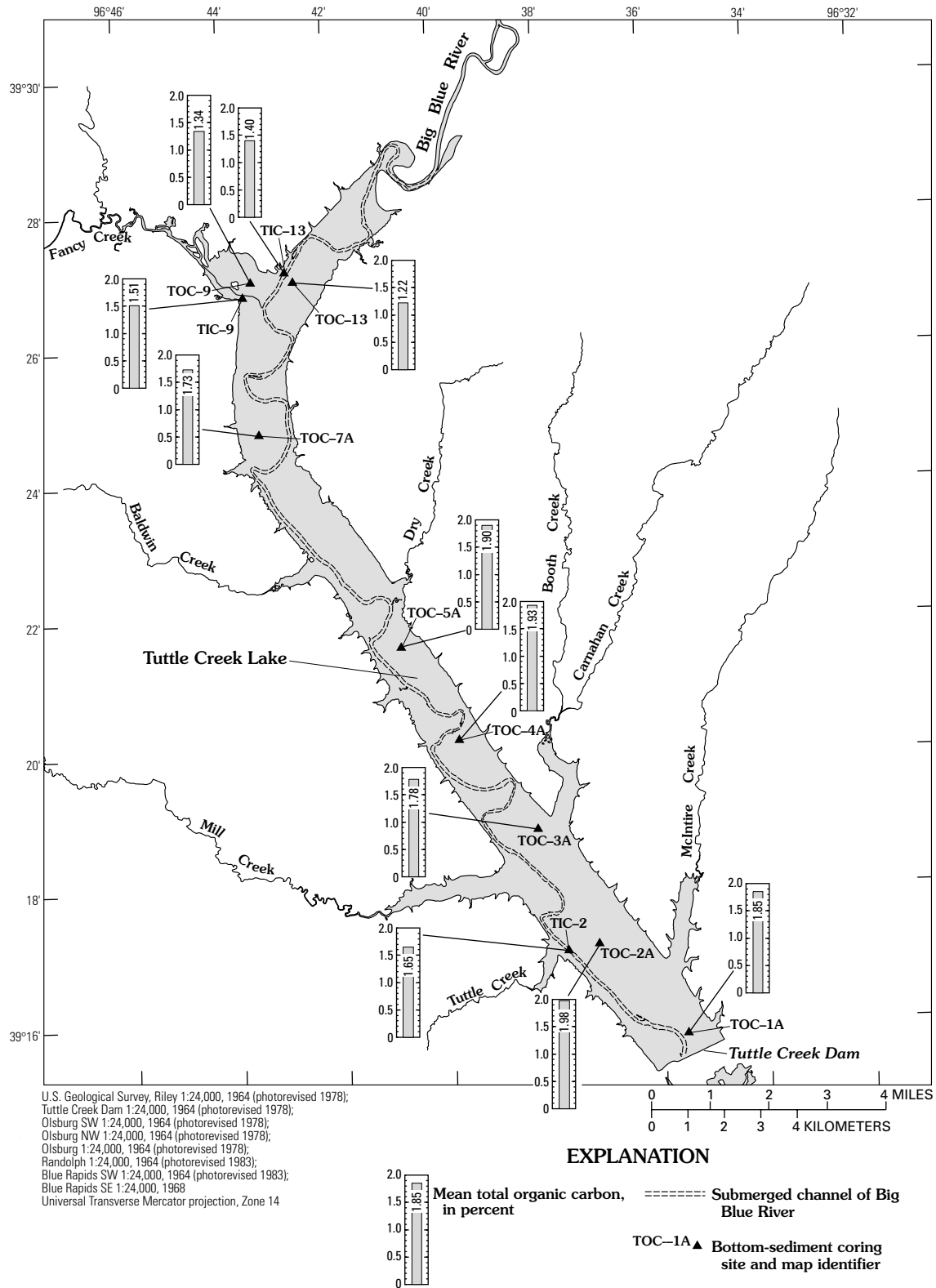


Figure 12. Mean concentrations of total organic carbon in bottom-sediment cores collected from Tuttle Creek Lake, 1999.

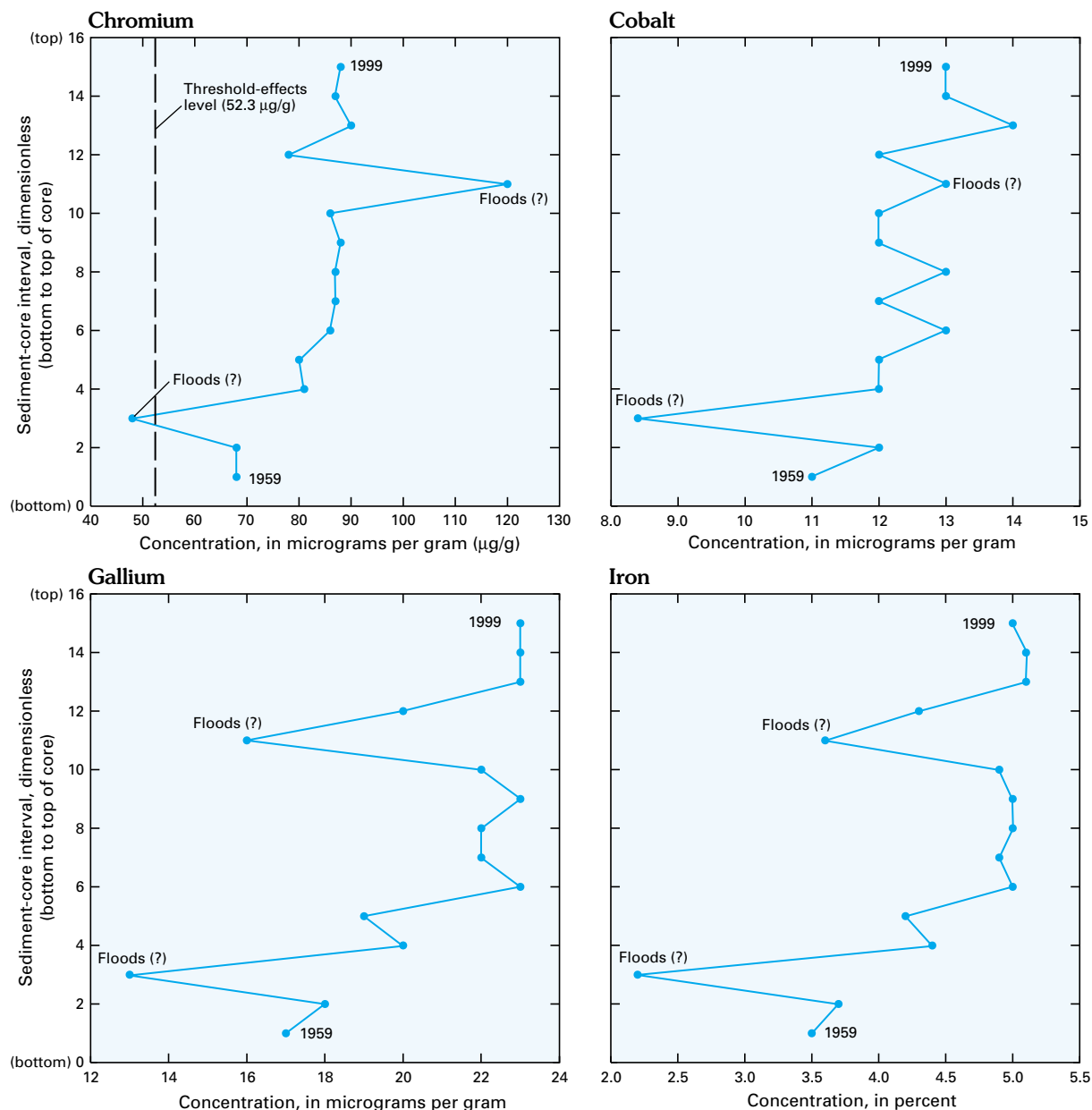


Figure 13. Variation in concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999, for chromium, cobalt, gallium, and iron. Threshold-effects level from U.S. Environmental Protection Agency (1997).

industrial or commercial activities such as those located in intensively urbanized areas, PCBs generally would not be expected in reservoir bottom sediment from a predominantly agricultural basin.

COMPARISON OF DEPOSITIONAL TRENDS TO STREAMFLOW AND HUMAN ACTIVITY

In this study, trend analyses indicated a statistically significant positive depositional trend over time

for chromium, cobalt, gallium, iron, lithium, magnesium, mercury, molybdenum, nickel, scandium, selenium, tantalum, tin, and zinc (table 10, figs. 13–16). However, for reasons previously discussed, the indicated trends may or may not be representative of actual conditions. In general, differences in the deposition of nutrients, metals, trace elements, and organochlorine compounds over time may be due, in part, to several factors including changes in the particle size and composition of the sediment, redox conditions (oxidation/reduction potential of the

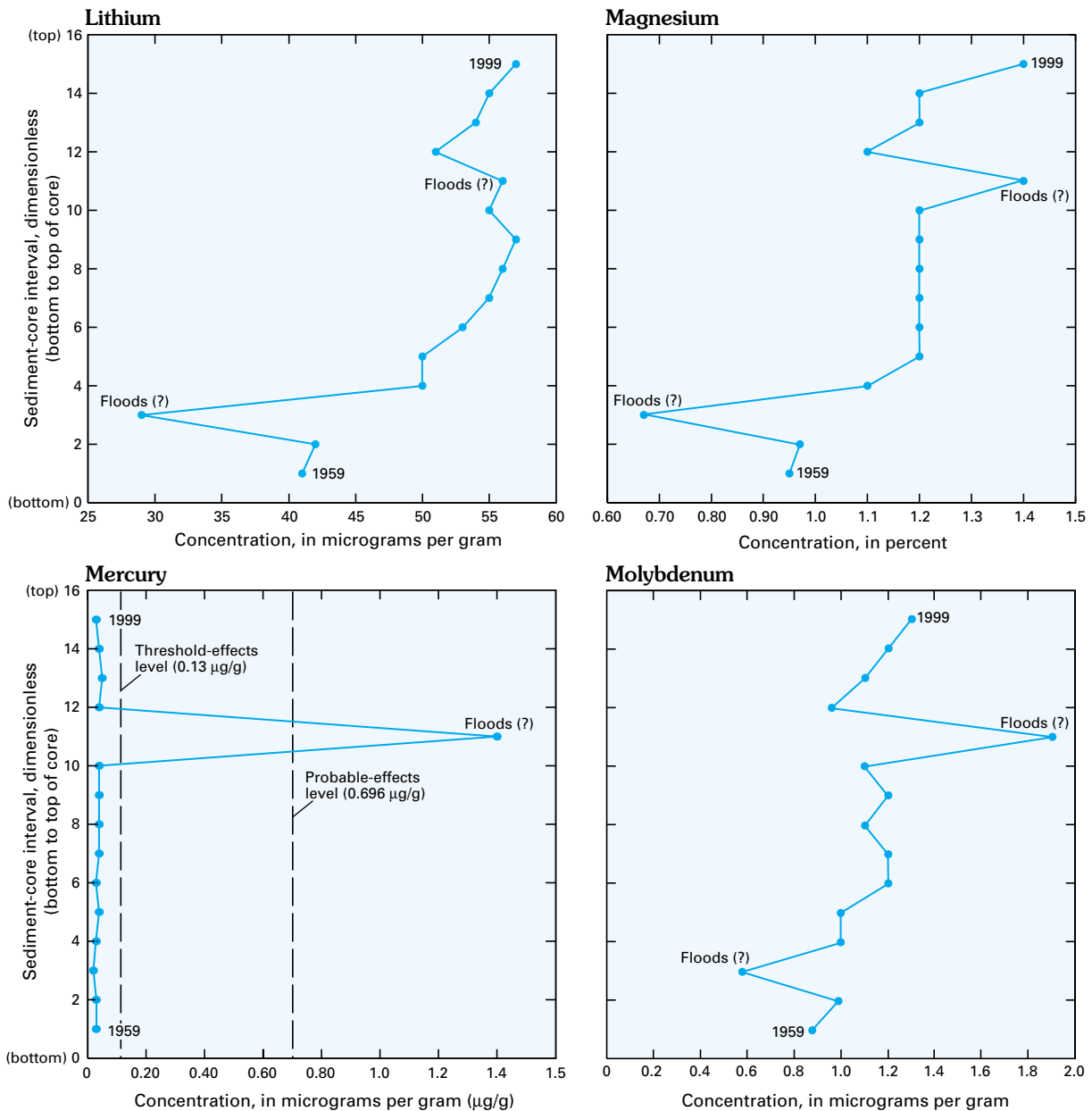


Figure 14. Variation in concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999, for lithium, magnesium, mercury, and molybdenum. Threshold- and probable-effects levels from U.S. Environmental Protection Agency (1997).

environment), precipitation, streamflow, land use, irrigation (source of water and method of application), and land-management practices.

To describe conditions for the mostly agricultural Big Blue River Basin that may affect the deposition of constituents in Tuttle Creek Lake, the factors streamflow, population, crop production, irrigation, and livestock production were investigated. The time period of interest was 1960 through 2000. County-level data were used to assess changes in population, crop

production, irrigation, and livestock production. For this study, only counties that were located completely or mostly within the Big Blue River Basin were included. For Kansas, data were compiled for Marshall and Washington Counties (fig. 1). For Nebraska, data were compiled for Adams, Clay, Fillmore, Gage, Hamilton, Jefferson, Nuckolls, Saline, Seward, Thayer, and York Counties (fig. 1). Because complete information on crop production and irrigation was not available for the Kansas counties for the time period of

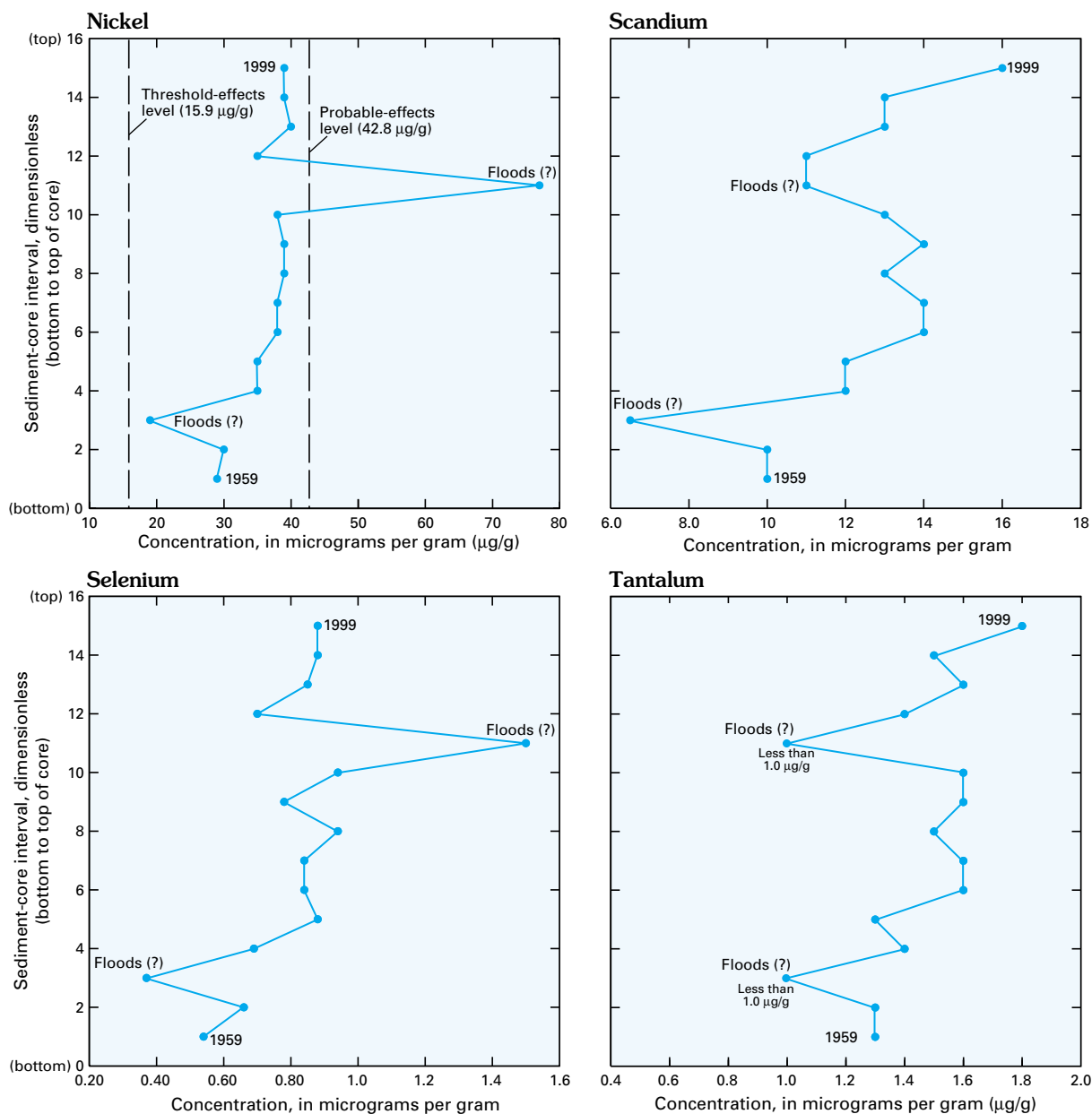


Figure 15. Variation in concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999, for nickel, scandium, selenium, and tantalum. Threshold- and probable-effects levels from U.S. Environmental Protection Agency (1997).

interest (1960–2000), only the Nebraska counties were used in the compilation of data for these activities. However, because about 75 percent of the Big Blue River Basin is located in Nebraska, the results may be considered as representative of crop production and irrigation activities throughout the basin.

