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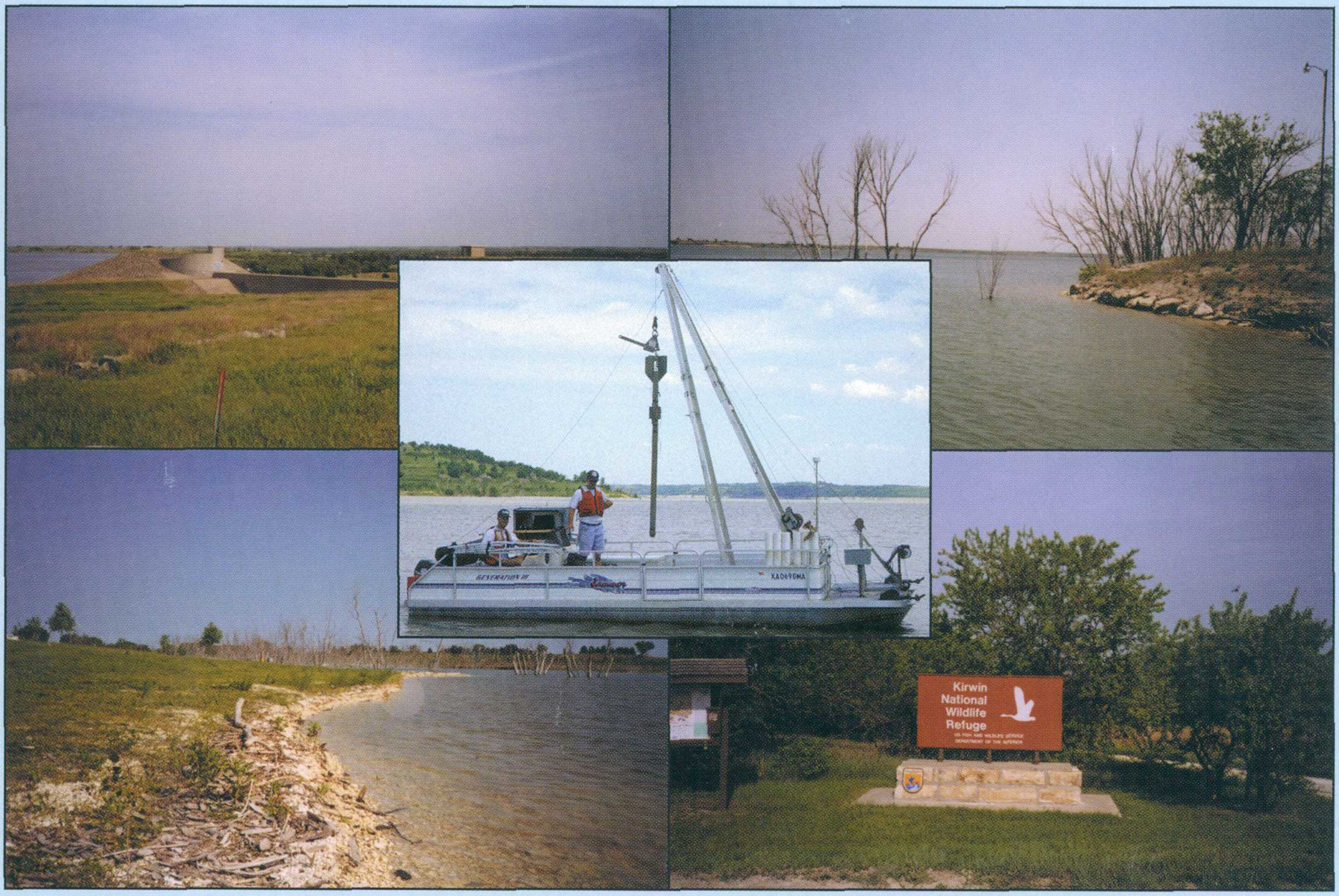
Deposition of Selenium and Other Constituents in Reservoir Bottom Sediment of the Solomon River Basin, North-Central Kansas

Water-Resources Investigations Report 99–4230



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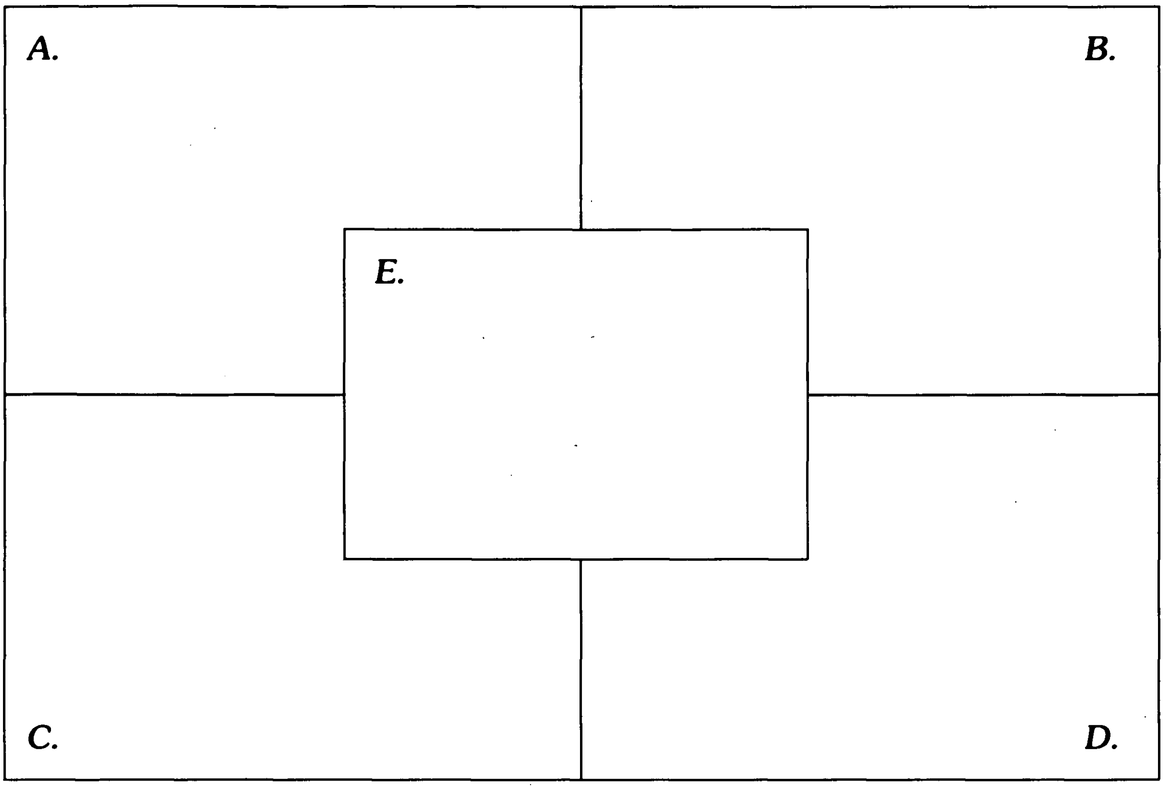

A. Dam overlooking Kirwin Reservoir

B. Waconda Lake

C. Webster Reservoir

D. Kirwin National Wildlife Refuge

E. Gravity corer mounted on pontoon boat

(photographs *A–D* taken by author;
photograph *E* taken by David P. Mau,
U.S. Geological Survey, Lawrence, Kansas)

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Deposition of Selenium and Other Constituents in Reservoir Bottom Sediment of the Solomon River Basin, North-Central Kansas

By VICTORIA G. CHRISTENSEN

Water-Resources Investigations Report 99–4230

Lawrence, Kansas
1999

U.S. Department of the Interior

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Box 25286, Federal Center
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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
acre	4,047	square meter
acre-feet (acre-ft)	1,233	cubic meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
pound (lb)	0.4536	kilogram
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter
pound per year (lb/yr)	0.4536	kilogram per year
square mile (mi^2)	2.590	square kilometer

Temperatures in this report can be converted to degrees Celsius (°C) or degrees Fahrenheit (°F) by the equations:

$$°C = 5/9\ (°F-32)$$
$$°F = 9/5\ (°C) + 32.$$

Water year: Water year as used in this report refers to the 12-month period beginning October 1 and ending September 30. The water year is designated by the calendar year in which it ends; for example, the 1998 water year begins October 1, 1997, and ends September 30, 1998.