Streamflow, specifically mean annual discharge for the period of record, was examined for five USGS streamflow-gaging stations located in the Big Blue River Basin—the Big Blue River at Marysville,

Kansas (station 06882510, period of record 1985–2000), the Little Blue River near Barnes, Kansas (station 06884400, period of record 1959–2000), Mill Creek at Washington, Kansas (station 06884200, period of record 1960–99), the Black Vermillion River near Frankfort, Kansas (station 06885500, period of record 1954–2000), and the Big Blue River near Crete, Nebraska (station 06881000, period of record 1954–2000) (fig. 1). In each case, the year-to-year variability in mean annual discharge was evident. No

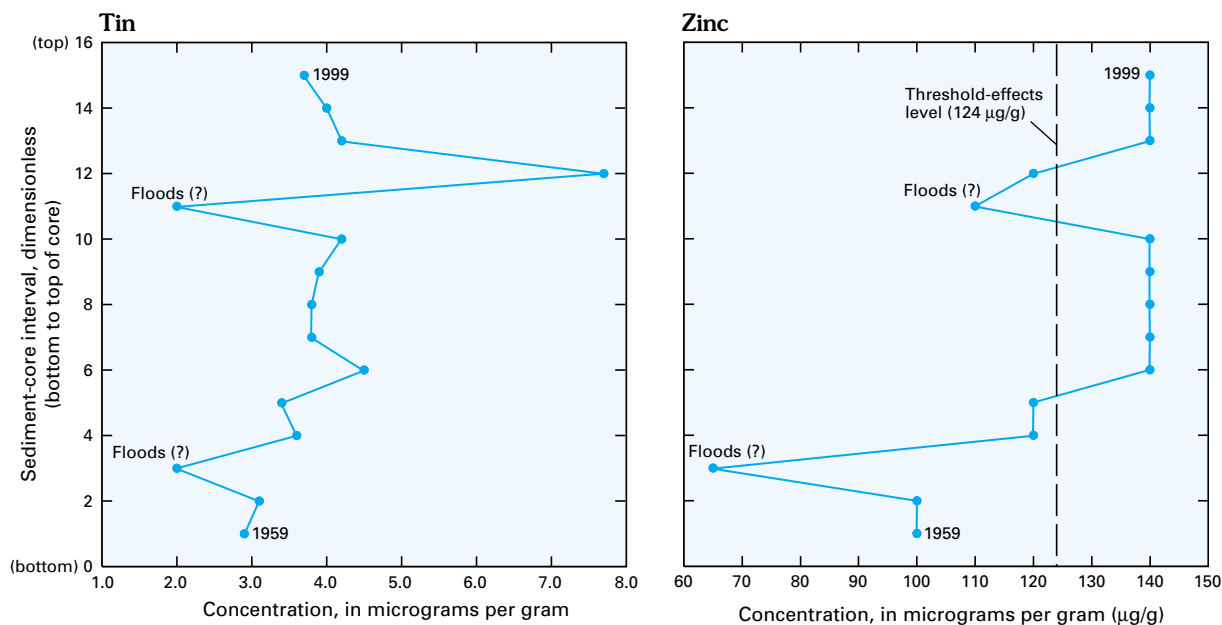


Figure 16. Variation in concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999, for tin and zinc. Threshold-effects level from U.S. Environmental Protection Agency (1997).

statistically significant trends in streamflow were determined.

The mean annual discharge for 1993 was the largest for the period of record at the four Kansas gaging stations and the second largest for the period of record at the Nebraska gaging station. The Big Blue River Basin was affected by major flooding in 1993, which may account, in part, for the anomalous constituent concentrations that were measured for interval 11 of the sediment core collected at site TIC-2 (fig. 2). Likewise, major flooding in 1973 may account, in part, for the anomalous constituent concentrations that were measured for interval 3 of the same core.

Population change over time can provide a general indication of human activity and the associated potential for environmental pollution. For the Big Blue River Basin, population estimates for the years 1960, 1970, 1980, 1990, and 2000 were compiled for the 13 counties listed previously (U.S. Census Bureau, 2001). Population in the basin has declined from 1960 to 2000 by about 10 percent (fig. 24).

Crop production can have a substantial effect on water and sediment quality in a basin due to repeated disturbance of the land surface, application of pesticides and fertilizers, and irrigation. Cropland is typified by higher runoff volumes and sediment yields than grassland and woodland (Novotny and Chesters, 1981; Novotny, 1995; Morris and Fan, 1997).

Increased runoff from cropland is attributable to several factors, including the removal of native vegetation and soil compaction, which decrease surface permeability.

Pesticides and fertilizers are potential sources of metal and trace element pollution. Pesticides may contain arsenic, copper, mercury, lead, manganese, and zinc. Impurities in fertilizers may include cadmium, chromium, molybdenum, uranium, vanadium, and zinc (Alloway and Ayres, 1997).

Irrigation can degrade water and sediment quality through the mobilization, transport, and deposition of various constituents. For example, metals and trace elements often are redistributed by irrigated agriculture. Also, the use of ground water for irrigation may provide an additional source of metals and trace elements. In the Big Blue River Basin, ground water from the High Plains aquifer (fig. 1) is used for most of the irrigation (Jordan and Stamer, 1995). Among the metals and trace elements that have been detected in ground water from the High Plains aquifer are arsenic, barium, cadmium, chromium, copper, iron, lead, manganese, mercury, selenium, silver, and zinc (Engberg, 1984).

Crop production and irrigation data were compiled at 5-year intervals for five principal crops in the Big Blue River Basin—alfalfa, grain corn, grain sorghum, soybeans, and wheat. Alfalfa production declined

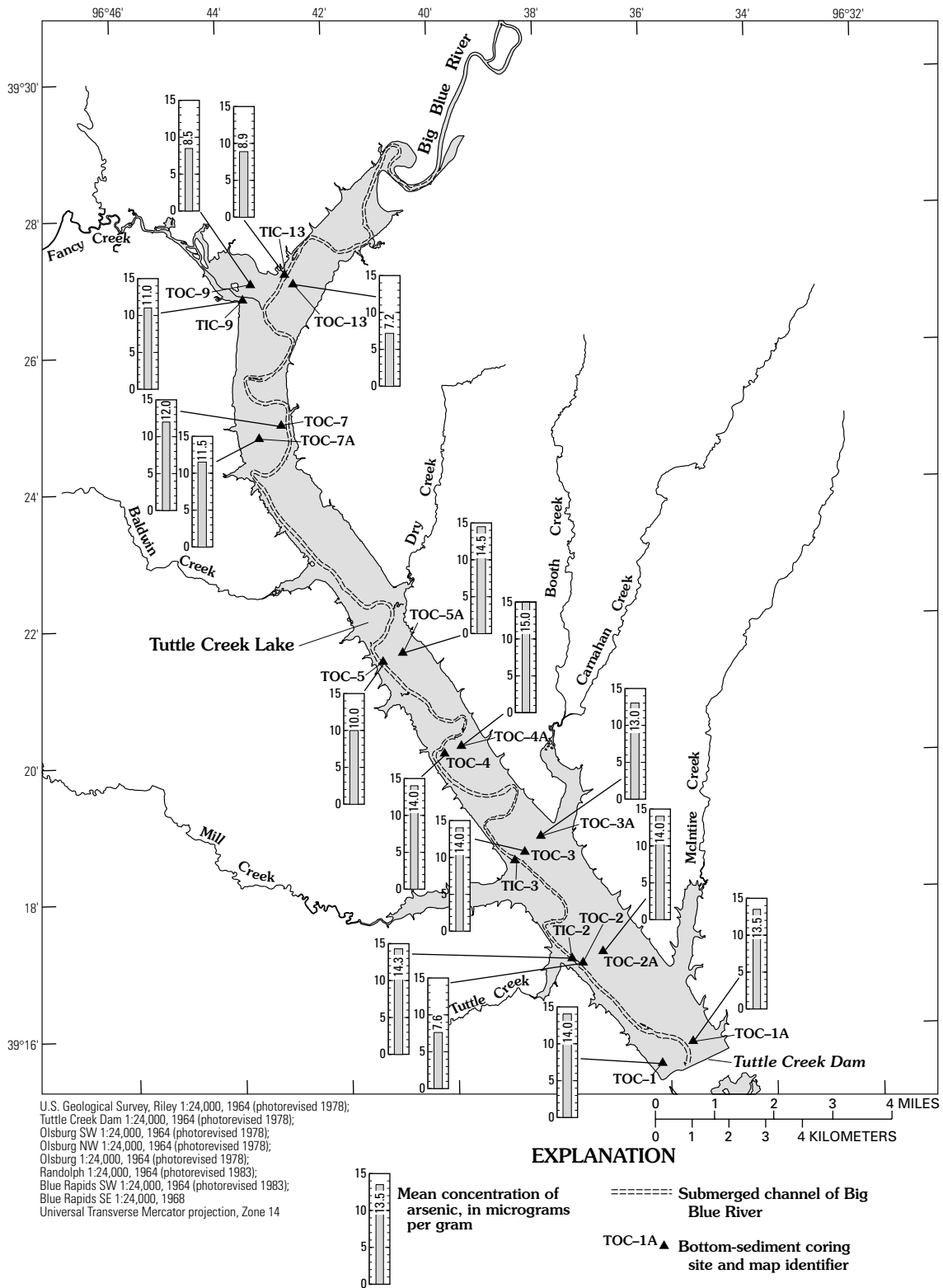


Figure 17. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for arsenic.

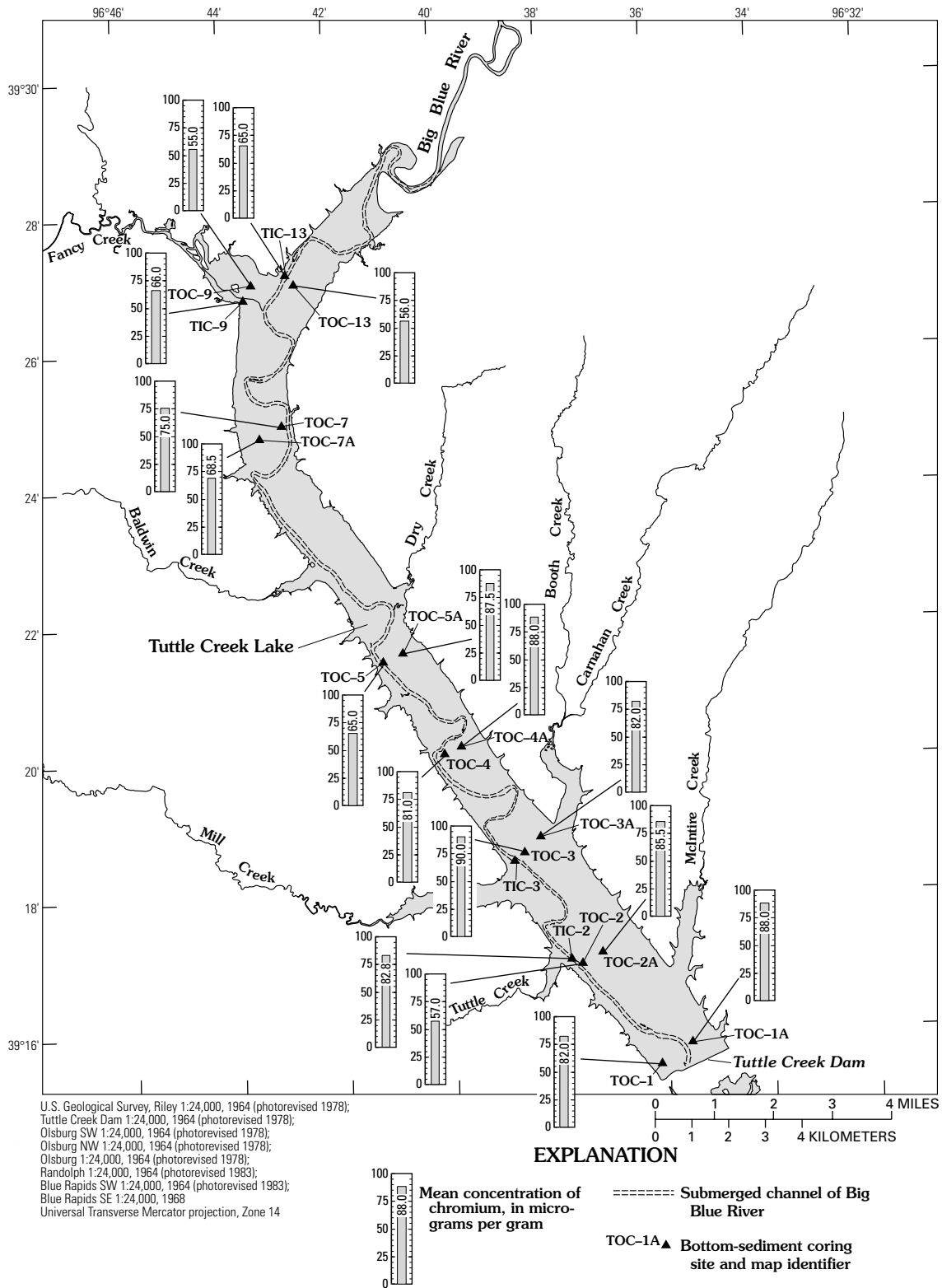


Figure 18. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for chromium.

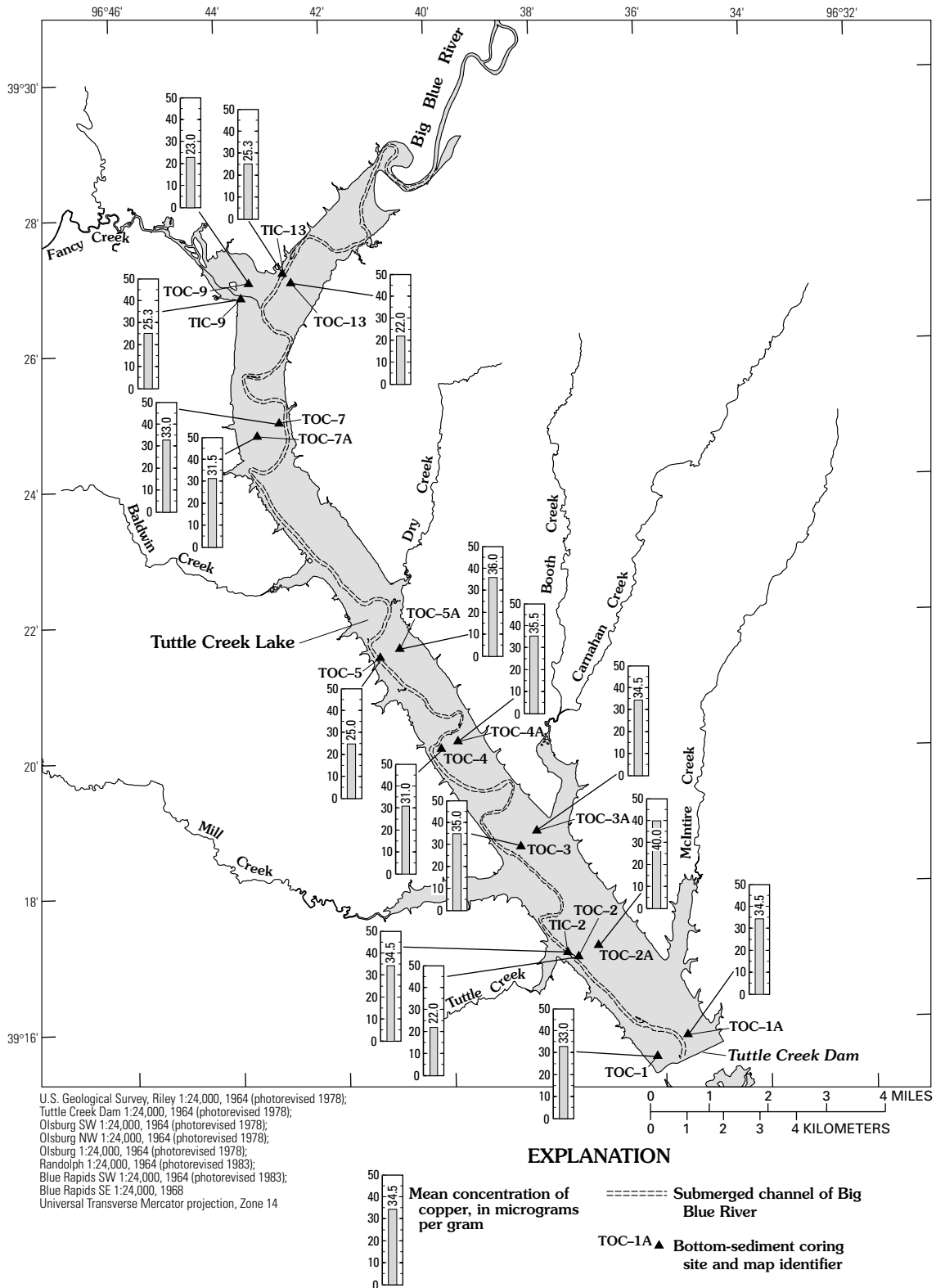


Figure 19. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for copper.

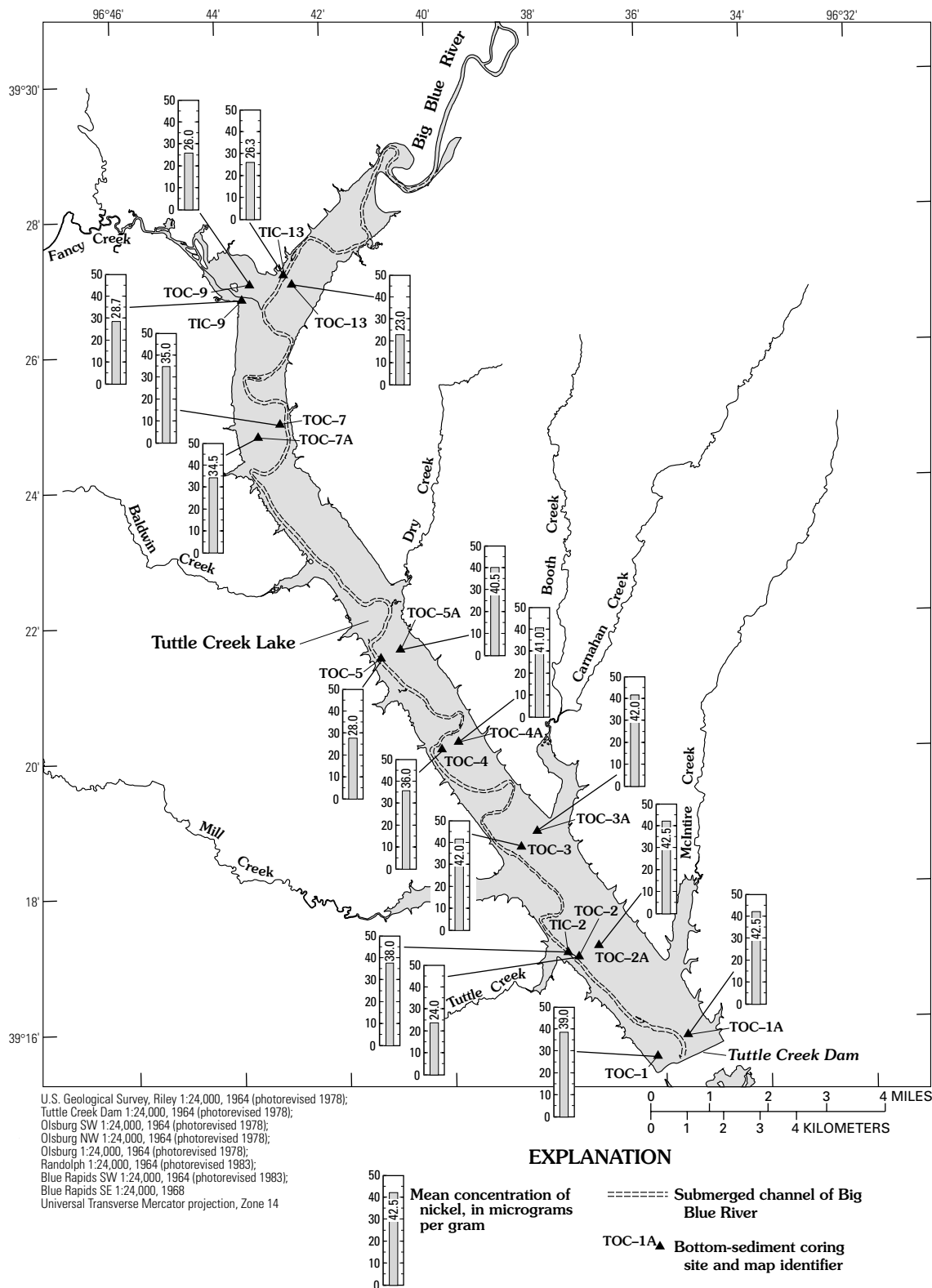


Figure 20. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for nickel.