Deposition of Selenium and Other Constituents in Reservoir Bottom Sediment of the Solomon River Basin, North-Central Kansas

By Victoria G. Christensen

Abstract

The Solomon River drains approximately 6,840 square miles of mainly agricultural land in north-central Kansas. The Bureau of Reclamation, U.S. Department of the Interior, has begun a Resource Management Assessment (RMA) of the Solomon River Basin to provide the necessary data for National Environmental Policy Act (NEPA) compliance before renewal of long-term water-service contracts with irrigation districts in the basin. In May 1998, the U.S. Geological Survey (USGS) collected bottom-sediment cores from Kirwin and Webster Reservoirs, which are not affected by Bureau irrigation, and Waconda Lake, which receives water from both Bureau and non-Bureau irrigated lands. The cores were analyzed for selected physical properties, total recoverable metals, nutrients, cesium-137, and total organic carbon.

Spearman's rho correlations and Kendall's tau trend tests were done for sediment concentrations in cores from each reservoir. Selenium, arsenic, and strontium were the only constituents that showed an increasing trend in concentrations for core samples from more than one reservoir. Concentrations and trends for these three constituents were compared to information on historical irrigation to determine any causal effect. Increases in selenium, arsenic, and strontium concentrations can not be completely explained by Bureau irrigation. However, mean selenium, arsenic, and strontium concentrations in sediment from all three reservoirs may be related to total irrigated acres (Bureau and non-Bureau irrigation) in the basin. Selenium, arsenic, and strontium loads were calculated for Webster Reservoir to determine if annual loads deposited in the reservoir were increasing along with constituent concentrations. Background selenium, arsenic, and strontium loads in Webster Reservoir are significantly larger than post-background loads.

INTRODUCTION

The Solomon River Basin extends across parts of 17 counties in north-central Kansas (fig. 1) and includes the Solomon River and its major tributaries—the North Fork Solomon River and the South Fork Solomon River. The Solomon River drains about 6,840 mi^2 of mainly agricultural land. The Solomon River Basin is underlain by strata of marine origin. Irrigation return flow in areas underlain by these strata may contain concentrations of selenium that, when introduced into a lake, reservoir, or wetland area, could bioaccumulate to levels toxic to aquatic organisms, predatory species, or potentially could affect human health through consumption of contaminated organisms (Ramirez and Armstrong, 1992; Roy and O'Brien, 1992).

Selenium often is redistributed by irrigated agriculture (Sharma and Singh, 1983), and there is a concern about selenium concentrations in the Solomon River Basin where irrigation by the Bureau of Reclamation (Bureau), U.S. Department of the Interior, began in the late 1950's. Irrigation return flow also may contain large concentrations of dissolved constituents that may affect the quality of receiving stream water (Mueller and others, 1991; Engberg, 1993).

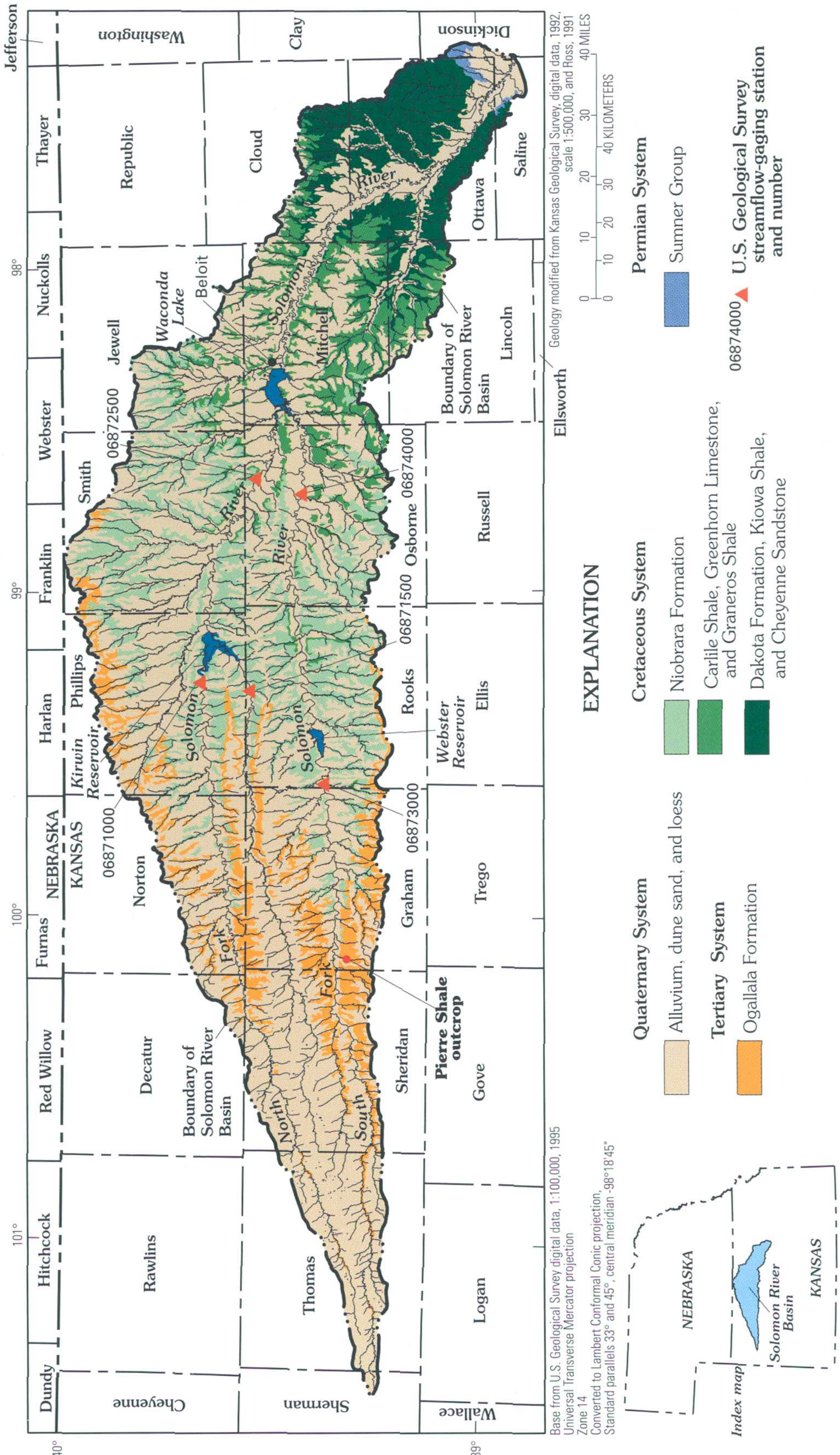


Figure 1. Location and near-surface geology of the Solomon River Basin, north-central Kansas.

Public Law 99–294, National Environmental Policy Act (NEPA) of 1986, requires that the Bureau investigate soil characteristics that may result in toxic or hazardous irrigation return flows. The Bureau, in response, has begun a Resource Management Assessment (RMA) of the Solomon River Basin to provide the necessary data for NEPA compliance before renewal of long-term water-service contracts with irrigation districts in the basin.

The study described in this report was begun in the spring of 1998 by the U.S. Geological Survey (USGS) in cooperation with the Bureau to determine if Bureau-operated irrigation (hereinafter referred to as Bureau irrigation) has increased selenium or other constituent concentrations in the basin. There are three reservoirs in the Solomon River Basin—Kirwin Reservoir on the North Fork Solomon; Webster Reservoir on the South Fork Solomon; and Waconda Lake on the main stem of the Solomon River (fig. 1). Three Bureau water-resource developments are located within the basin—the Kirwin Irrigation District, the Webster Irrigation District, and the Glen Elder Irrigation District (Bureau of Reclamation, 1984). The drainage areas upstream from Kirwin and Webster Reservoirs are not affected by Bureau irrigation, and therefore, bottom sediment from these reservoirs was used to determine background sediment concentrations of selected constituents and to evaluate the effects of other (non-Bureau) irrigation activities. Waconda Lake receives water from both the Kirwin Irrigation District and the Webster Irrigation District, and therefore, the bottom sediment from Waconda Lake was used to assess trends in chemical constituents in sediment for the entire Solomon River Basin and to help distinguish the effect of Bureau irrigation in the basin. Sediment quality is of concern because it reflects the quality of the overlying water column.

PURPOSE AND OBJECTIVES

The primary purpose of this report is to document baseline conditions and trends in deposition of selenium and other constituents in three reservoirs of the Solomon River Basin. Other objectives of this report are: (1) to evaluate these trends in relation to Bureau irrigation in the basin, (2) to document the volume and mass of sediment accumulated in Webster Reservoir (for which bathymetric and sedimentation data were available) since dam closure, and (3) to estimate the mass and annual load of selenium, arsenic, and strontium deposited in Webster Reservoir.

Baseline conditions and trends in bottom-sediment quality were documented through chemical analysis and age dating of bottom-sediment cores. Trends in constituent concentrations were determined using Spearman's rho correlation and Kendall's tau trend tests. The constituents (selenium, arsenic, and strontium) that have increasing trends in more than one reservoir are discussed in detail.

Additional samples collected from Webster Reservoir and Bureau sedimentation data were used to estimate the mass of sediment accumulated in Webster Reservoir since dam closure. These additional samples and data also were used to estimate the mass and annual load of selenium, arsenic, and strontium transported into Webster Reservoir for the purpose of comparing the annual loads to any trend in constituent concentration.

Results contained in this report may have transferability to other reservoir watersheds in Kansas and the Nation or to other areas with similar soils, geology, land use, and agricultural and cropping practices.

BASIN DESCRIPTION

The Solomon River Basin has a subhumid climate, with a mean annual temperature of about 53 °F and average annual precipitation of about 28 in. (National Oceanic and Atmospheric Administration, 1997). The drainage pattern of the Solomon River is dendritic (tree-like branching) and lacks symmetry, which suggests the lack of faults and folds and the presence of flat underlying rock units (Bureau of Reclamation, 1984). The topography of the basin is generally flat with shallow valleys and low relief.

The soils in the valleys are slightly sloping, friable, and generally have high agricultural productivity. In the western and central parts of the basin, soils are generally friable and relatively impermeable, with some silt loam and loess. The more level soils in the western and central parts of the basin are used for grain cultivation and are moderately productive. The soils in the eastern part of the basin range from shallow sandy soils to thick clay soils and generally have low agricultural productivity (Bureau of Reclamation, 1984).

Near-surface rocks in the Solomon River Basin are sedimentary and range in age from Permian to Quaternary (fig. 1). The near-surface geology has a general east-west pattern, with the oldest rocks in the east and the youngest rocks in the west. The oldest near-surface rocks are the Permian-age Sumner Group (which includes the Wellington Formation and the Ninnescah Shale) at the far eastern end of the study area. Overlying the Sumner Group are marine strata of Cretaceous age that include the Cheyenne Sandstone, Kiowa Shale, Dakota Formation, Graneros Shale, Greenhorn Limestone, and Carlile Shale. These rocks are exposed at the land surface in parts of Ottawa County in the east to parts of Osborne County in the west (Moore and Landes, 1937). Overlying the Carlile Shale are the Niobrara Formation, which is exposed in much of the North Fork Solomon River Basin (Leonard, 1952), and the Pierre Shale, of which there is only one known outcrop in the basin (Moore and Landes, 1937; Ross, 1991). At the western end of the basin, parts of the Ogallala Formation occur at the land surface.

In the Great Plains (a semiarid region that includes Kansas), the main source of selenium is Cretaceous-age marine shale, specifically the Pierre Shale (McNeal and Balistrieri, 1989). The only known outcrop of Pierre Shale in the basin is upstream from Webster Reservoir (fig. 1); however, other marine rocks do contain selenium. Selenate (SeO_4^{2-}), the most dominant form of selenium, is highly mobile and easily leached from soils by irrigation return flows. Reservoir-bottom sediment is an integrator of the water quality upstream from the reservoirs, and changes in land- and water-use practices through time are recorded with the deposition of sediment in reservoirs (Van Metre and others, 1996, 1997).

The three Bureau reservoirs in the Solomon River Basin provide water for irrigation; municipal, industrial, and domestic use; flood control; recreation; and fish and wildlife habitat. Fishing, hunting, and water-related recreation play an increasingly important role in the economy of the basin (Bureau of Reclamation, written commun., 1996).

Kirwin Reservoir, completed in 1952, has a contributing drainage area of 1,367 mi^2, with a total storage capacity of 314,550 acre-ft of water allocated among flood control (215,115 acre-ft), conservation storage (89,650 acre-ft), and inactive and dead storage (9,785 acre-ft). During typical conditions, there are 5,073 acres of water-surface area that are available for recreation. Also, there are 5,923 acres of land surrounding the reservoir that are available for recreational use. The Kirwin National Wildlife Refuge, operated on public lands by the U.S. Fish and Wildlife Service, provides for the preservation of waterfowl, other animals, and plant life. Inflow to the reservoir may be affected by irrigation return flow from non-Bureau-operated irrigation areas. The Bureau-operated Kirwin Irrigation District No. 1 is located downstream from the reservoir and provides surface-water outflow from the reservoir to irrigate as much as 11,490 acres of farmland (Bureau of Reclamation, 1996), generally within 5 mi of the North Fork Solomon River.

Webster Reservoir, completed in 1956, has a contributing drainage area of 1,150 mi^2, with a total storage capacity of 260,740 acre-ft of water allocated among flood control (183,369 acre-ft), conservation storage (72,071 acre-ft), and inactive and dead storage (5,300 acre-ft). During typical conditions, there are 3,766 acres of water-surface area that are available for recreation. Also, there are 2,733 acres of land surrounding the reservoir that are available for recreational use. Inflow to the reservoir may be affected by irrigation return flow from non-Bureau-operated irrigation areas. The Bureau-operated Webster Irrigation District No. 4 is located downstream from the reservoir and provides surface-water outflow from the reservoir to irrigate as much as 8,500 acres of farmland (Bureau of Reclamation, 1996), generally within 5 mi of the South Fork Solomon River.

Waconda Lake, completed in 1967, has a contributing drainage area of 5,076 mi^2, with a total storage capacity of 963,775 acre-ft of water allocated among flood control (722,315 acre-ft), conservation storage (204,789 acre-ft), and inactive and dead storage (36,671 acre-ft). During typical conditions, there are 12,602 acres of water-surface area that are available for recreation. Also, there are 13,890 acres of land surrounding the reservoir that are available for recreational use. Inflow to Waconda Lake may be affected by non-Bureau-operated irrigation areas and the Bureau-operated Kirwin Irrigation District No. 1 and Webster Irrigation District No. 4. Waconda Lake provides water to irrigate as much as 6,000 acres of farmland in the Bureau-operated Glen Elder Irrigation District No. 8, a rural water district, and the city of Beloit, Kansas (Bureau of Reclamation, 1996).

Historically, the Solomon River Basin's economy centers around agriculture in terms of employment and income. Population has been slowly declining over the years, particularly among the rural population as mechanization of farms and a downsizing of the farm economy have eliminated many jobs (Bureau of Reclamation, written commun., 1996). The primary crop grown in the basin is wheat, with smaller acreages of alfalfa, corn, sorghum, soybeans, and sunflowers. Livestock production consists mainly of cattle, with lesser numbers of hogs and sheep.

Approximately 3 to 4 percent of the Solomon River Basin is irrigated. Water for irrigation in the basin comes primarily from ground water upstream from Kirwin and Webster Reservoirs (about 87 percent), and primarily from surface water downstream from Kirwin and Webster Reservoirs (about 80 percent) (Leonard, 1952; Joan Kenny, U.S. Geological Survey, written commun., 1999).

On the basis of 1995 irrigation data, approximately 48 percent of the total irrigated acres downstream from Kirwin, Webster, and Waconda are supplied water from Bureau-operated irrigation districts. However, no Bureau irrigation water is used upstream from Kirwin and Webster Reservoirs, making Bureau-irrigated acres only 12.1 percent of the total number of irrigated acres in the Solomon River Basin (table 1).