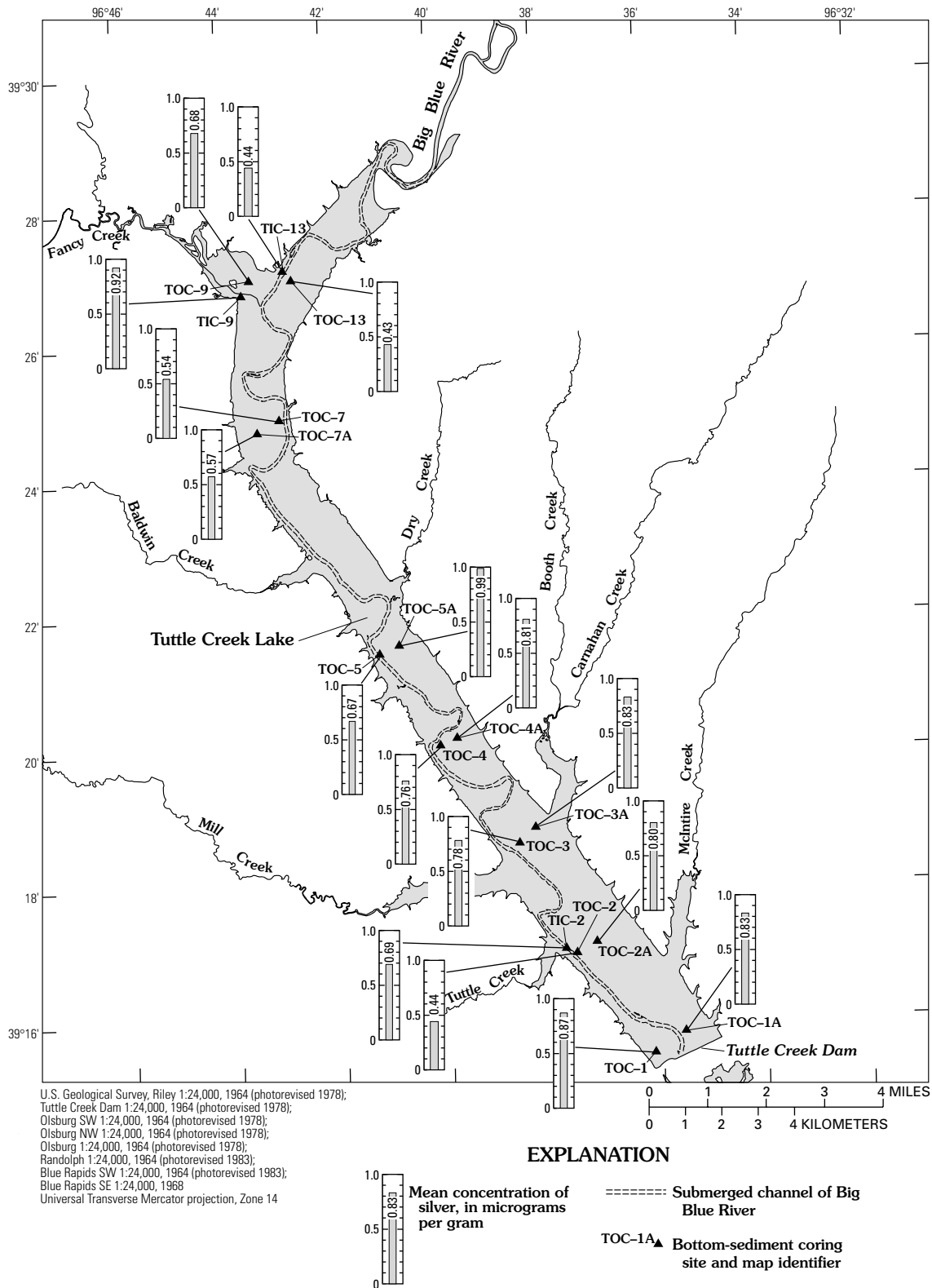


Figure 21. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for silver.

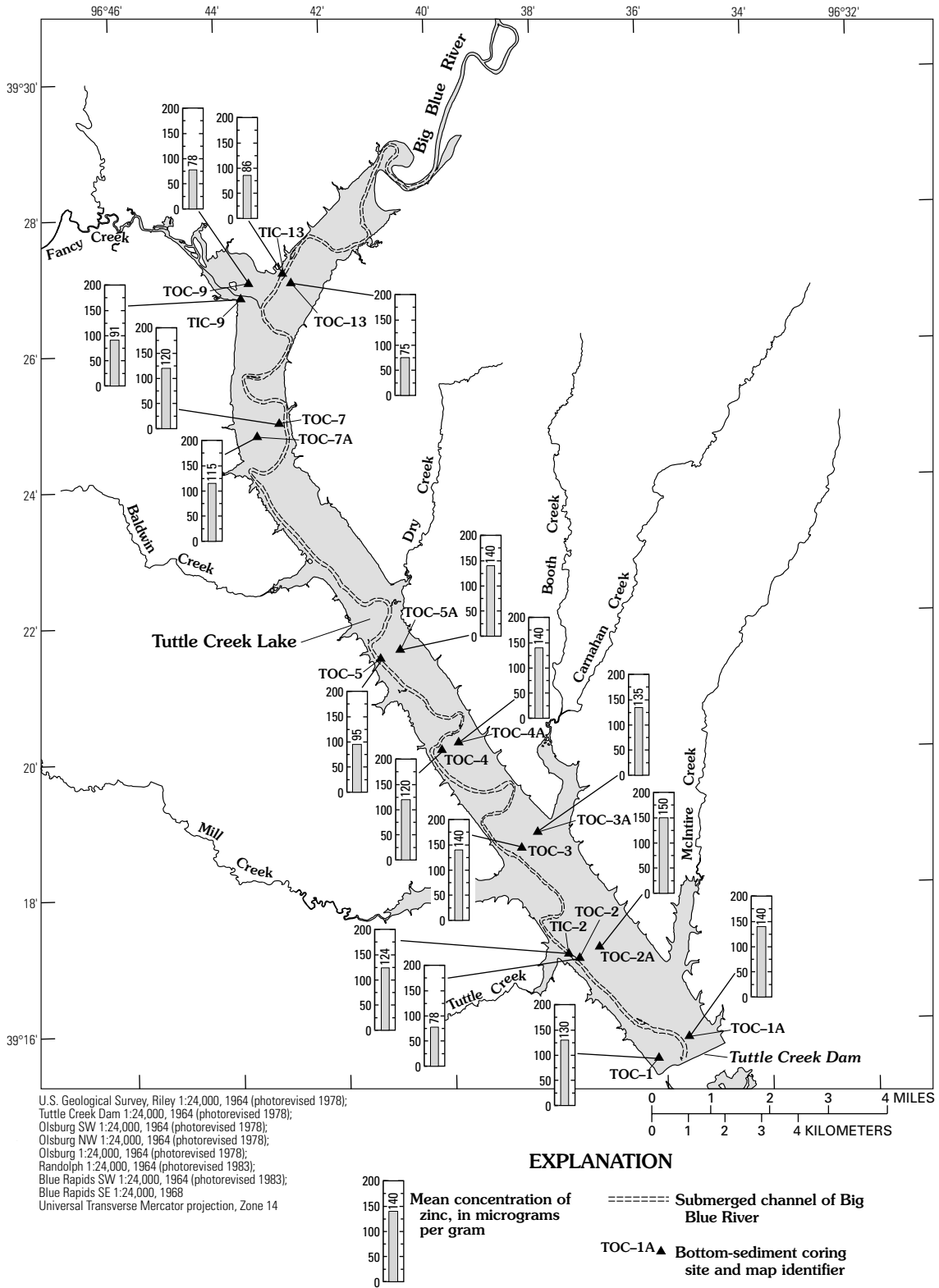


Figure 22. Mean concentrations in bottom-sediment cores collected from Tuttle Creek Lake, August and September 1999, for zinc.

from almost 200,000 acres harvested in 1965 to about 85,000 acres harvested in 1999 (fig. 25). Typically, alfalfa was not irrigated, with total irrigated acres less than 25,000 acres (U.S. Department of Agriculture, 2001).

Following a decrease in 1965, grain corn production steadily increased from about 400,000 acres harvested in 1965 to almost 1.5 million acres harvested in 2000 (fig. 26). Most of the grain corn produced was irrigated. Following a decrease in 1965, total irrigated acres for grain corn increased from about 300,000 acres in 1965 to about 1.2 million acres in 1995. In 2000, about 1 million acres were irrigated (U.S. Department of Agriculture, 2001).

Grain sorghum production in the Big Blue River Basin peaked at about 930,000 acres harvested in 1980 and then steadily declined to about 310,000 acres harvested in 2000 (fig. 27). Most of the grain sorghum was not irrigated. Total irrigated acres declined from about 210,000 acres in 1965 to only about 12,000 acres in 2000 (U.S. Department of Agriculture, 2001).

Soybean production increased substantially in the basin from less than 2,000 acres harvested in 1960 to about 1 million acres harvested in 2000 (fig. 28). Likewise, the total acres of soybeans irrigated increased from only about 300 to almost 540,000 over the same time period (U.S. Department of Agriculture, 2001).

Wheat production decreased substantially from about 665,000 acres harvested in 1965 to about 140,000 acres harvested in 2000 (fig. 29). Typically, wheat was not irrigated, with total irrigated acres generally less than 10,000 acres (U.S. Department of Agriculture, 2001).

Livestock production data were compiled at 5-year intervals for cattle and hogs. Cattle production increased from about 560,000 animals in 1960 to a peak of about 810,000 animals in

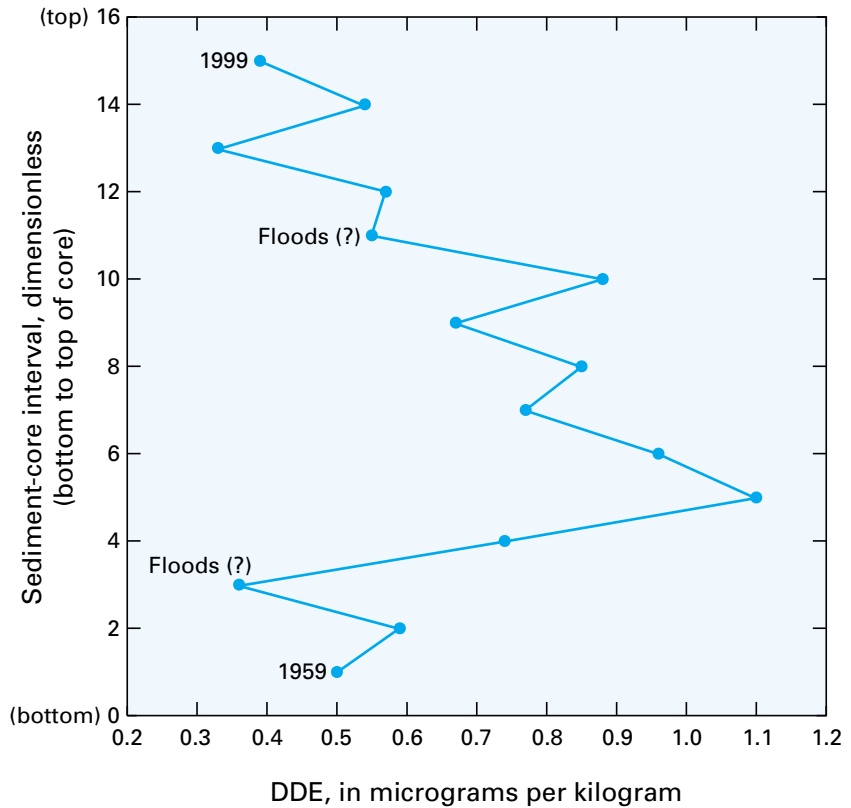


Figure 23. Variation in concentrations with depth of bottom-sediment core samples collected from site TIC-2 in Tuttle Creek Lake, September 1999, for DDE. Location of site shown in figure 2.

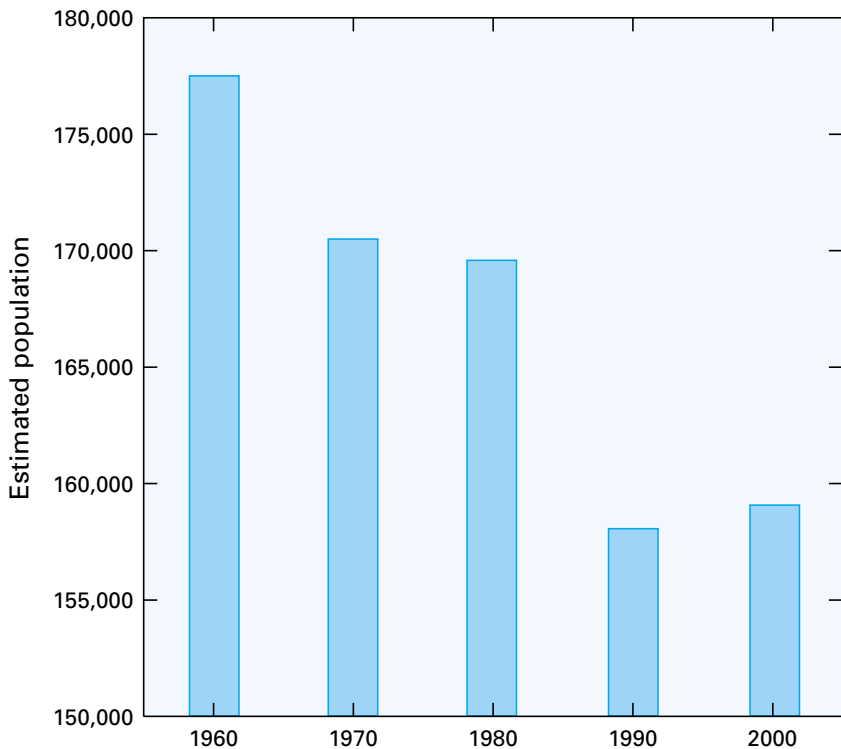


Figure 24. Estimated population in Big Blue River Basin, 1960–2000 (data from U.S. Census Bureau, 2001).

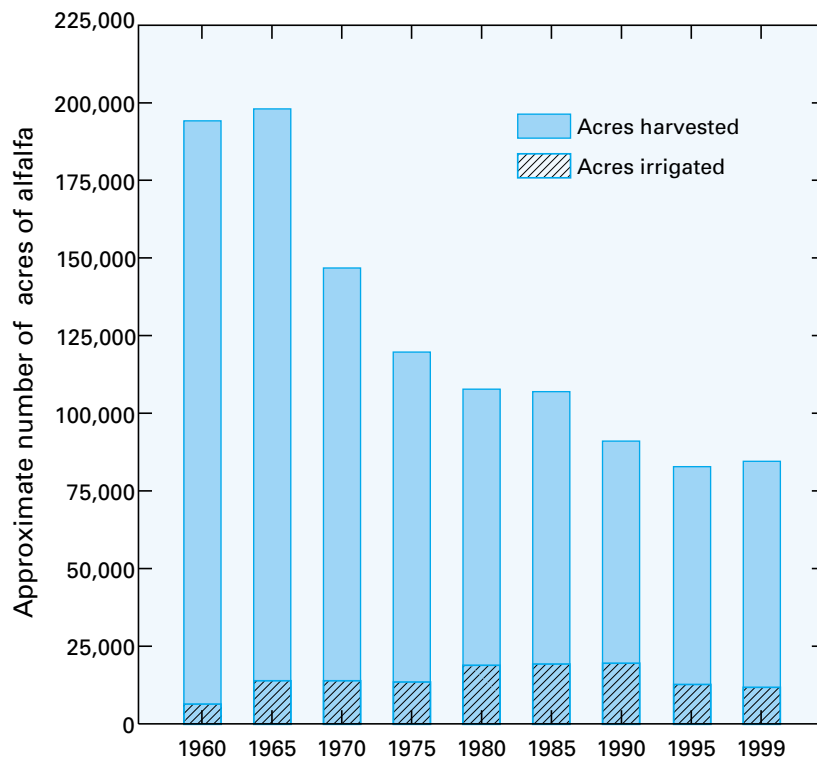


Figure 25. Approximate number of acres harvested and irrigated in Big Blue River Basin, 1960–99, for alfalfa (data compiled from U.S. Department of Agriculture, 2001).