METHODS

Although a one-time, synoptic sampling may define constituent concentrations in the areas of concern, analyzing water quality or shallow bottom-sediment samples collected simultaneously cannot document a trend in the deposition of selenium or other constituents with time or how the effects of irrigation differ through time. Furthermore, a synoptic approach will not provide insight into naturally occurring selenium in sediment deposited in reservoirs prior to the onset of major irrigation development. Therefore, the depositional trends of selenium and other constituents in this study were determined through examination and chemical analysis of layers of reservoir-bottom sediment that represent the deposition of constituents with time.

Because selenium can be transported on sediment derived from marine deposits, a background for naturally occurring concentrations in the reservoir-bottom sediment of the Solomon River Basin needs to be determined before the effects of irrigation can be addressed. Kirwin and Webster Reservoirs were constructed in the early 1950's before irrigation became widely practiced. Background is defined as the sediment concentrations of a constituent that are representative of conditions that predate the period of major irrigation development in the basin (approximately the early to mid-1960's). A comparison of these background concentrations to constituent concentrations associated with later deposition will help to assess the effect of total (Bureau and non-Bureau) irrigation.

The effect of Bureau irrigation on constituent concentrations can be assessed by comparing constituent concentrations and trends in Kirwin and Webster Reservoirs, which do not receive water from Bureau irrigation districts, to constituent concentrations and trends in Waconda Lake, which receives water from the Bureau-operated Kirwin and Webster Irrigation Districts.

Sediment-Core Collection, Processing, and Analysis

To determine trends in selenium and other selected constituents, bottom-sediment cores were collected in May 1998 from two sites each in Kirwin Reservoir, Webster Reservoir, and Waconda Lake (fig. 2). The two coring sites were compared to assess sampling variability at each reservoir. The cores were collected in the original channel bed near the dam where the sediment is least likely to be disturbed by biological

Table 1. Distribution of irrigated acres in the Solomon River Basin, 1995

[data from Craig Scott, Bureau of Reclamation, written commun., 1998; Joan Kenny, U.S. Geological Survey, written commun., 1999]

Subbasin area	Drainage area (acres)	Irrigated acres	Percentage of subbasin area irrigated	Bureau of Reclamation irrigated acres
Upstream from Kirwin Reservoir	889,248	60,600	6.8	0
Downstream from Kirwin Reservoir	859,918	15,630	1.8	8,072
Upstream from Webster Reservoir	744,422	51,170	6.9	0
Downstream from Webster Reservoir	677,761	6,940	1.0	4,551
Downstream from Waconda Lake	1,208,109	15,000	1.2	5,400
Total Solomon River Basin	**4,379,458**	**149,340**	**3.4**	**18,023**

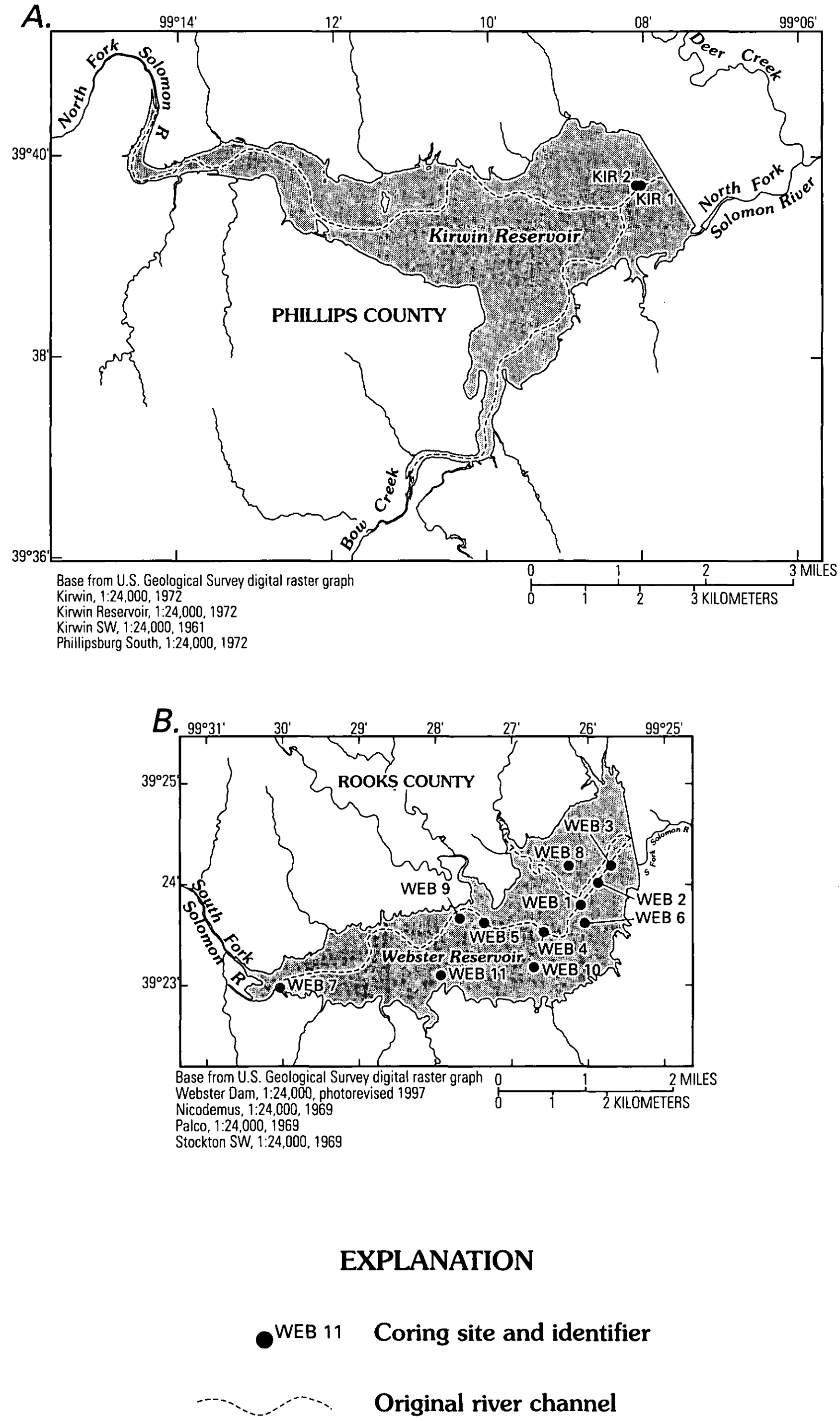
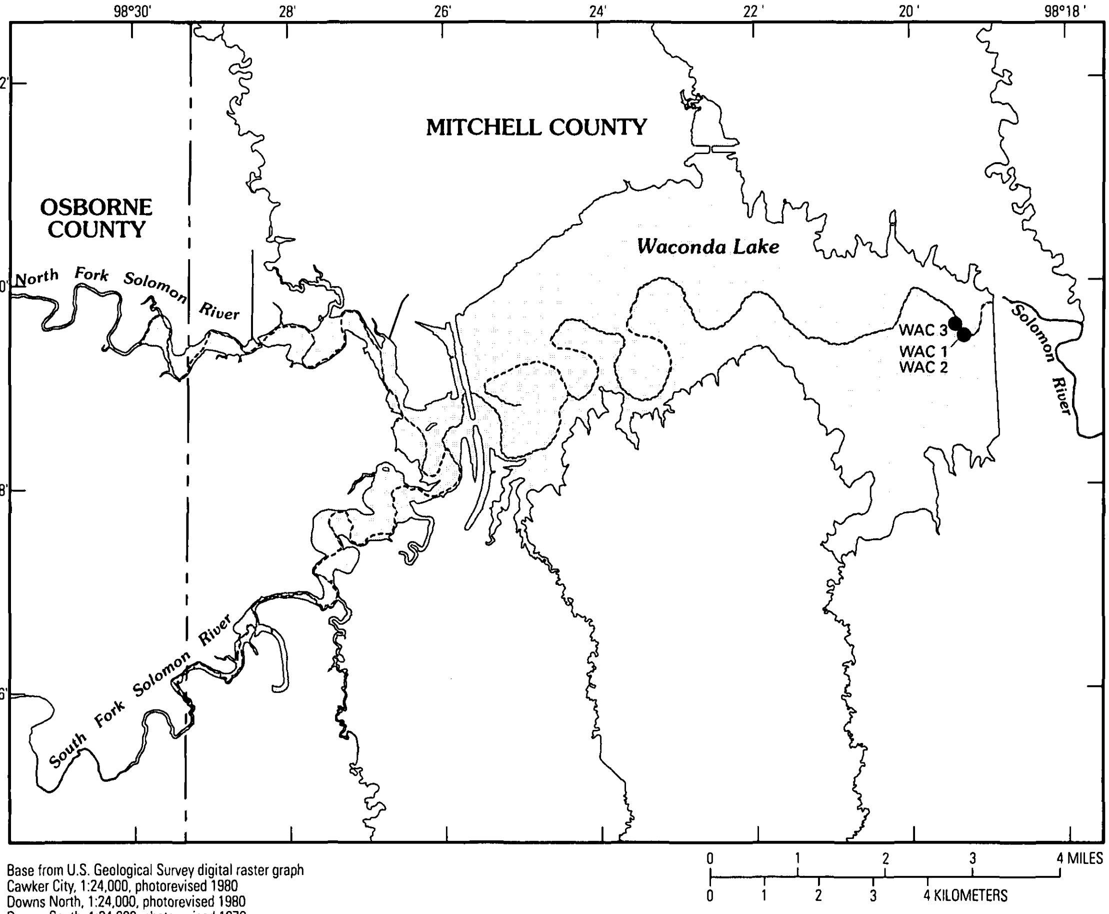