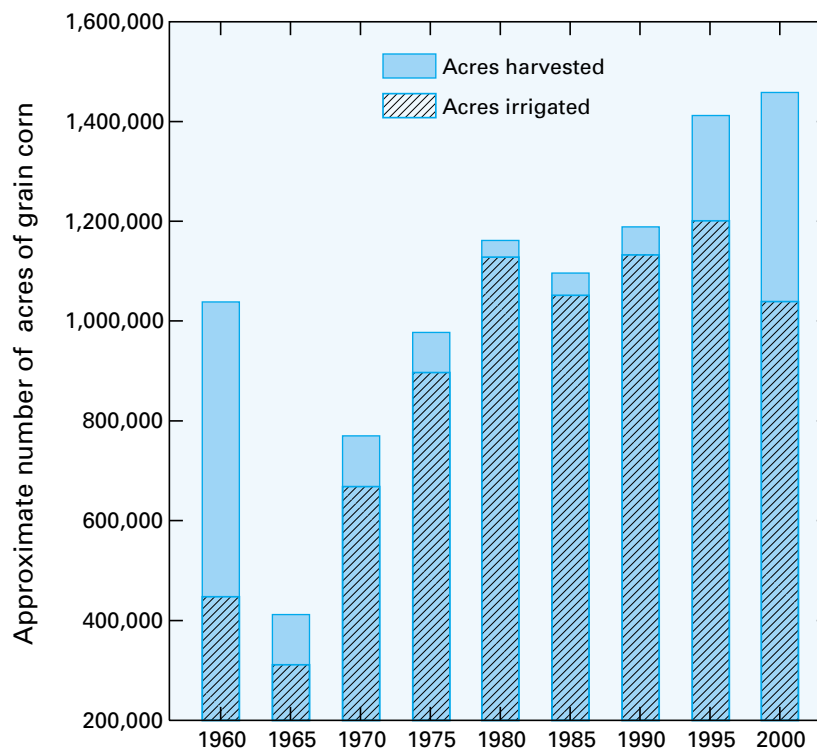


Figure 26. Approximate number of acres harvested and irrigated in Big Blue River Basin, 1960–2000, for grain corn (data compiled from U.S. Department of Agriculture, 2001).

1975, then decreased to about 600,000 animals in 1995 and 2000 (fig. 30). Hog production increased from about 350,000 animals in 1960 to a peak of about 970,000 animals in 1990, then decreased to about 725,000 animals in 1998 (fig. 31) (U.S. Department of Agriculture, 2001). Wastes from hog production may include arsenic, cadmium, copper, lead, nickel, and zinc (Alloway and Ayres, 1997).

SUMMARY AND CONCLUSIONS

A combination of bathymetric surveying and bottom-sediment coring was used to investigate sediment deposition and the occurrence of selected nutrients (total ammonia plus organic nitrogen and total phosphorus), 44 metals and trace elements, 15 organochlorine compounds, and 1 radionuclide in bottom sediment of Tuttle Creek Lake, northeast Kansas. The total estimated volume of bottom sediment in the original (1962) conservation-pool area of the lake was 6,170 million ft³ (142,000 acre-ft). The volume of sediment occupies about 33 percent of the original conservation-pool, water-storage capacity of the lake. The total estimated mass of bottom sediment in the original conservation-pool area of the lake was 292,400 million lb (133,000 million kg). Mean annual net sediment deposition since 1962 was estimated to be 7,900 million lb (3,600 million kg). Mean annual net sediment yield from the Tuttle Creek Lake Basin was estimated to be 821,000 lb/mi² (1,440 kg/ha).

The estimated mean annual net loads of total ammonia plus organic nitrogen and total phosphorus deposited in the bottom sediment of Tuttle Creek Lake were 6,350,000 lb/yr (2,880,000 kg/yr) and 3,330,000 lb/yr (1,510,000 kg/yr), respectively. The estimated mean annual net yields of total ammonia plus organic nitrogen and total phosphorus from the Tuttle Creek Lake Basin

were 657 (lb/mi²)/yr [1.15 (kg/ha)/yr] and 348 (lb/mi²)/yr [0.61 (kg/ha)/yr], respectively.

Trend analysis indicated no statistically significant trend for total phosphorus deposition in the bottom sediment of Tuttle Creek Lake (trend analysis for total ammonia plus organic nitrogen was not performed). A statistically significant positive depositional trend (constituent concentration increased with decreasing depth in the sediment core) was indicated for the elements chromium, cobalt, gallium, iron, lithium, magnesium, molybdenum, nickel, scandium, selenium, tantalum, tin, and zinc. However, due to analytical variance, the positive trends may not be representative of actual conditions.

Visual inspection of the vertical profiles indicated that most of the constituents for which a positive trend was indicated actually had a bimodal distribution rather than a trend. In general, the bimodal distribution was characterized by relatively small concentrations in the bottom one-fifth of the core and relatively large and uniform concentrations in the upper four-fifths of the core. A possible explanation for the smaller concentrations at the bottom of the core may be locally derived sediment deposited during the initial filling of the reservoir. Such locally derived sediment may be chemically different from sediment originating elsewhere in the basin. Also, following an initial positive trend, a statistically significant negative depositional trend (constituent concentration decreased with decreasing depth in the sediment core) was indicated

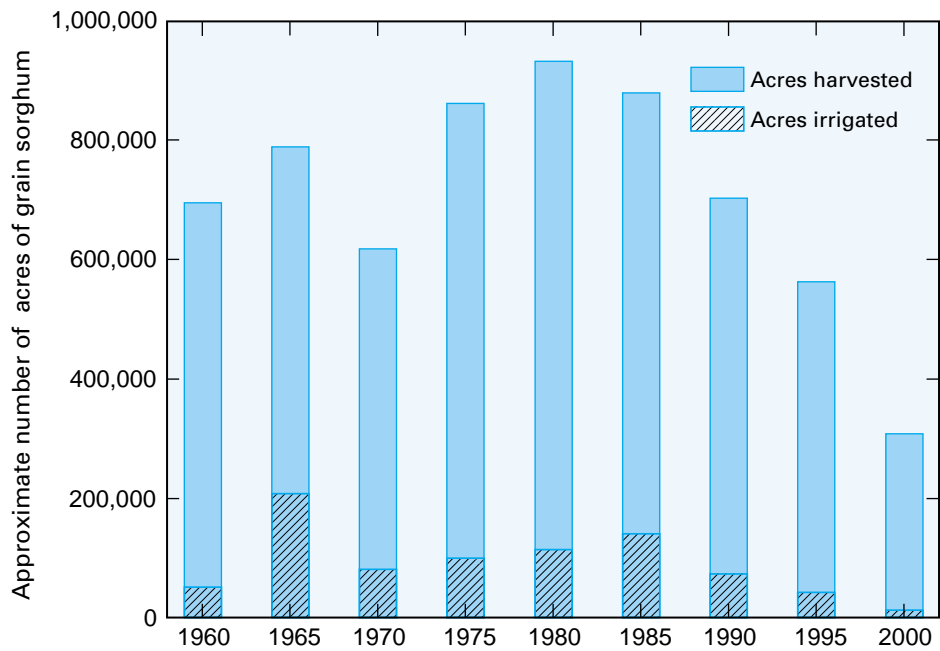


Figure 27. Approximate number of acres harvested and irrigated in Big Blue River Basin, 1960–2000, for grain sorghum (data compiled from U.S. Department of Agriculture, 2001).

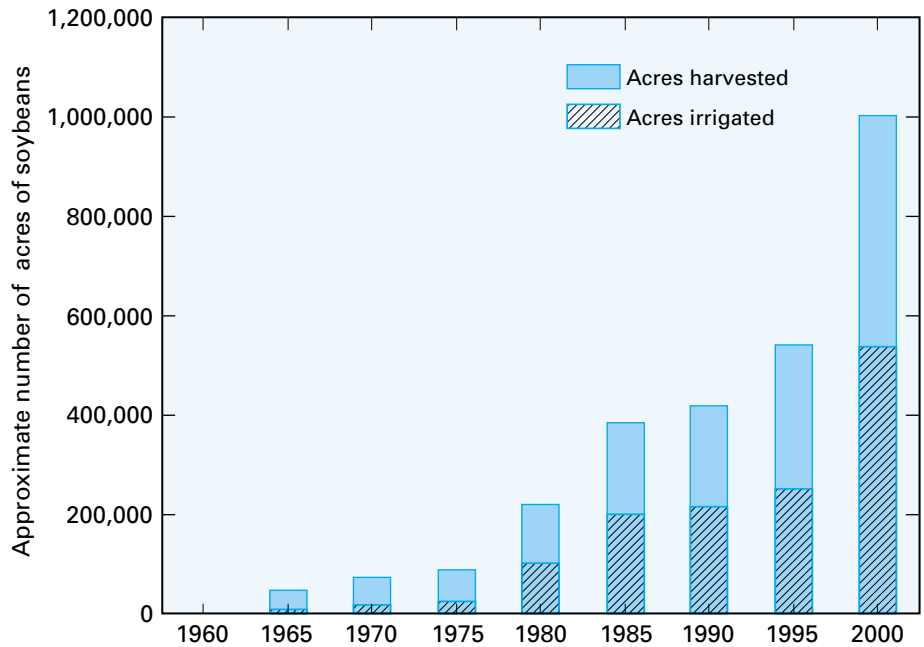


Figure 28. Approximate number of acres harvested and irrigated in Big Blue River Basin, 1960–2000, for soybeans (data compiled from U.S. Department of Agriculture, 2001).

for DDE (degradation product of DDT), which was consistent with the history of DDT use.

On the basis of available sediment-quality guidelines, concentrations of arsenic, chromium, copper,

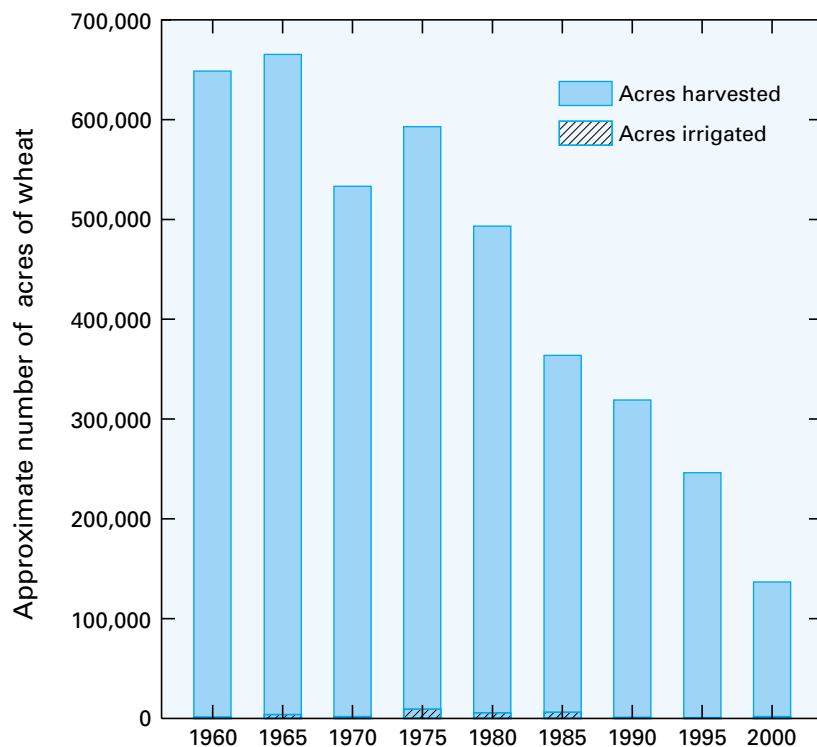


Figure 29. Approximate number of acres harvested and irrigated in Big Blue River Basin, 1960–2000, for wheat (data compiled from U.S. Department of Agriculture, 2001).

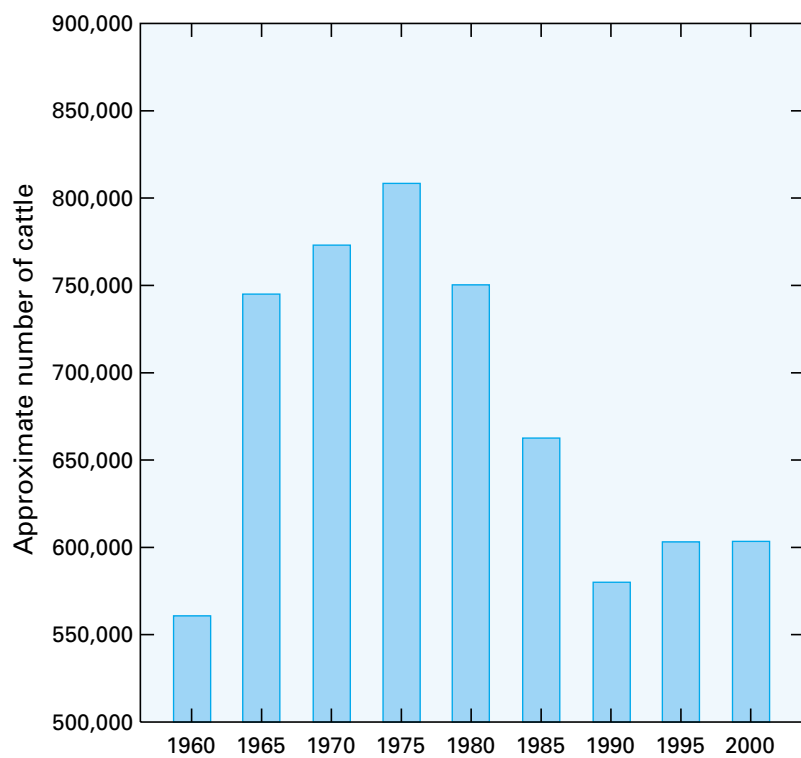


Figure 30. Approximate number of cattle in Big Blue River Basin, 1960–2000 (data compiled from U.S. Department of Agriculture, 2001).

nickel, silver, and zinc in the bottom sediment of Tuttle Creek Lake frequently or typically exceeded the threshold-effects levels (TELS). For arsenic and chromium, most of the sediment samples analyzed had concentrations that exceeded the TELS but were less than the probable-effects levels (PELs) for toxic biological effects. For copper, all concentrations exceeded the TEL but were less than the PEL. Likewise, all nickel concentrations exceeded the TEL. The median nickel concentration was close to the PEL, and one value exceeded the PEL. For silver and zinc, about one-half of the concentrations exceeded the TELS but were less than the PELs. Cadmium, lead, and mercury concentrations generally were less than the TELS. Likewise, organochlorine compounds either were not detected or were detected at concentrations that generally were less than the TELS. Of the four organochlorine compounds detected, DDE was detected in virtually all sediment samples analyzed, whereas aldrin, DDD, and dieldrin were detected infrequently.

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

Notable changes in human activity within the basin included a substantial increase in the production of grain corn and soybeans from the 1960s to the 1990s. This increase in production was accompanied by a pronounced increase in the number of irrigated acres. Also, during the same time period, there was an overall increase in hog production. These changes in human

activity have not had a discernible effect on the deposition of chemical constituents in the bottom sediment of Tuttle Creek Lake.

Information from this study may be used to partly reconstruct historical water-quality records, to provide a present-day baseline with which to evaluate long-term changes in reservoir water and sediment quality, and to assist in the development and evaluation of total maximum daily loads for chemical constituents that contribute to the water and sediment quality of Tuttle Creek Lake.

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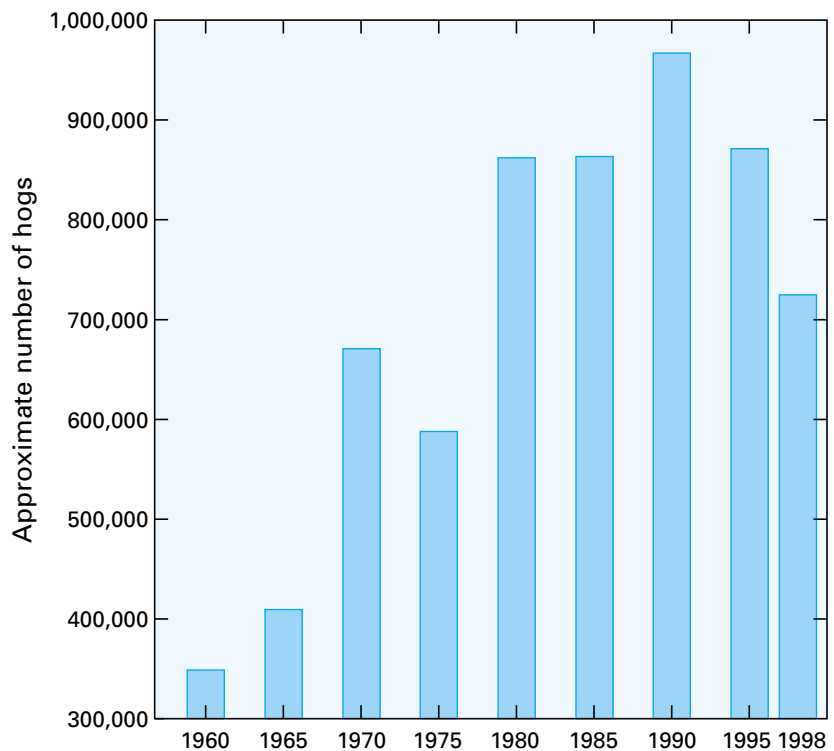


Figure 31. Approximate number of hogs in Big Blue River Basin, 1960-98 (data compiled from U.S. Department of Agriculture, 2001).

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SUPPLEMENTAL INFORMATION

Table 12. Latitude and longitude coordinates for end points of U.S. Army Corps of Engineers range lines used in bathymetric surveys of Tuttle Creek Lake, northeast Kansas

Range line (fig. 2)	Right end point ¹		Left end point ¹	
	Latitude (decimal degrees)	Longitude (decimal degrees)	Latitude (decimal degrees)	Longitude (decimal degrees)
1	39.2572	96.6093	39.2683	96.5874
2	39.2802	96.6303	39.2920	96.6094
3	39.3077	96.6513	39.3188	96.6365
4	39.3334	96.6737	39.3405	96.6574
5	39.3581	96.6912	39.3638	96.6748
6	39.3832	96.7115	39.3924	96.6965
7	39.4108	96.7323	39.4168	96.7135
8	39.4422	96.7322	39.4348	96.7123
9	39.4422	96.7322	39.4542	96.7231
10	39.4638	96.7613	39.4722	96.7608
² 11	39.4605	96.7903	39.4654	96.7935
² 12	39.4719	96.8324	39.4726	96.8323
13	39.4572	96.7161	39.4466	96.7029
14	39.4664	96.7029	39.4566	96.6897
15	39.4776	96.6893	39.4669	96.6757
16	39.4925	96.6709	39.4822	96.6554
17	39.4996	96.6635	39.4951	96.6403
18	39.5108	96.6513	39.5064	96.6368
19	39.5242	96.6418	39.5188	96.6347
20	39.5339	96.6318	39.5253	96.6171
21	39.5493	96.6032	39.5421	96.5929

¹Right and left end points were designated as looking in the downstream direction.

²Range lines 11 and 12 were not used in the study because these range lines were not considered necessary for estimating total sediment deposition in the lake. The range lines are located on Fancy Creek upstream from the original (1962) conservation pool of Tuttle Creek Lake.