Figure 2. Approximate location of sediment-coring sites in *(A)* Kirwin Reservoir, *(B)* Webster Reservoir, and *(C)* Waconda Lake.

C.



Base from U.S. Geological Survey digital raster graph
Cawker City, 1:24,000, photorevised 1980
Downs North, 1:24,000, photorevised 1980
Downs South, 1:24,000, photorevised 1979
Glen Elder North, 1:24,000, photorevised 1980
Glen Elder South, 1:24,000, photorevised 1979
Mill Creek, 1:24,000, photorevised 1979

EXPLANATION

● WAC 1 **Coring site and identifier**

Original river channel

Figure 2. Approximate location of sediment-coring sites in *(A)* Kirwin Reservoir, *(B)* Webster Reservoir, and *(C)* Waconda Lake—Continued.

activity, inflows or outflows, human activity, or wind-induced currents. A third coring site was sampled in Waconda Lake for quality assurance, and nine additional coring sites were sampled in Webster Reservoir to determine mass of sediment and selected constituents (table 2).

At each coring site, as many as four cores were collected using a Benthos gravity corer mounted on a pontoon boat (fig. 3*A*). The liner used in the corer was cellulose acetate butylate transparent tubing with a 2.625-in. inside diameter. Samples were identified first by site and then by the order in which they were collected (for example, the cores collected from site 1 in Kirwin Reservoir are identified as KIR 1.1, KIR 1.2, KIR 1.3, and KIR 1.4). All but one core (KIR 2.1 from Kirwin Reservoir) penetrated the entire thickness of reservoir sediment and into the original channel-bed or soil-surface material. Multiple cores were required to provide sufficient sediment material for laboratory analyses.

For each site, separate cores were analyzed for selected physical properties, total recoverable metals, nutrients, cesium-137 (^{137}Cs), and total organic carbon. The samples from the nine additional coring sites in Webster Reservoir (coring sites WEB 3 through WEB 11, table 2) were analyzed for selenium, arsenic, strontium, and phosphorus. Selenium and arsenic were selected for additional analysis because both are a

Table 2. Location of bottom-sediment coring sites in the Solomon River Basin, May 1998

Coring-site identifier (fig. 2)	U.S. Geological Survey identification number	Latitude (degrees, minutes, seconds)	Longitude (degrees, minutes, seconds)
	Kirwin Reservoir		
KIR 1	393942099080400	39° 39' 42.90"	99° 08' 04.83"
KIR 2	393942099080100	39° 39' 42.91"	99° 08' 01.17"
	Webster Reservoir		
WEB 1	392349099260500	39° 23' 49.35"	99° 26' 05.35"
WEB 2	392403099255000	39° 24' 03.88"	99° 25' 50.70"
WEB 3	392410099254200	39° 24' 10.12"	99° 25' 42.10"
WEB 4	392330099263600	39° 23' 30.50"	99° 26' 36.64"
WEB 5	392335099272000	39° 23' 35.86"	99° 27' 20.78"
WEB 6	392339099260200	39° 23' 39.24"	99° 26' 02.57"
WEB 7	392300099300300	39° 23' 00.63"	99° 30' 03.85"
WEB 8	392411099261500	39° 24' 11.11"	99° 26' 15.00"
WEB 9	392346099274000	39° 23' 46.04"	99° 27' 40.48"
WEB 10	392312099264300	39° 23' 12.31"	99° 26' 43.80"
WEB 11	392307099275700	39° 23' 07.94"	99° 27' 57.05"
	Waconda Lake		
WAC 1	392927098191900	39° 29' 27.73"	98° 19' 19.11"
WAC 2	392927098191900	39° 29' 27.50"	98° 19' 19.11"
WAC 3	392934098192500	39° 29' 34.19"	98° 19' 25.84"

concern for human health and because there is a natural source for both constituents (marine strata) in the Solomon River Basin. Strontium was selected for additional analysis because a previous study in the adjacent Republican River Basin identified an increasing trend in strontium concentrations in bottom sediment from three reservoirs (Kyle Juracek, U.S. Geological Survey, oral commun., 1998). Phosphorus was selected for additional analysis because reservoir sediment may contain large quantities of phosphorus as a result of inflow transport of particulate and dissolved forms (Pope, 1998) and because phosphorus may accumulate in reservoir sediment (Juracek, 1997).

Processing of core samples and analysis of sediment characteristics were conducted at the USGS laboratory in Lawrence, Kansas. Each core was extracted from the liner and split lengthwise to expose the relatively undisturbed inner part of the core for examination and sampling (fig. 3*B*). Depending on the total sediment thickness, as many as 12 samples were collected from each core. Sediment characteristics that were determined included a core description, grain size, bulk density, and percentage of moisture. The core description involved recording the stratigraphic layers of the sediment from the pre-reservoir material up to the current depositional layers. The presence of pre-reservoir material was determined by a change in particle-size composition of the sediment or the presence of organic matter, such as plant material, roots, root hairs, sticks, and twigs, that would indicate the pre-reservoir soil surface. Grain size, bulk density, and moisture percentage were determined according to methods presented in Guy (1969).

Chemical constituent analyses were performed by the Bureau laboratory in Bismarck, North Dakota, using U.S. Environmental Protection Agency (USEPA) (U.S. Environmental Protection Agency, 1997a) and USGS methods (Skougstad and others,