Table 13. Latitude and longitude coordinates for sediment-coring sites in Tuttle Creek Lake, northeast Kansas

Sediment-coring site identifier (fig. 2)	Latitude (decimal degrees)	Longitude (decimal degrees)
In-channel sites		
TIC-1	39.2642	96.6008
TIC-2	39.2842	96.6303
TIC-3	39.3067	96.6490
TIC-4	39.3342	96.6719
TIC-5	39.3589	96.6897
TIC-9	39.4442	96.7292
TIC-13	39.4525	96.7150
TIC-16	39.4869	96.6633
Out-of-channel sites		
TOC-1	39.2581	96.6028
TOC-1A	39.2631	96.5931
TOC-2	39.2831	96.6269
TOC-2A	39.2856	96.6203
TOC-3	39.3092	96.6458
TOC-3A	39.3142	96.6392
TOC-4	39.3347	96.6686
TOC-4A	39.3367	96.6633
TOC-5	39.3575	96.6869
TOC-5A	39.3597	96.6808
TOC-7	39.4158	96.7172
TOC-7A	39.4128	96.7242
TOC-9	39.4478	96.7267
TOC-13	39.4503	96.7125

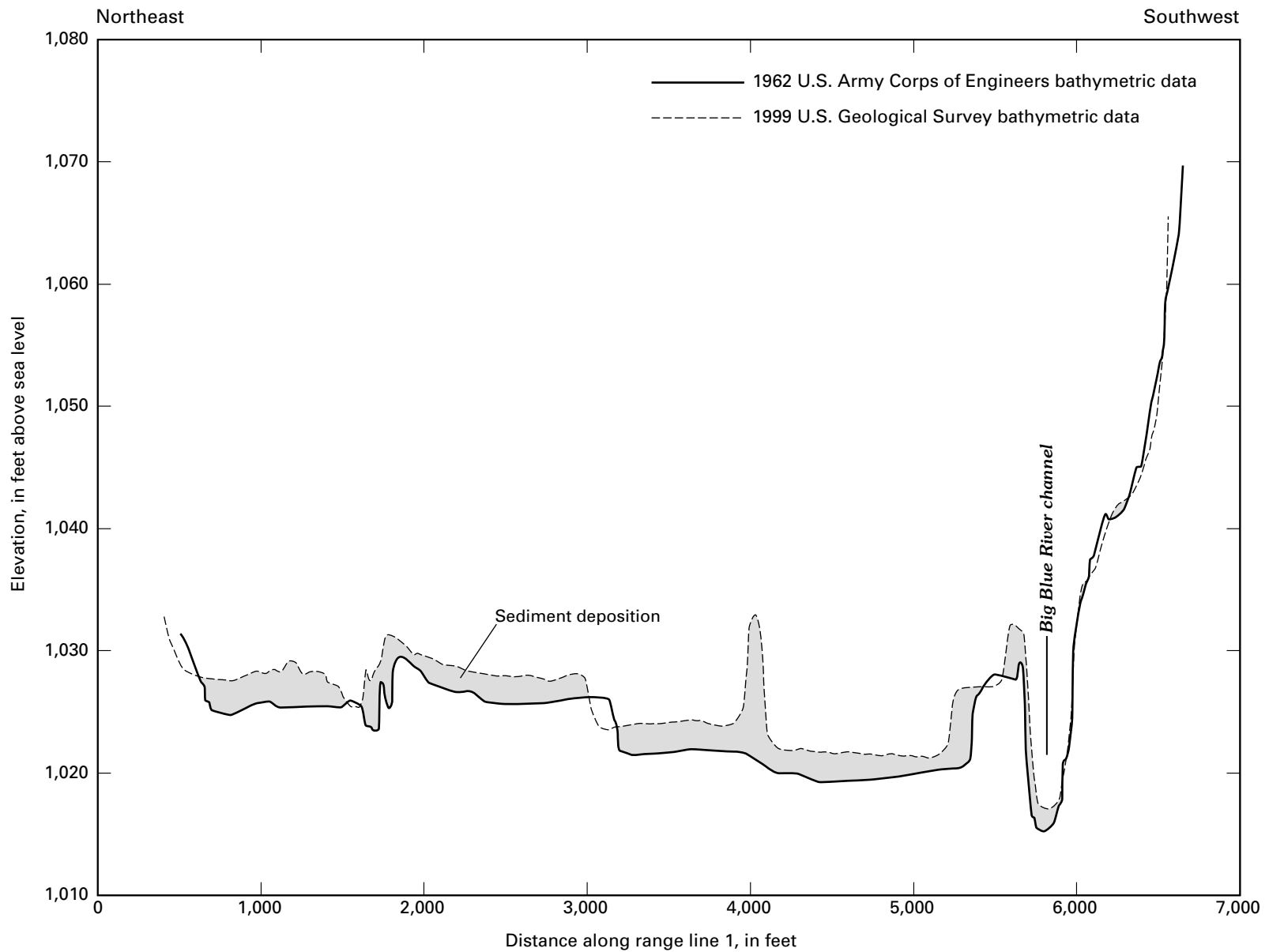


Figure 32. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 1. Location of range line shown in figure 2.

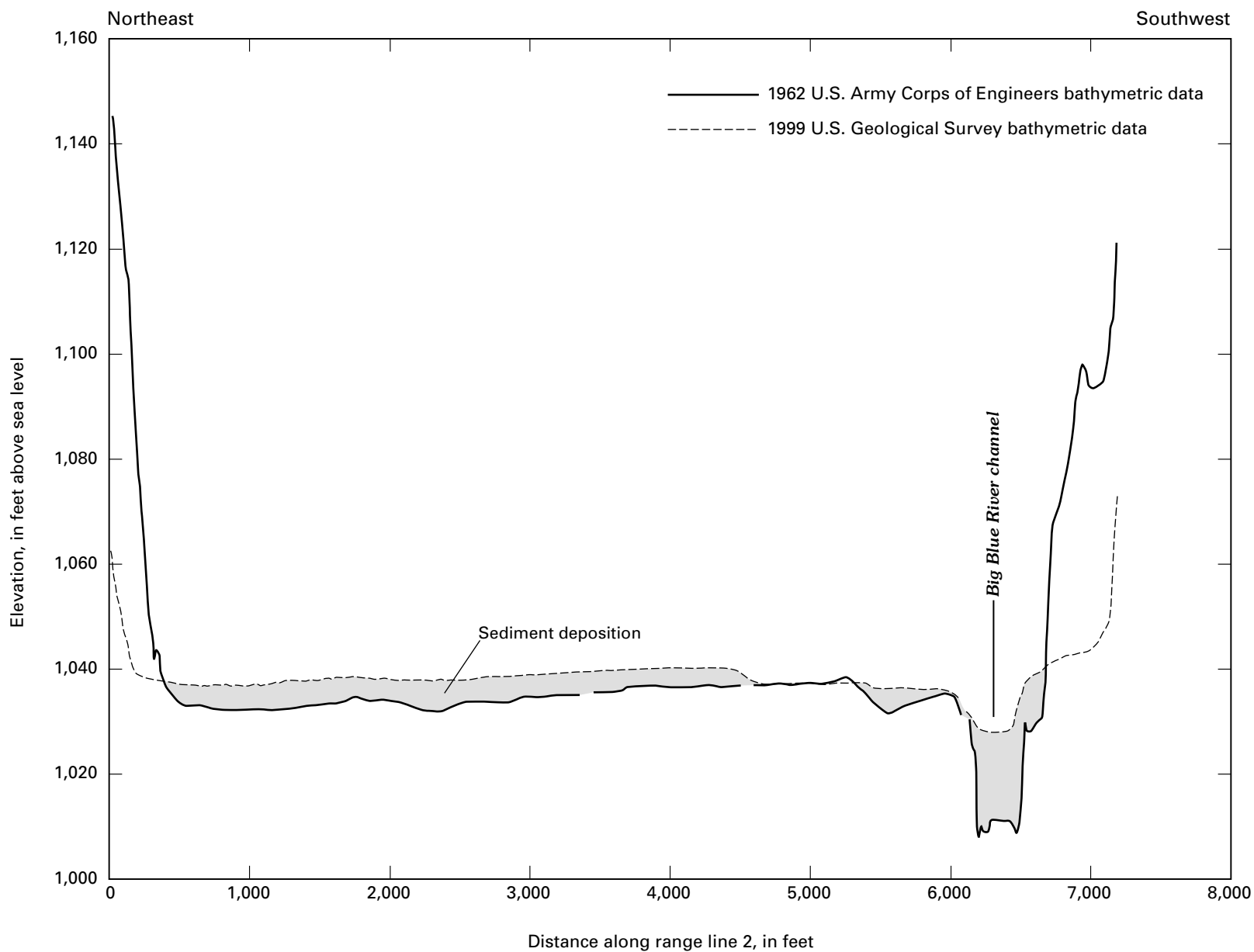


Figure 33. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 2. Location of range line shown in figure 2.

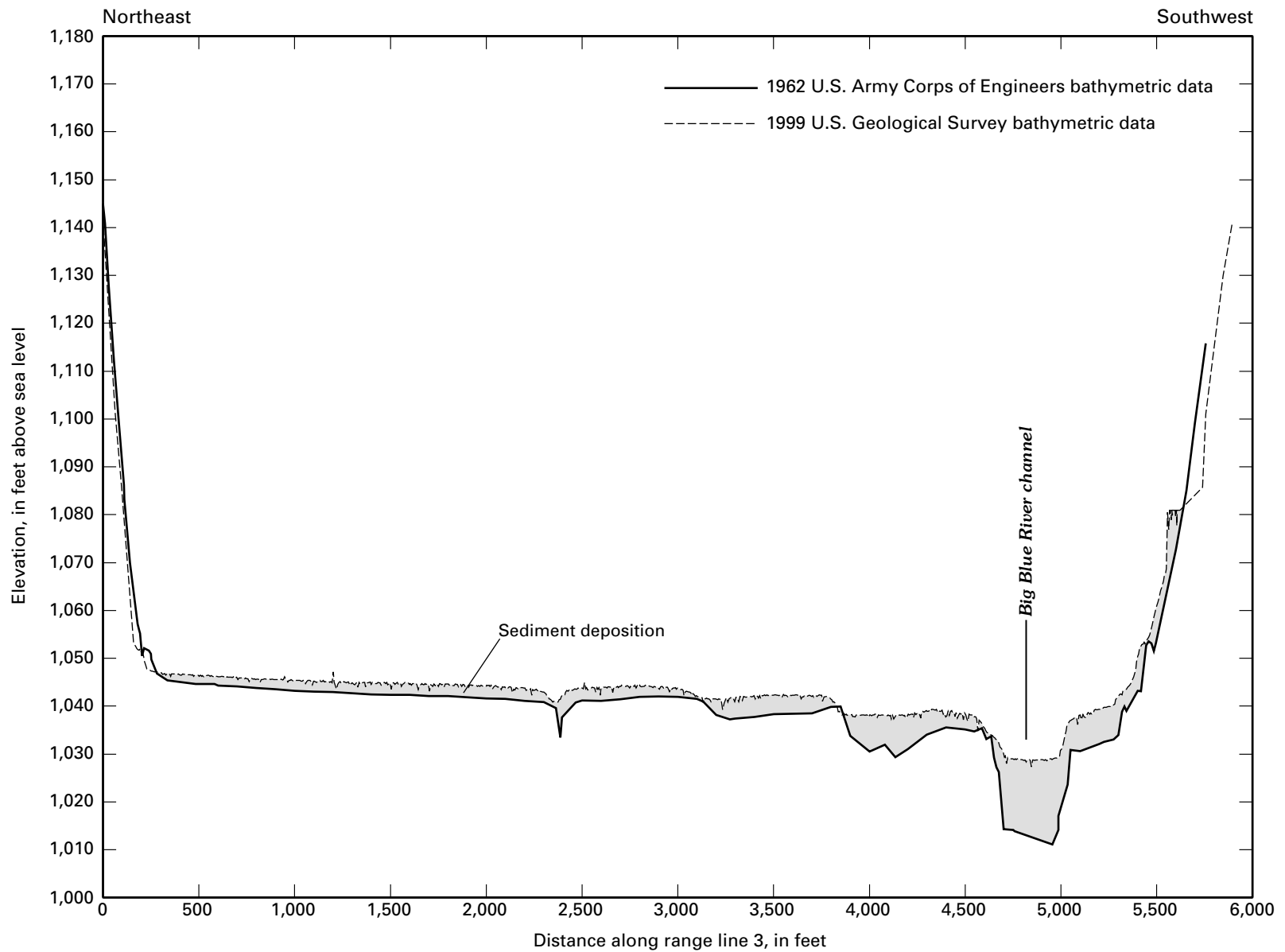


Figure 34. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 3. Location of range line shown in figure 2.

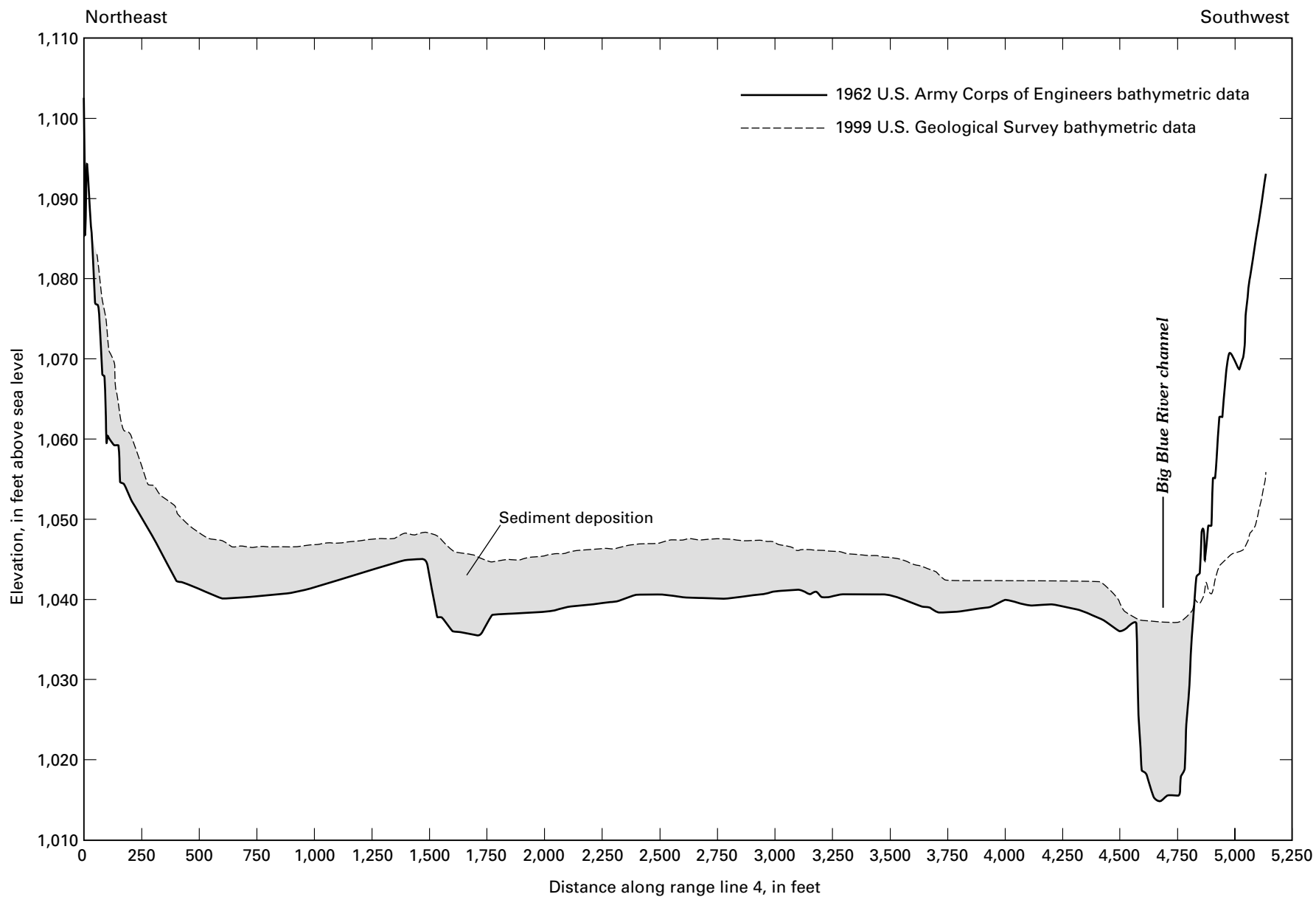


Figure 35. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 4. Location of range line shown in figure 2.

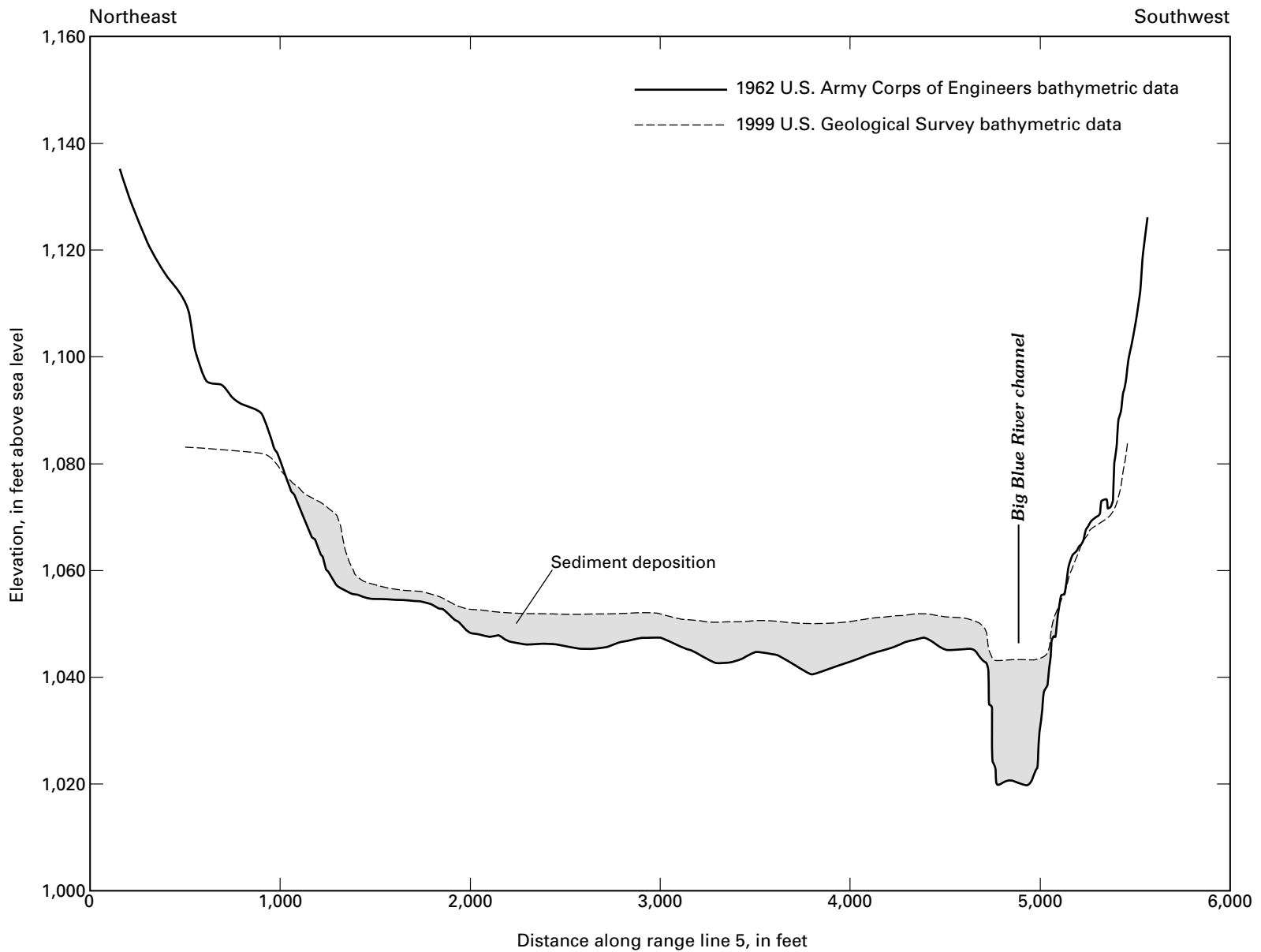


Figure 36. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 5. Location of range line shown in figure 2.

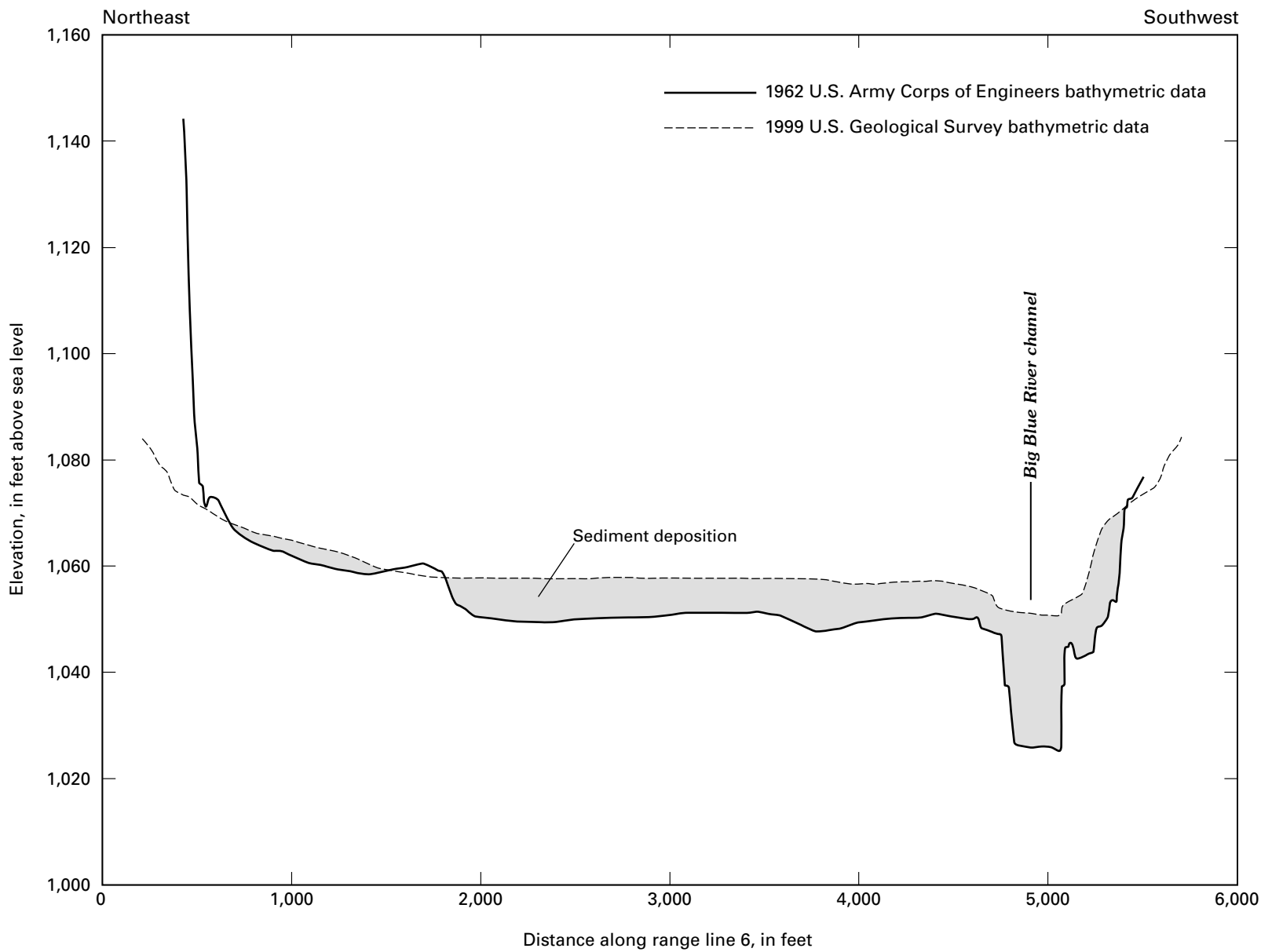


Figure 37. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 6. Location of range line shown in figure 2.

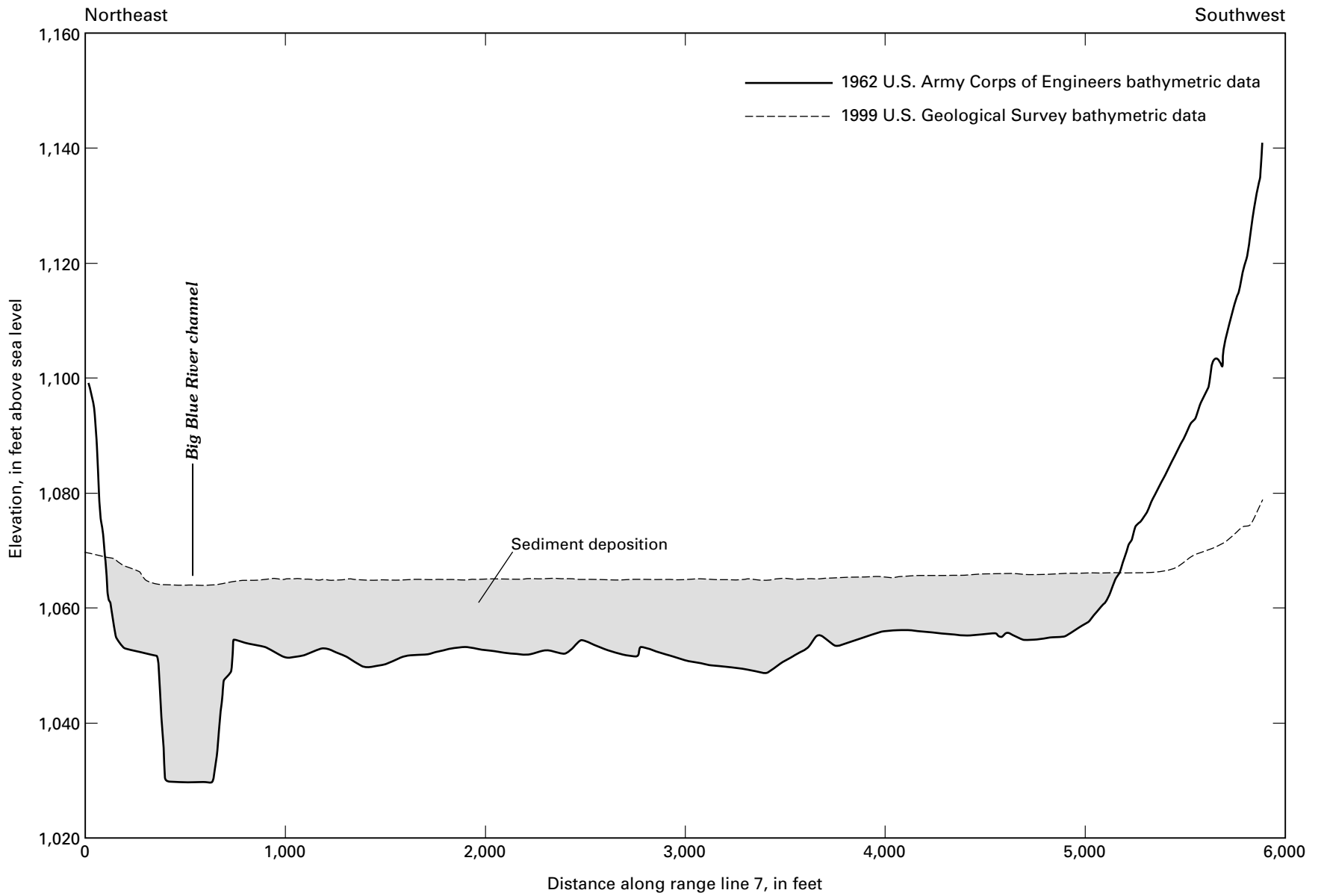


Figure 38. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 7. Location of range line shown in figure 2.

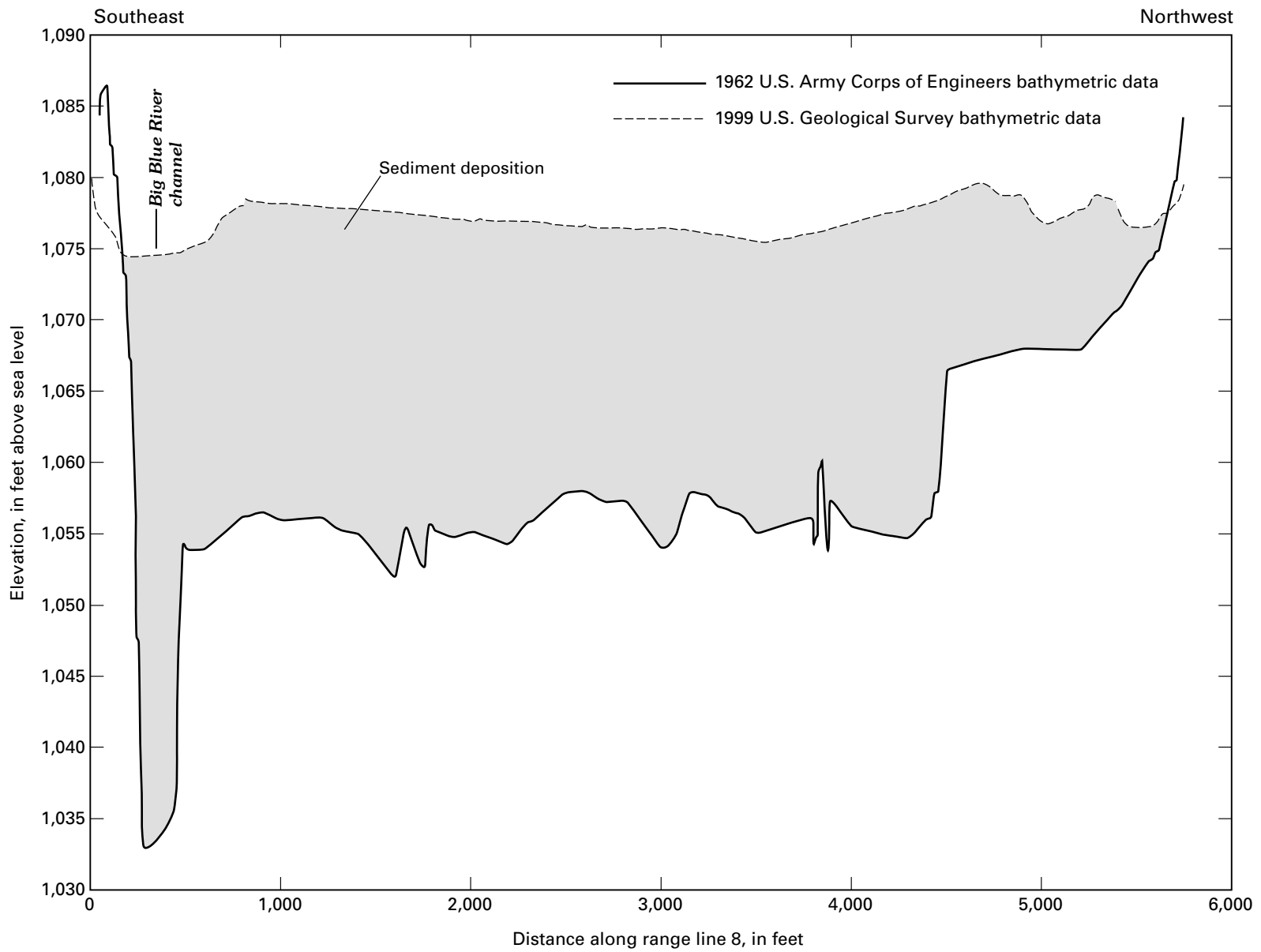


Figure 39. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Turtle Creek Lake, range line 8. Location of range line shown in figure 2.

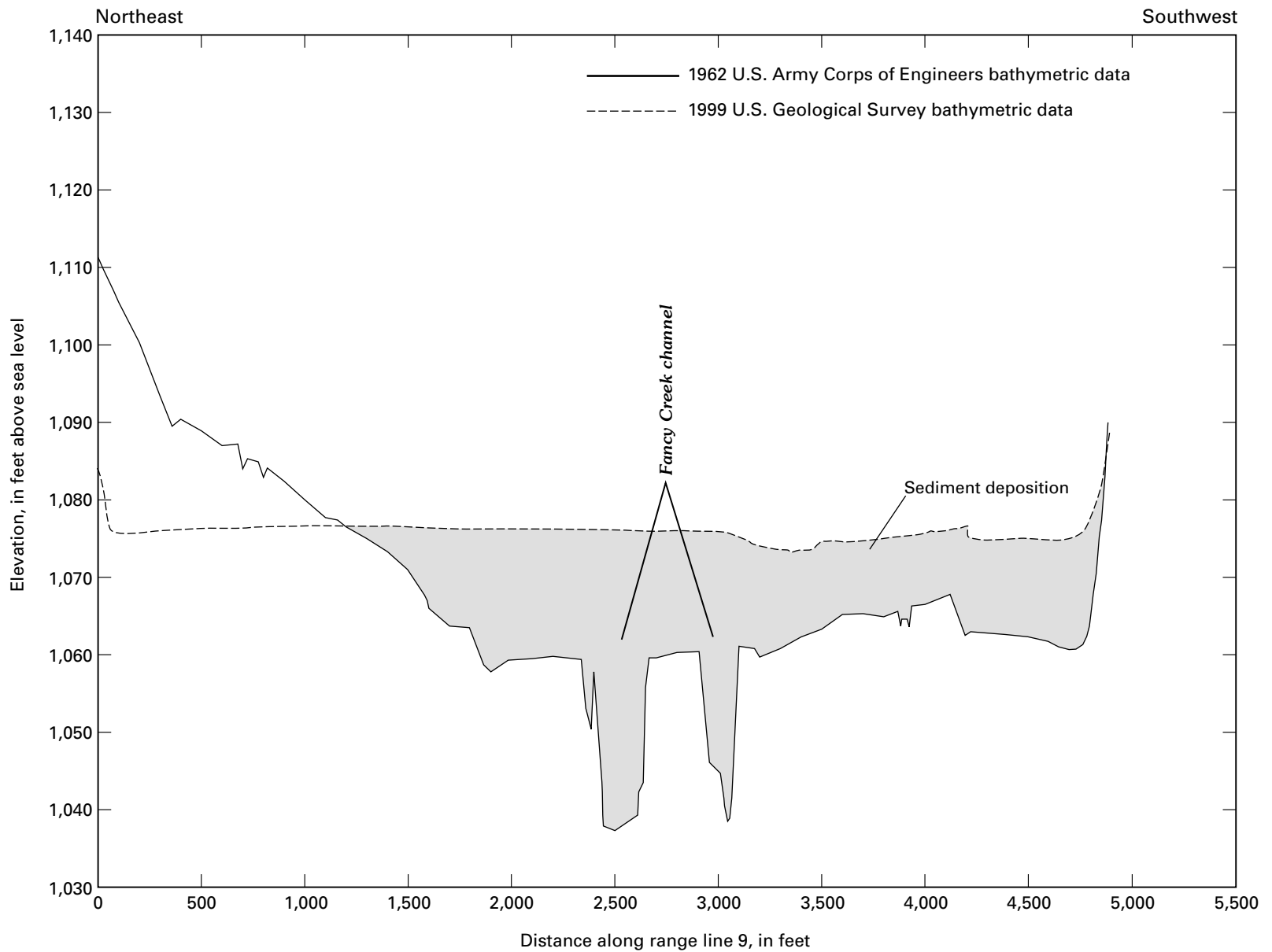


Figure 40. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 9. Location of range line shown in figure 2.