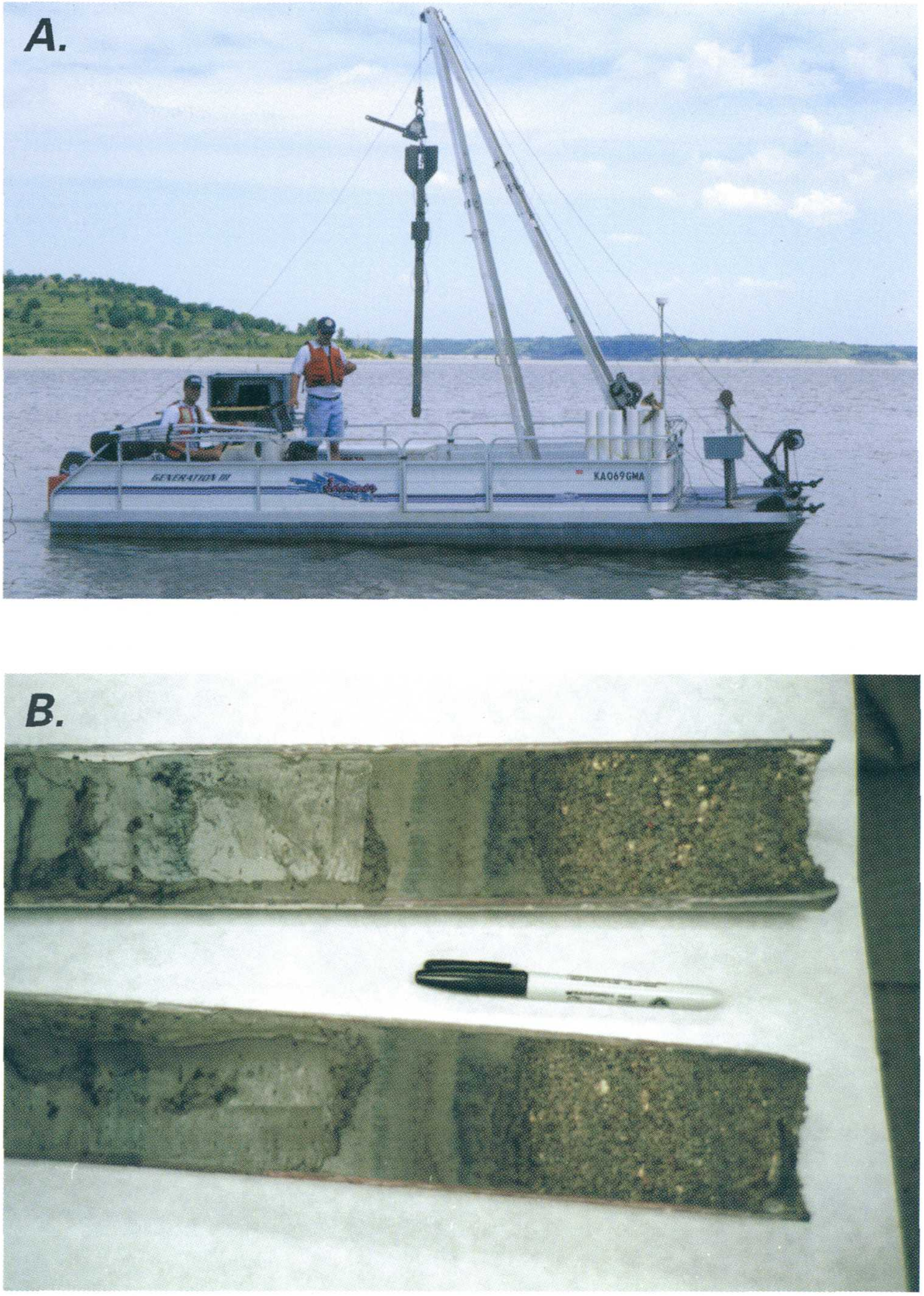


Figure 3. Photographs showing *(A)* gravity corer mounted on pontoon boat and *(B)* core preparation.

1979). Microwave-assisted digestion using nitric acid (USEPA method 3051) was used on all samples. Graphite furnace atomic absorption was used for arsenic (USEPA Method 7060A), lead, and selenium (USEPA Method 7740). Flame atomic absorption was used for strontium (USEPA Method 7780). Cold vapor atomic absorption (USEPA Method 7471A) was used for mercury. For all other metals, inductively coupled argon plasma (USEPA Method 6010B) was used. A flow injection analyzer was used for the analysis of total nitrogen (USEPA Method 350.1) and total phosphorus (USGS Method I–2601–78). A carbon analyzer was used for the analysis of total organic carbon (USEPA Method 9060).

To calculate mean and median constituent concentrations for samples with concentrations less than the laboratory detection limit and for constituents with multiple detection limits, a value of one-half the highest detection limit reported for that constituent in each reservoir was arbitrarily assigned. Mean and median values were not calculated when there were more than five samples in a core with concentrations less than the laboratory detection limits.

Cesium-137 (^{137}Cs) concentrations were determined by Quanterra Laboratory in Denver, Colorado. The concentration of ^{137}Cs was determined to assist in age dating the samples. ^{137}Cs is a radioactive isotope that is a by-product of nuclear weapons testing. Measurable concentrations of this isotope first appeared in the atmosphere in about 1952, peaked during 1963–64, and have since declined (Holmes, 1998). ^{137}Cs strongly sorbs to fine-grained sediment, making it useful in many studies to age date sediment that has been exposed to atmospheric fallout (Callender and Robbins, 1993; Van Metre and others, 1996, 1997; Benninger and others, 1997; Wallbrink and others, 1998). It also can be used to demonstrate that the sediment is undisturbed if a relatively uniform decrease in ^{137}Cs concentration follows the 1963–64 peak (Pope, 1998).

Quality Control

Without quality-control data, bottom-sediment data cannot be interpreted adequately because errors associated with sample data are unknown. For this study, within-site variability as well as site-to-site variability were determined. Within-site variability of data associated with all phases of sample collection and analysis was analyzed through the collection of sequential, replicate bottom cores from Waconda Lake coring site 2 (WAC 2, fig. 2), which was immediately adjacent to Waconda Lake coring site 1 (WAC 1, fig. 2). The cores from coring site WAC 2 were collected within 15 minutes of collecting the final core from coring site WAC 1. The very small change in location from site WAC 1 to site WAC 2 (table 2) was due to drifting of the pontoon boat.

Cores from coring sites WAC 1 and WAC 2 were segmented into 12 sample intervals of various lengths, according to changes in physical characteristics (fig. 3*B*). Each core segment was homogenized and then analyzed for selected physical characteristics, total recoverable metals, nutrients, ^{137}Cs, and total organic carbon concentrations to provide information on the variability of the constituents that were analyzed for all in-channel, near-dam cores. The relative percentage difference between the two sample concentrations from coring sites WAC 1 and WAC 2 was defined by the following equation:

$$RPD = \frac{(C1 - C2)x100}{\frac{(C1 + C2)}{2}}, \qquad (1)$$

where

RPD = relative percentage difference;

$C1$ = larger of two concentration values; and

$C2$ = smaller of two concentration values.

The mean relative percentage differences for all total recoverable metals, nutrients, and total organic carbon in the sequential replicate samples (coring sites WAC 1 and WAC 2) are listed in table 3. The mean relative percentage differences for constituent concentrations between coring sites WAC 1 and WAC 2 ranged from 1.66 percent for manganese to 8.56 percent for selenium, with a mean relative percentage difference for all constituents of 3.70 percent.

Table 3. Mean relative percentage differences for total recoverable metals, nutrients, and total organic carbon concentrations in sequential replicate samples from bottom-sediment coring sites WAC 1 and WAC 2 (fig. 2) in Waconda Lake, May 1998

[--, not calculated]

Constituent	Mean relative percentage difference
Total recoverable metals	
Aluminum	2.48
Arsenic	2.53
Barium	2.14
Beryllium	--
Boron	--
Cadmium	--
Chromium	5.46
Copper	3.14
Iron	1.71
Lead	2.92
Magnesium	1.76
Manganese	1.66
Mercury	--
Nickel	6.22
Selenium	8.56
Strontium	3.25
Vanadium	2.68
Zinc	4.70
Nutrients	
Total nitrogen	5.54
Total phosphorus	6.12
Organic carbon	
Total organic carbon	2.11

A typical quality-control objective for precision of replicate samples is a maximum relative percentage difference of 20 percent (Taylor, 1987). Not only does the sequential replicate bottom-sediment sample represent within-site variability but also includes any sample contamination incurred during collection and preparation. Percentage differences need to be taken into account when evaluating the variability between bottom-sediment cores from the same site. It should be noted that relative percentage differences were not calculated for chemical constituents that were not detected and that selenium showed the greatest variability among all constituents that were analyzed. Selenium concentrations were close to their method detection limit, which may account for their increased variability.