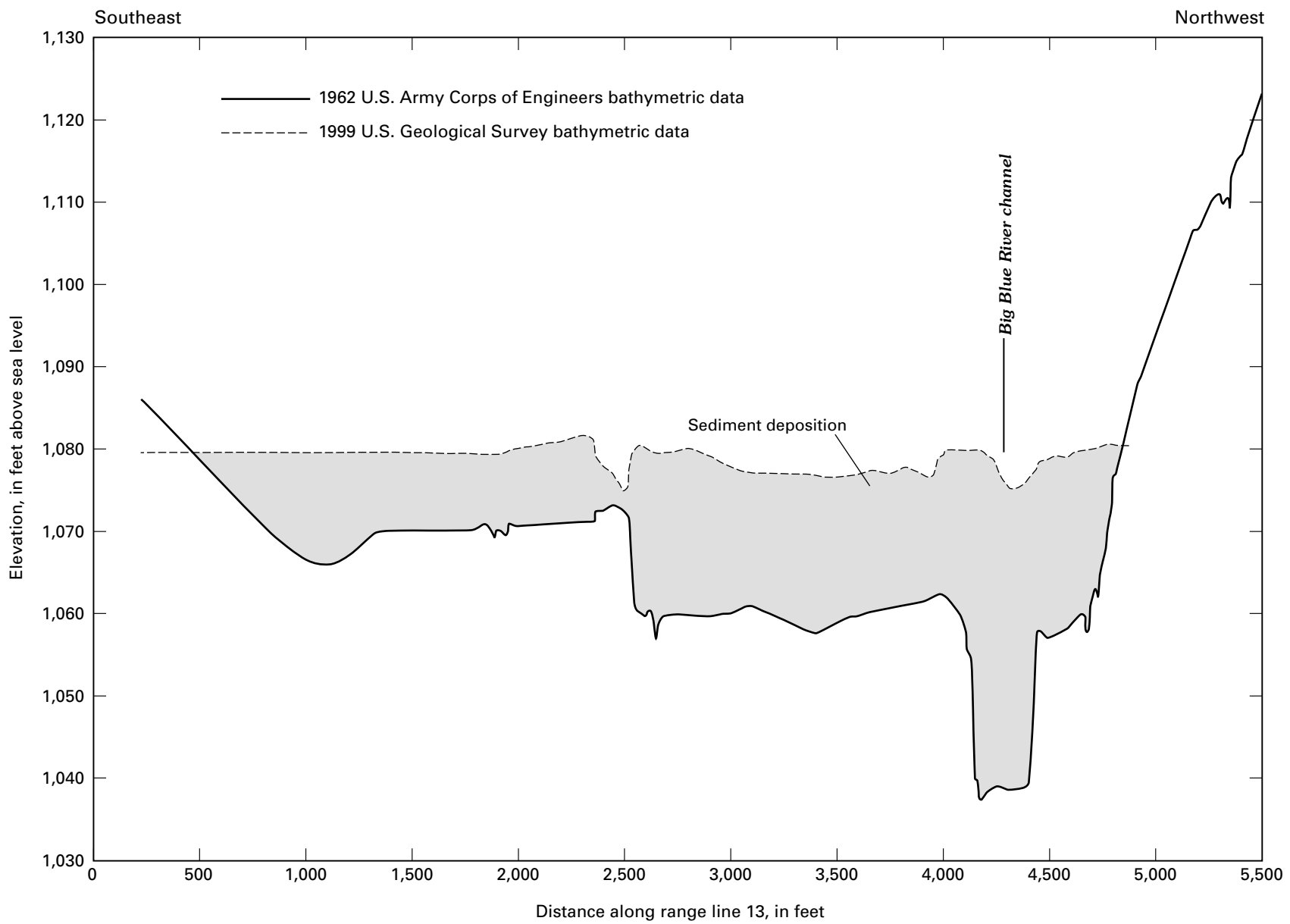


Figure 41. Comparison of 1962 U.S. Army Corps of Engineers bathymetric data and 1999 U.S. Geological Survey bathymetric data for Tuttle Creek Lake, range line 13. Location of range line shown in figure 2.

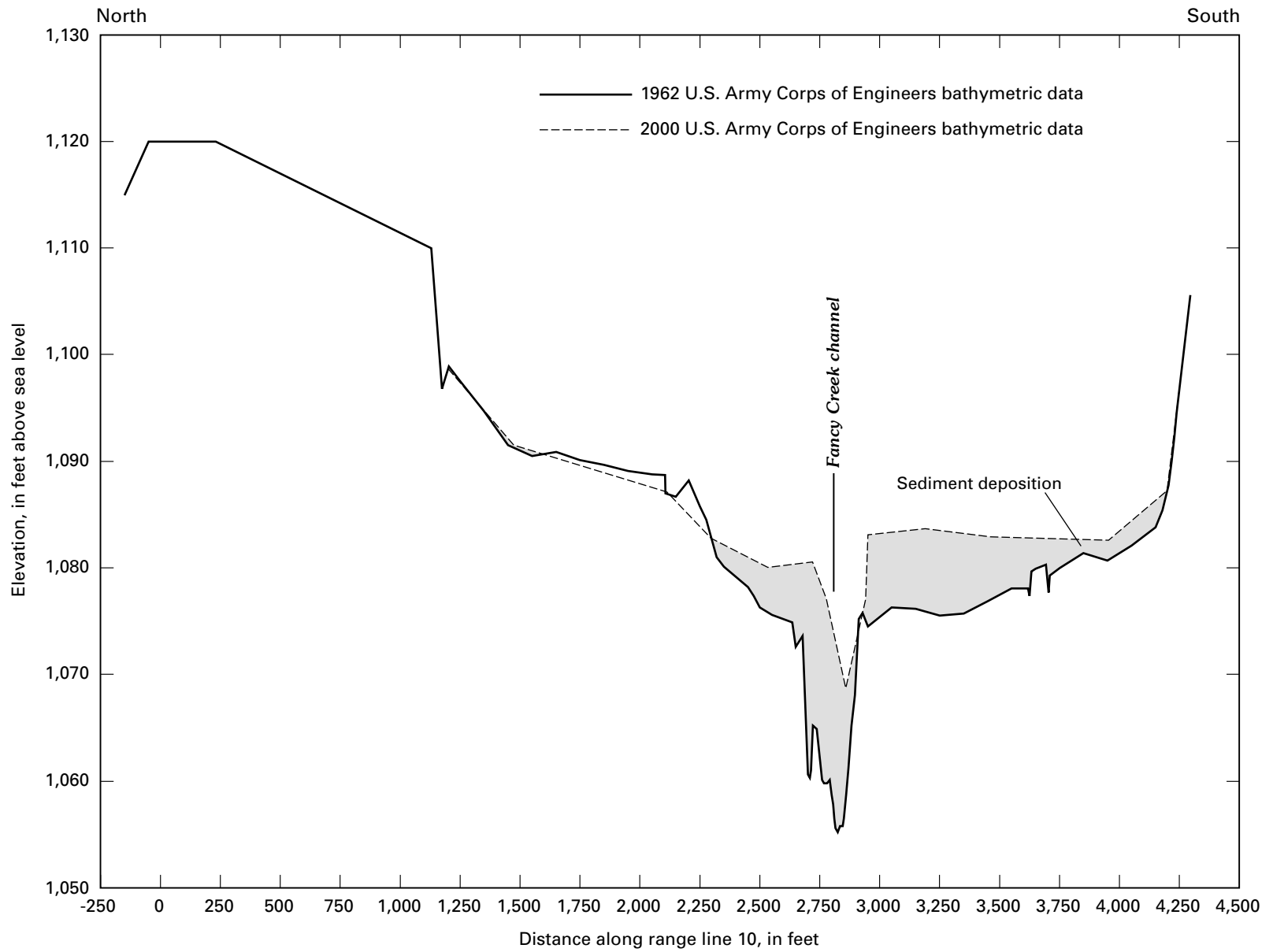


Figure 42. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 10. Location of range line shown in figure 2.

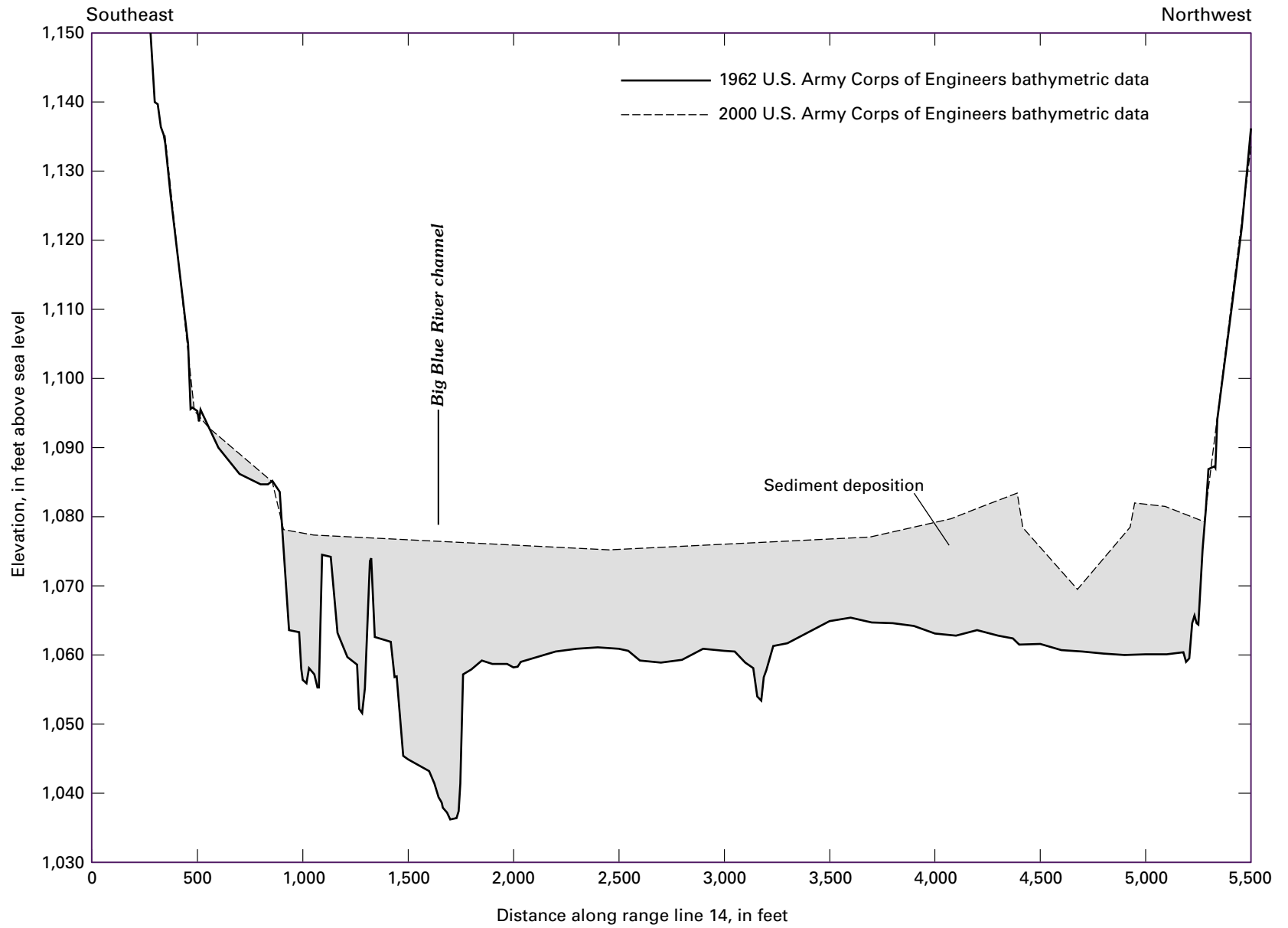


Figure 43. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 14. Location of range line shown in figure 2.

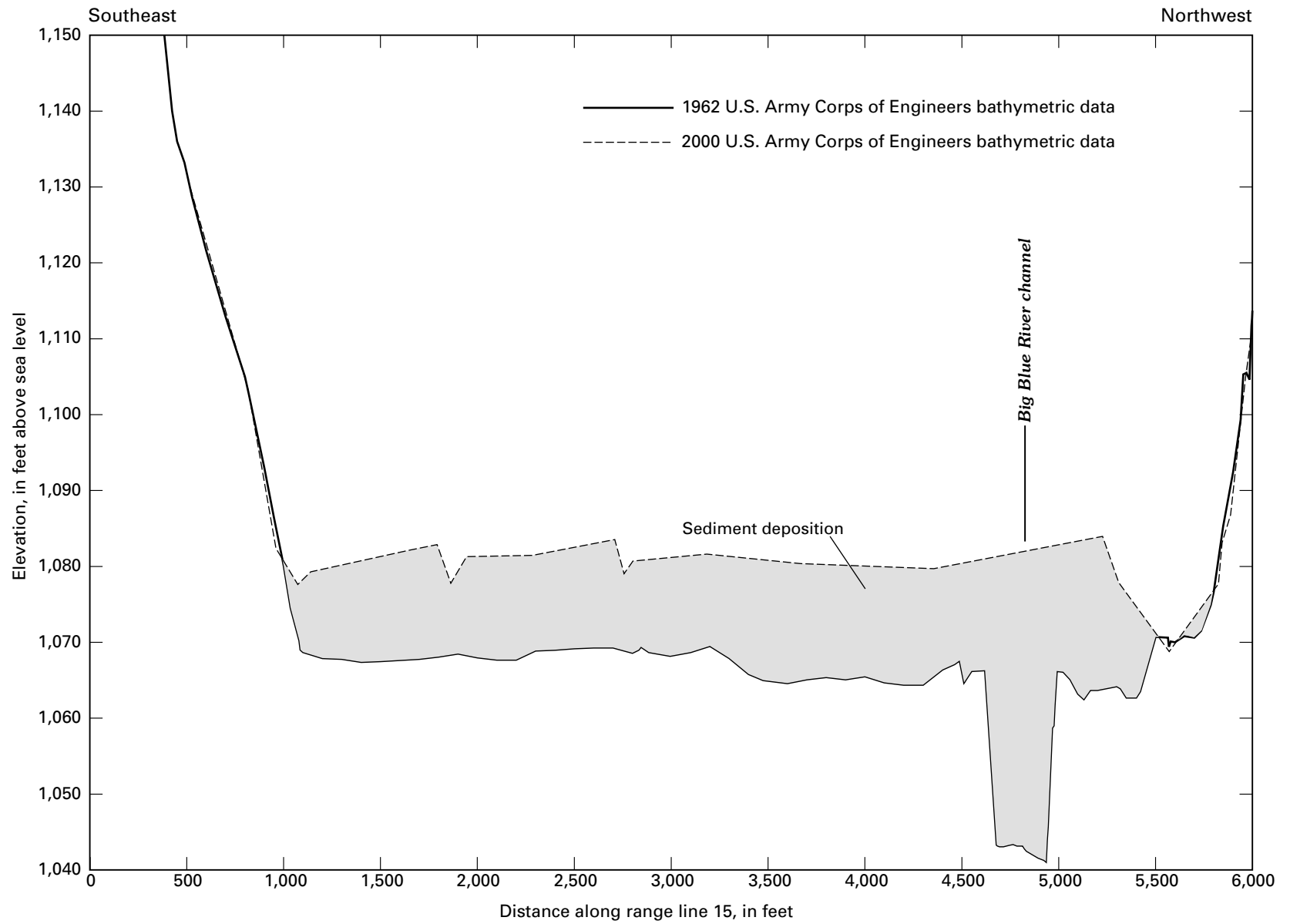


Figure 44. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 15. Location of range line shown in figure 2.

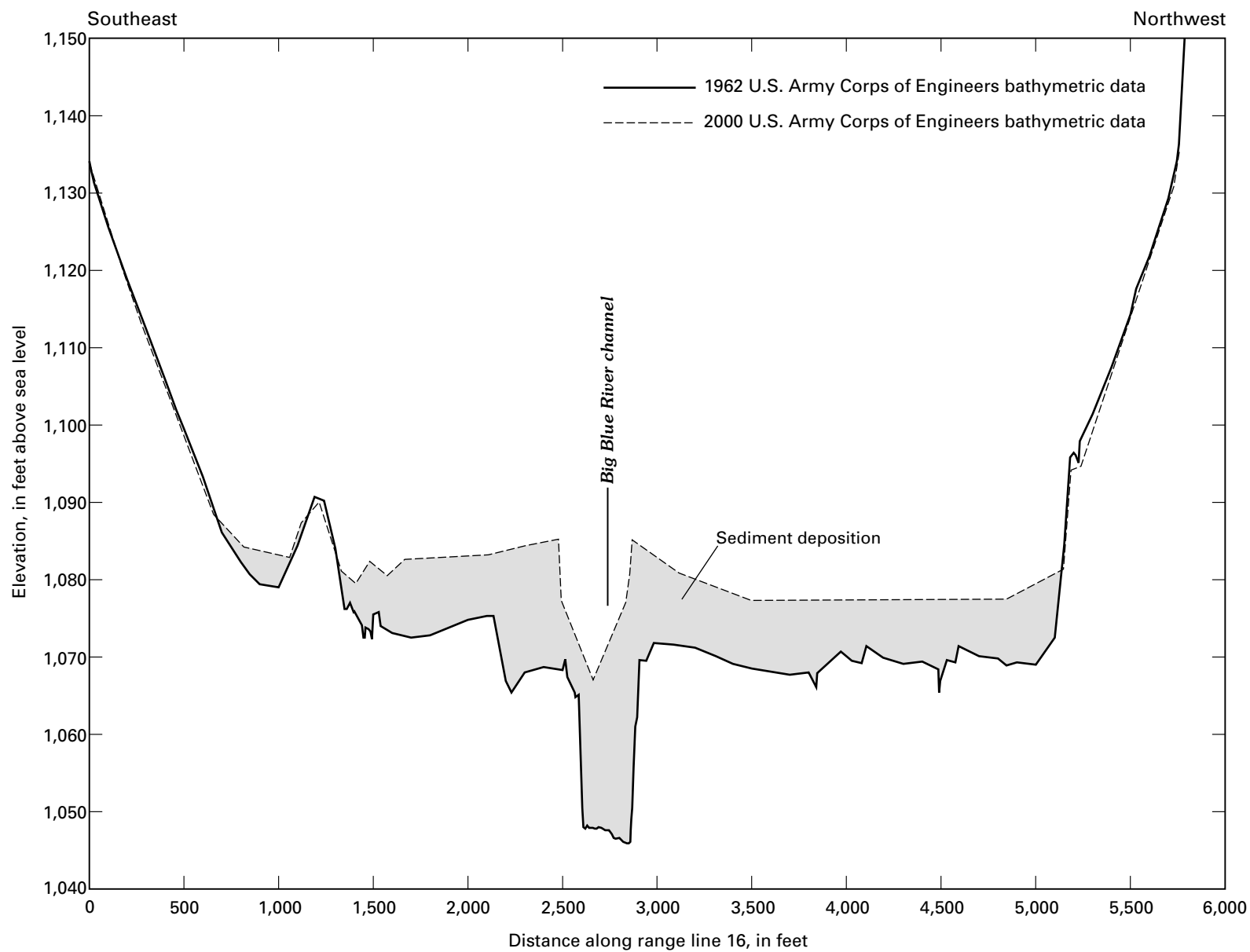


Figure 45. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 16. Location of range line shown in figure 2.