No standard method exists for obtaining representative samples of bottom sediment in reservoirs. Therefore, to gain some knowledge of the amount of variability between sites in the original channel, site-to-site variability was analyzed through the examination of constituent concentrations in samples from two coring sites each in Kirwin and Webster Reservoirs. The two sites in each reservoir were located in the original channel bed near the dam. The two sites in Kirwin Reservoir (KIR 1 and KIR 2, fig. 2) were about 200 ft apart, whereas the two sites in Webster Reservoir (WEB 1 and WEB 2, fig. 2) were about 1,000 ft apart. Relative percentage differences were determined using equation 1. Mean relative percentage differences between each site in Kirwin Reservoir for total recoverable metals, nutrients, and total organic carbon ranged from 2.15 percent for copper to 11.5 percent for chromium. In Webster Reservoir, the differences ranged from 1.91 percent for barium to 14.2 percent for chromium (table 4). The mean relative percentage difference for all constituents in table 4 was slightly larger for Webster Reservoir (5.85 percent) with sites 1,000 ft apart than for Kirwin Reservoir (5.43 percent) with sites 200 ft apart. On the basis of these comparisons, there is not substantial variability in sediment chemistry even over the fairly large distance between sampling sites.

Table 4. Mean relative percentage differences for total recoverable metals, nutrients, and total organic carbon concentrations in bottom-sediment samples from Kirwin and Webster Reservoirs, May 1998

[--, not calculated]

Constituent	Mean relative percentage difference: Kirwin Reservoir coring sites KIR 1 and KIR 2 (fig. 2)	Mean relative percentage difference: Webster Reservoir coring sites WEB 1 and WEB 2 (fig. 2)
Total recoverable metals		
Aluminum	9.29	8.88
Arsenic	3.97	2.70
Barium	2.30	1.91
Beryllium	--	--
Boron	6.13	8.31
Cadmium	--	--
Chromium	11.5	14.2
Copper	2.15	2.05
Iron	4.48	4.67
Lead	4.47	5.29
Magnesium	4.59	5.07
Manganese	2.45	3.79
Mercury	--	--
Nickel	5.90	5.60
Selenium	10.2	6.56
Strontium	3.40	3.66
Vanadium	10.9	9.98
Zinc	3.99	3.29
Nutrients		
Total nitrogen	4.47	11.2
Total phosphorus	4.85	5.36
Organic carbon		
Total organic carbon	2.73	2.73

Trend Analysis

Spearman's rho (r) correlation and Kendall's tau (τ) trend tests were done for sediment concentrations in cores from each reservoir. Both tests were used because each offered a possible advantage over the other. Spearman's rho gives more weight to differences between data values ranked farther apart than does Kendall's tau. Spearman's rho was computed according to methods presented in Helsel and Hirsch (1992). Core-sample intervals were normalized by dividing the distance from the bottom of the core to the center of the sample by the total core length. Concentrations of selected constituents were paired with their associated normalized depth interval to determine a positive (constituent concentrations increasing with decreasing depth) or negative correlation (constituent concentrations decreasing with decreasing depth). Kendall's tau was calculated according to methods described in Hirsch and others (1993). Kendall's tau is a nonparametric trend test that is rank based and, therefore, resistant to the effects of extreme values and to derivations from a linear relation (Hirsch and others, 1993). Kendall's tau may be more appropriate than Spearman's rho for sample sizes less than 20 (Helsel and Hirsch, 1992).

Rho and tau were not calculated for cores having more than five samples with concentrations less than the detection limit. Trends were considered positive if either test (Spearman's rho or Kendall's tau) was significant, with p values less than 0.05 ($p<0.05$) in both cores from Kirwin and Webster Reservoirs or two of the three cores from Waconda Lake. Only those constituents that met the above criteria in more than one reservoir (selenium, arsenic, and strontium) will be discussed in detail later in this report. The p values discussed later in this report will be those associated with the Kendall's tau trend test.

RESULTS OF RESERVOIR BOTTOM-SEDIMENT ANALYSIS

Sediment-Core Lithology and Grain Size

The length of sediment cores collected as part of this study ranged from 1.4 to 8.0 ft (table 9 in "Supplementary Information" section). The cores from all three lakes appeared stratified, with alternating dark and light layers. These layers became less distinct at the top of the core. The deeper stratified layers could be correlated easily among the cores; the shallower layers were less easily correlated. This may account for a larger variance among concentrations of selected constituents in shallower sediment samples as compared to the deeper samples. In addition, the deeper layers tended to be thicker.

Before a comparison could be made between the length of the cores collected and the Bureau's sedimentation data, the effect of core shortening had to be determined. Core shortening is a phenomenon associated with the use of a gravity corer and has been estimated to shorten the core by as much as 50 percent (Emery and Hulsemann, 1964). Core shortening also has been observed in a previous study in Kansas that collected sediment using a gravity corer (Juracek, 1997). Hongve and Erlandsen (1979) attribute the shortening to compression of sediment and loss of water content. This shortening effect also has been attributed to the effects of friction of the sediment against the inner wall of the core liner (Emery and Deitz, 1941; Blomqvist and Bostrom, 1987). There is also the possibility that the core-shortening phenomenon is due to a loss of sediment from the core column. If this occurs, there may be an effect on bulk density and related calculations.

In this study, the amount of core shortening was determined by measuring the distance from the water surface to the top of the sediment with a weighted tape and confirming this distance with a depth finder. When the gravity corer was released into the reservoir, the distance from the water surface to the tip of the gravity corer was determined by marking and measuring the distance against the cable holding the coring device. The difference between this depth and the depth to the sediment (as measured by weighted tape) was determined to be the thickness of sediment, in situ. Once the sediment core was retrieved, its length was measured, and this was divided by the thickness of sediment and multiplied by 100 to determine the recovery percentage (table 5). In most cases, any original channel-bed or land-surface material in the liner was less than 0.1 ft and did not affect the calculation of the recovery percentage. The average recovery percentage for cores from all three reservoirs was 68 percent. Table 9 in the "Supplemental Information" section at the end of this report includes lengths of all cores collected during this study, uncorrected for original channel-bed or land-surface material thickness or core shortening.

The lengths of cores KIR 1.4 and KIR 2.1 used for analysis of core lithology and grain size from Kirwin Reservoir were 7.9 and 3.2 ft, respectively (table 9). Core KIR 2.1 was the only core collected during the study that did not reach original land-surface material, which accounts for the shorter core length. When visually compared to the other three cores collected from coring site KIR 2, it was evident that the deepest three samples were missing from core KIR 2.1. The percentage of silt and clay was equal to or greater than 97.7 percent in all samples from both Kirwin cores (table 10 in "Supplemental Information" section). The

Table 5. Sediment-recovery percentages in cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998

[--, not determined]

Reservoir	Sediment recovery (percent) In-channel	Out-of-channel
Kirwin Reservoir	64.0	--
Webster Reservoir	74.3	82.5
Waconda Lake	48.3	--

mean percentages of silt and clay determined for coring sites KIR 1 and KIR 2 were 99.4 and 99.5 percent, respectively (table 6). The mean percentage of sand was less than 1.0 percent for both coring sites. Bulk densities for samples from cores KIR 1.4 and KIR 2.1 ranged from 27.5 to 50.4 lb/ft^3 (table 10), with the larger bulk density in samples from the bottom (deeper) parts of each core. The percentage of moisture in samples from cores KIR 1.4 and KIR 2.1 ranged from 46.8 to 65.5 percent, with the shallower (top) samples having a larger percentage of moisture (table 10).

The lengths of cores WEB 1.1 and WEB 2.1 used for the analysis of core lithology and grain size for Webster Reservoir were 7.0 and 7.2 ft, respectively (table 9). The smallest percentage of silt and clay in all samples was 98.9 percent, and the percentage of sand in all samples was less than or equal to 1.1 percent (table 10). Bulk density ranged from 21.1 to 48.6 lb/ft^3 (table 10). Mean bulk-density values for the two cores were 35.4 and 34.8 lb/ft^3 (table 6). Larger bulk-density values generally occurred in the deeper samples. The percentage of moisture ranged from 46.6 to 72.9 percent, with samples at the top of the cores generally having a larger percentage of moisture (table 10). The additional cores collected in Webster Reservoir, because they were collected both in and out of the original channel bed, had a wider range in grain size, bulk density, and percentage of moisture. In general, grain sizes and bulk-density values were larger in out-of-channel cores as compared to in-channel cores, and the percentage of moisture was smaller in out-of-channel cores.