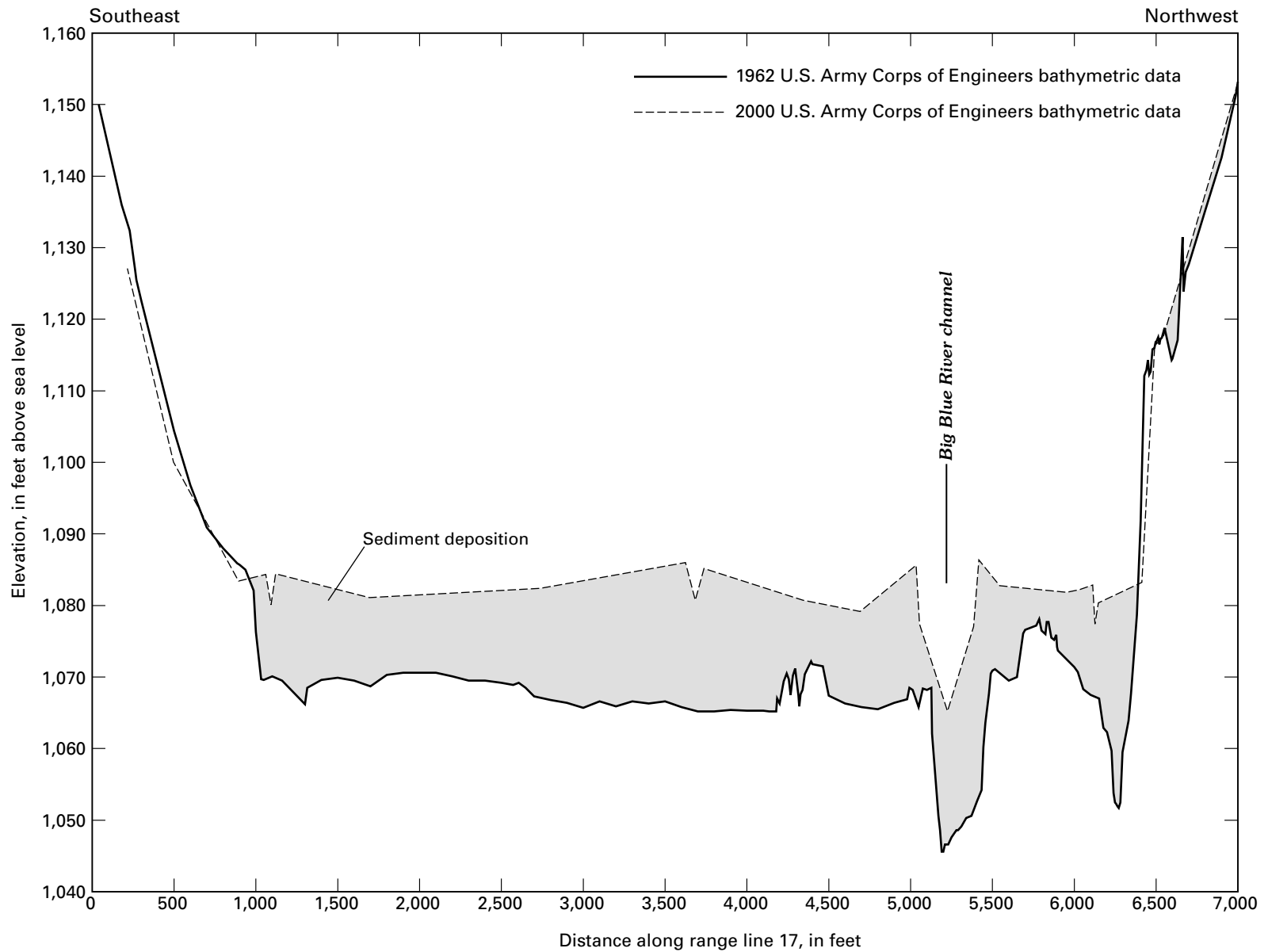


Figure 46. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 17. Location of range line shown in figure 2.

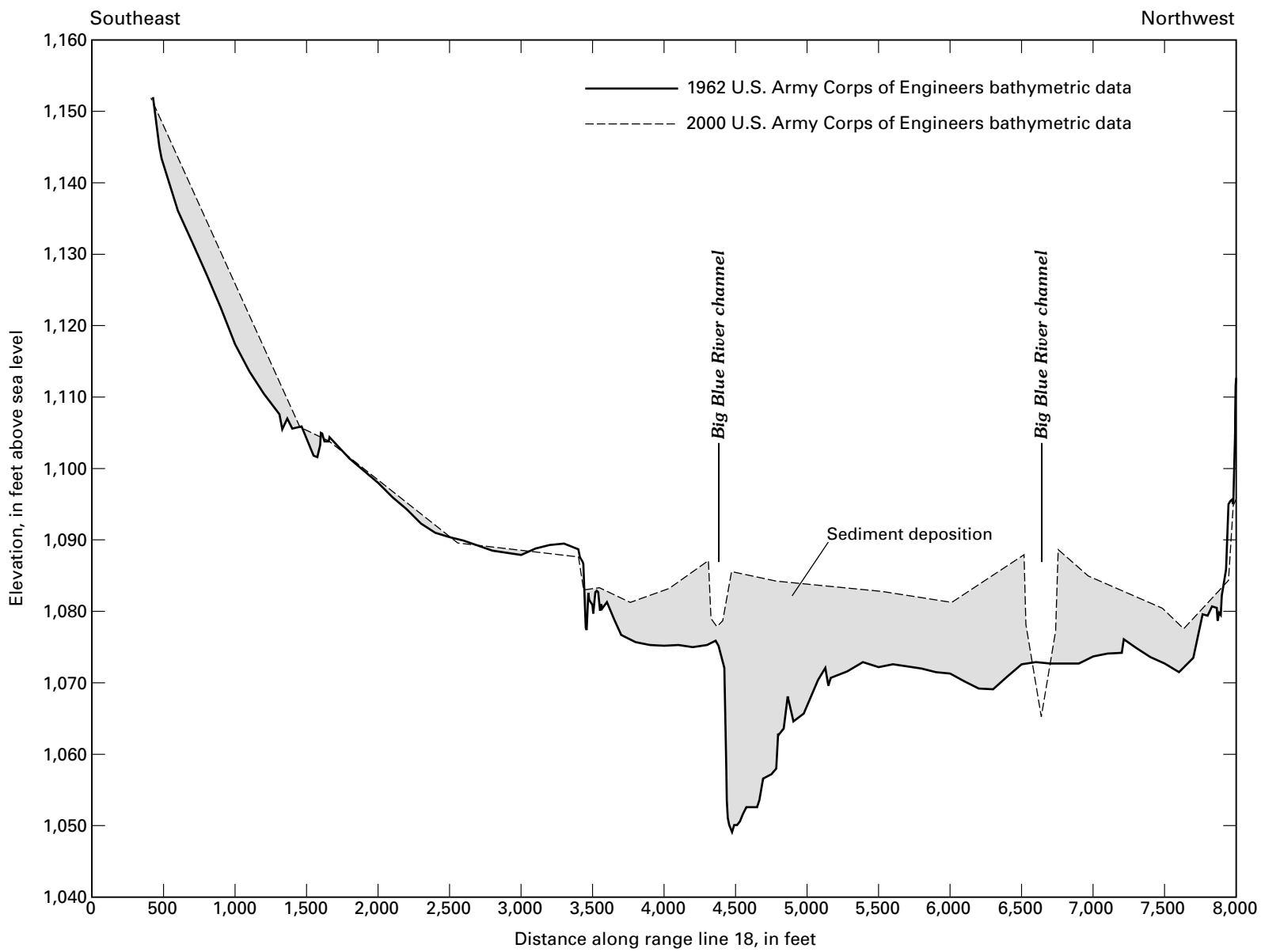


Figure 47. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 18. Location of range line shown in figure 2.

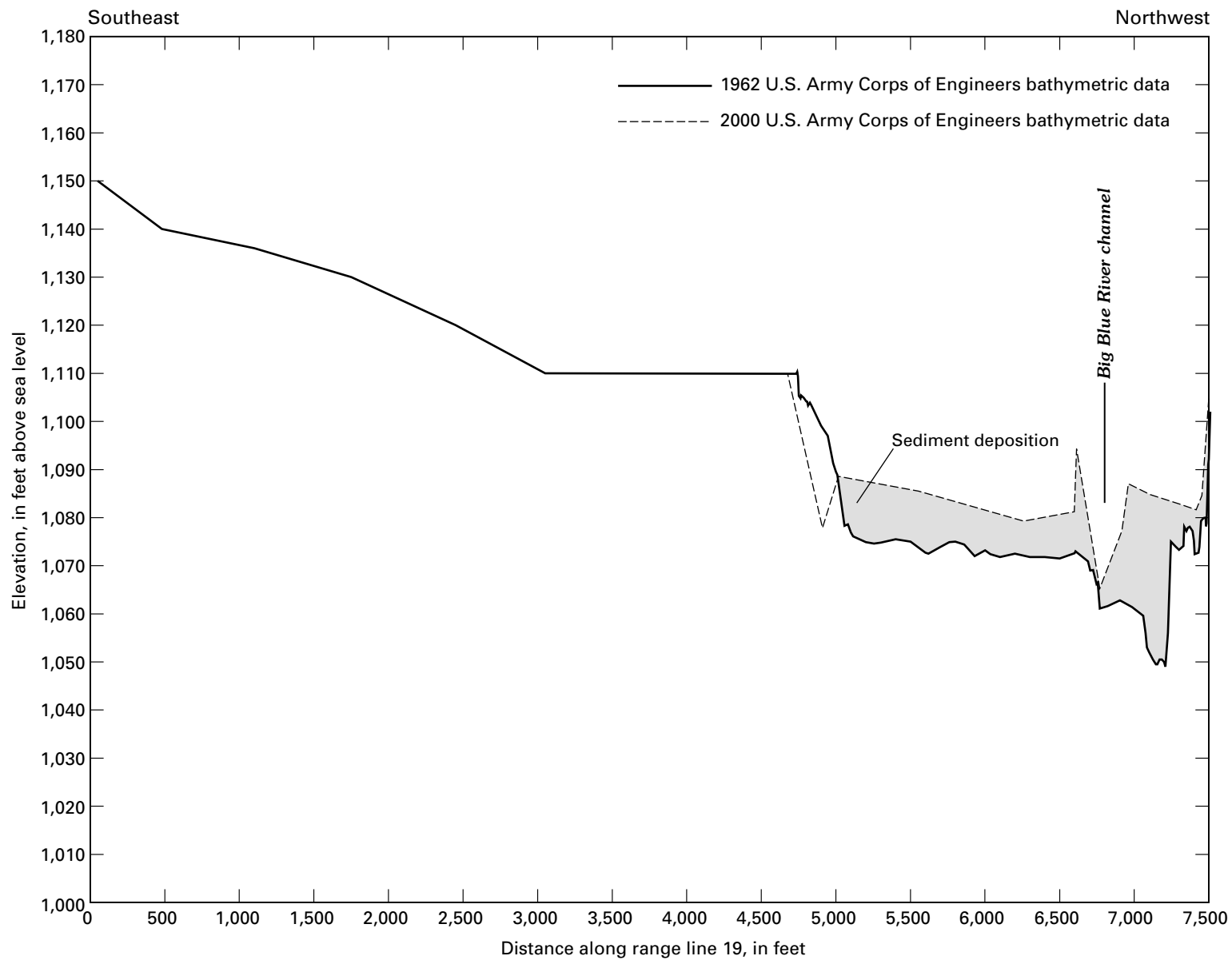


Figure 48. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 19. Location of range line shown in figure 2.

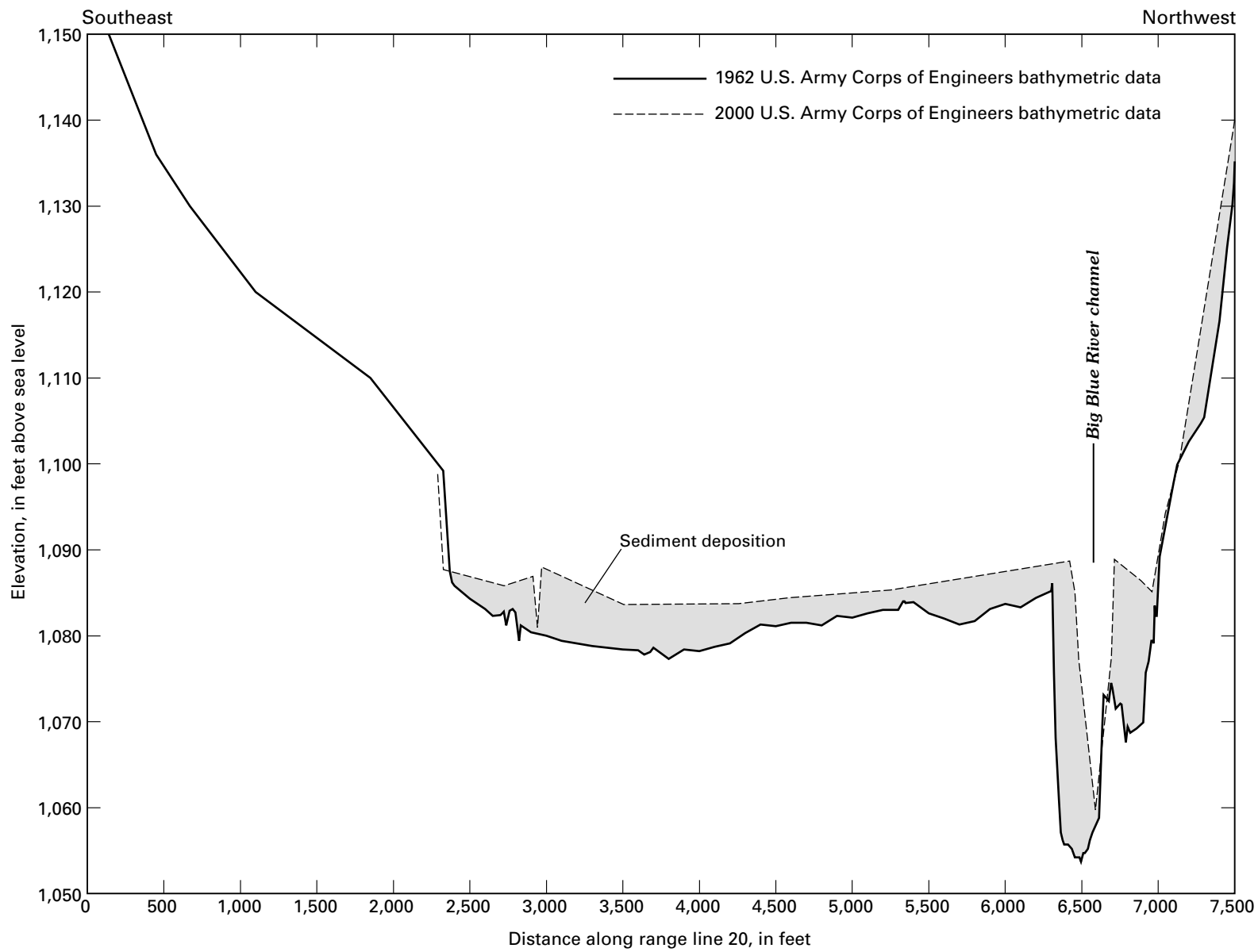


Figure 49. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 20. Location of range line shown in figure 2.

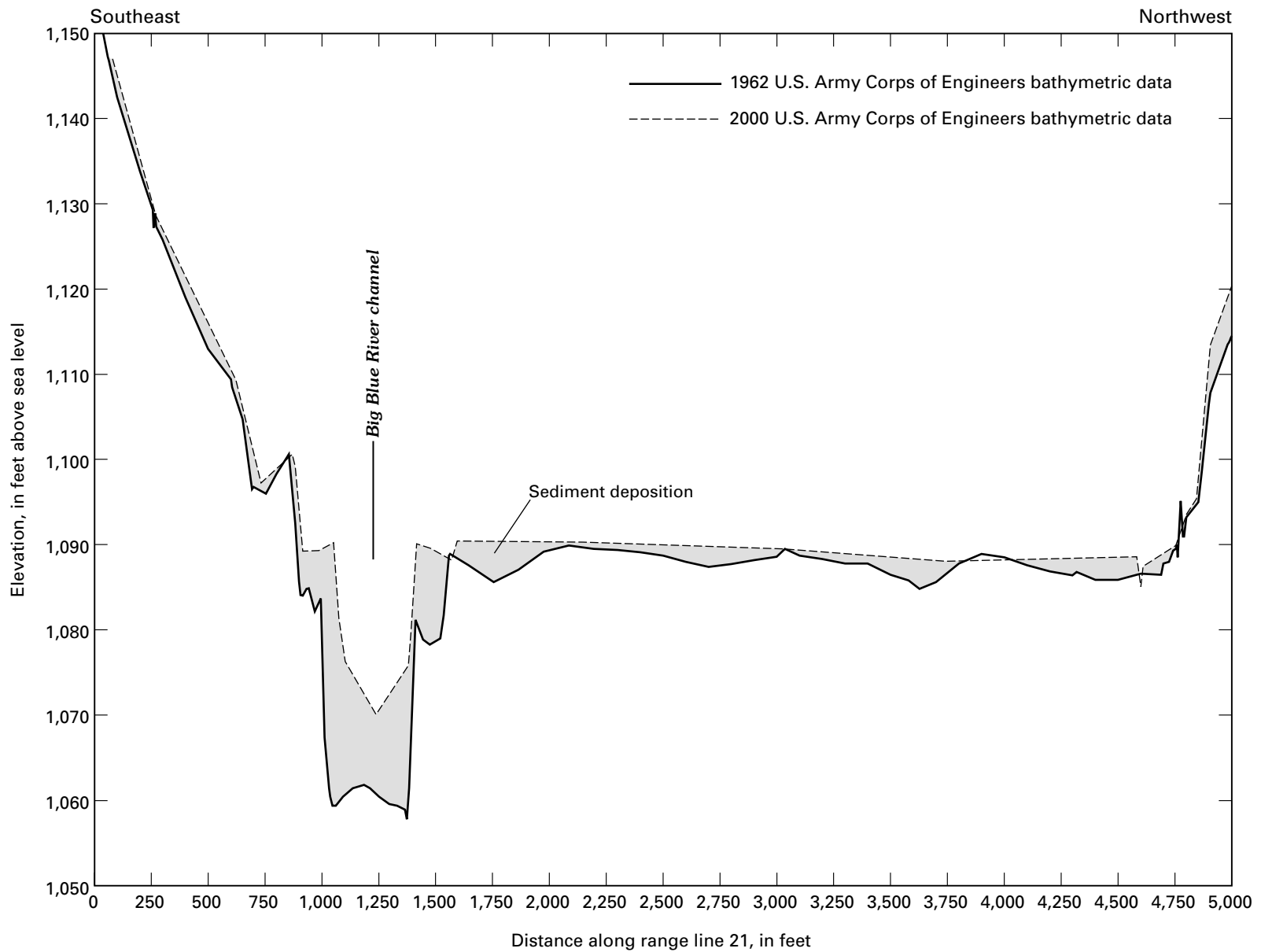


Figure 50. Comparison of 1962 and 2000 U.S. Army Corps of Engineers bathymetric data for Tuttle Creek Lake, range line 21. Location of range line shown in figure 2.