Table 6. Mean percentage of silt and clay, percentage of sand, bulk density, and percentage of moisture in bottom-sediment samples from coring sites in Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998

[lb/ft^3, pound per cubic foot]

Coring-site identifier (fig. 2)	Mean percentage of silt and clay	Mean percentage of sand	Mean bulk density (lb/ft^3)	Mean percentage of moisture
KIR 1	99.4	0.6	40.6	55.3
KIR 2	99.5	.5	37.7	56.9
WEB 1	99.8	.2	35.4	57.3
WEB 2	99.8	.2	34.8	61.2
WAC 1	99.8	.2	32.5	59.9
WAC 3	99.9	.1	29.2	64.1

The lengths of cores WAC 1.1 and WAC 3.2 used for the analysis of core lithology and grain size for Waconda Lake were 6.1 and 7.0 ft, respectively (table 9). The percentage of silt and clay in samples from both cores was greater than 99 percent, with less than 1 percent sand (table 10). Bulk density ranged from 21.6 to 47.0 lb/ft^3, with larger bulk-density values generally occurring in deeper samples (table 10). The percentage of moisture ranged from 46.3 to 73.1, with shallower samples generally having a larger percentage of moisture.

The cores from Kirwin, Webster, and Waconda that were collected within the channel and near the dam had mean percentages of silt and clay greater than 99 percent (table 6). In-channel core bulk-density values were generally larger in deeper samples, and the percentage of moisture was generally smaller when compared to shallower samples. The cores from Webster Reservoir that were collected outside of the original channel bed (coring sites WEB 6 through WEB 11) generally had larger sand percentages, larger bulk-density values, and smaller moisture percentages when compared to samples from in-channel cores.

Age Dating and Depositional Patterns of Bottom Sediment

Kirwin Reservoir, the oldest of the three reservoirs in the basin, was completed in 1952. This completion date coincides with the first occurrence of ^{137}Cs in the atmosphere. Therefore, the date of deposition of the sediment in the bottom of cores from Kirwin Reservoir was assumed to be 1952 (fig. 4). To make comparisons between coring sites and among the different reservoirs, core-sample intervals were normalized. The peak in ^{137}Cs concentration in sediment cores KIR 1.2 and KIR 2.3 from Kirwin Reservoir occurred near the normalized sample interval of 0.5 (dimensionless) (fig. 4). The date 1963–64, the peak of ^{137}Cs atmospheric deposition (Holmes, 1998), was assigned to this interval. The ^{137}Cs concentration following the peak shows a smooth decline in concentration, which would indicate that the sediment has been relatively undisturbed by biological activity, inflows or outflows, human activity, or wind-induced currents. One additional date, the date of sampling (1998), was assigned to the top of the core.

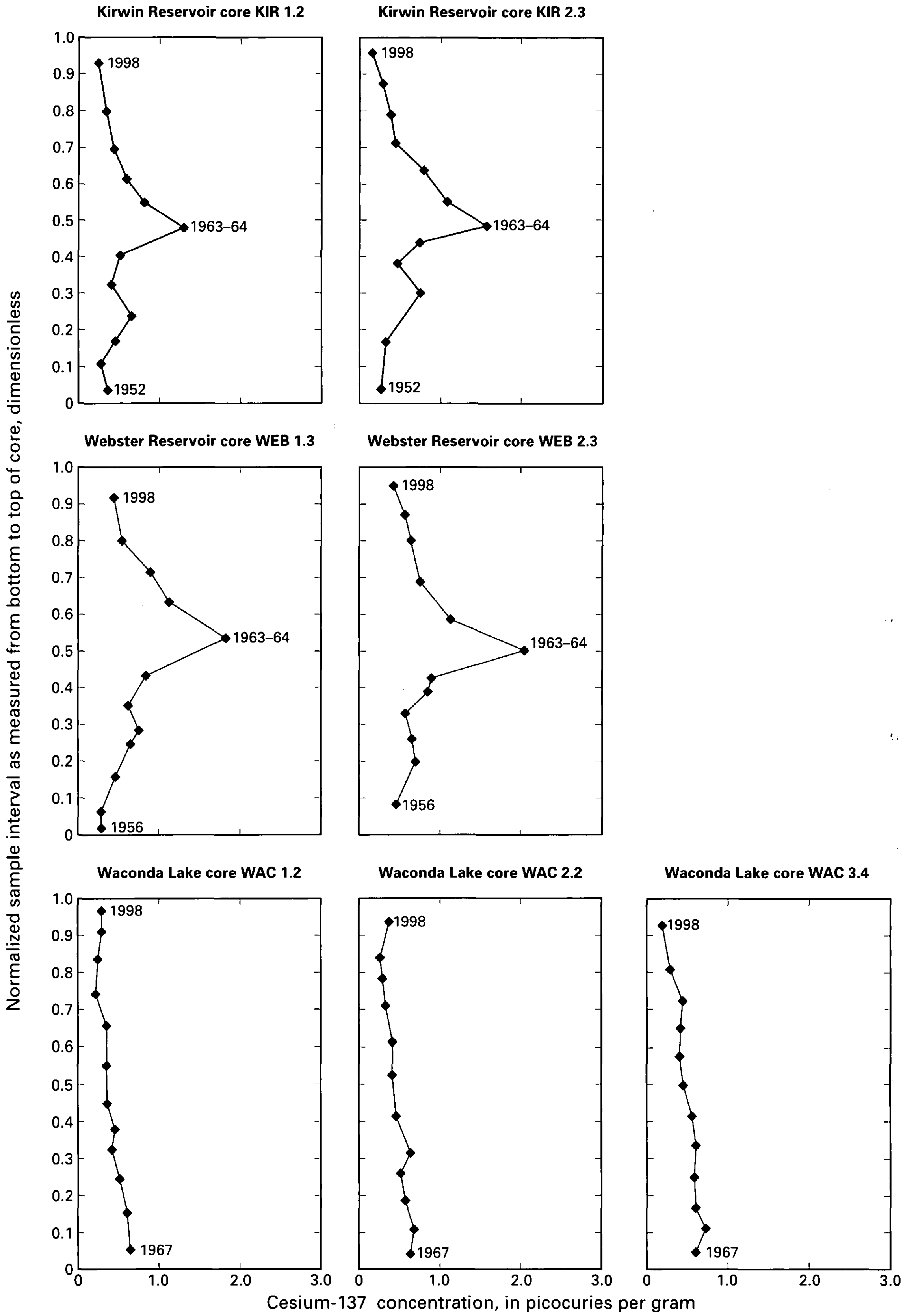


Figure 4. Depth-normalized cesium-137 profiles in selected bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake. Location of coring sites shown in figure 2.

Given the above dates, it may be possible to calculate depositional rates for sediment before 1963–64 and after 1964. However, these depositional rates may be misleading because of the core-shortening phenomenon discussed in the previous section. Because the cause of the core shortening is unknown, it is not possible to accurately correct for it. Additionally, although it is possible to verify that the entire sediment thickness has been penetrated and the deepest layers are present, it is not possible to verify that the shallowest layers are present. Because the gravity corer descends with great force, it may shift the shallowest, less consolidated layers so that they are not recovered in the core liner. Therefore, average depositional rates calculated on the basis of core length are not presented herein, but depositional patterns as they relate to reservoir inflows are discussed in more general terms.

In Kirwin Reservoir, it appears from the ^{137}Cs profiles (cores KIR 1.2 and KIR 2.3, fig. 4) that the 1963–64 peak is at approximately the center of each core. Because the normalized sample intervals between 0 and 0.5 represent approximately the first 12 years of sediment deposition and the normalized sample intervals between 0.5 and 1.0 represent approximately 34 years of sediment deposition, one might conclude that the depositional rate prior to 1963-64 was more than twice the depositional rate after 1964. However, because of the core shortening and recovery phenomena discussed previously, a depositional rate cannot be accurately established. There is evidence, however, that indicates that deposition was, in fact, greater in the early years of the reservoir. A visual examination of the cores from Kirwin Reservoir reveals thick layers of sediment in the deepest intervals. This is consistent with other reservoir studies (Ritchie and others, 1986; Callender and Robbins, 1993), which demonstrated that sedimentation rates decreased with reservoir age. Historical streamflow data for the inflow to Kirwin Reservoir indicate that much of the early sediment deposition in the lake may have been caused by floods during the 1957 and 1960 water years (fig. 5).

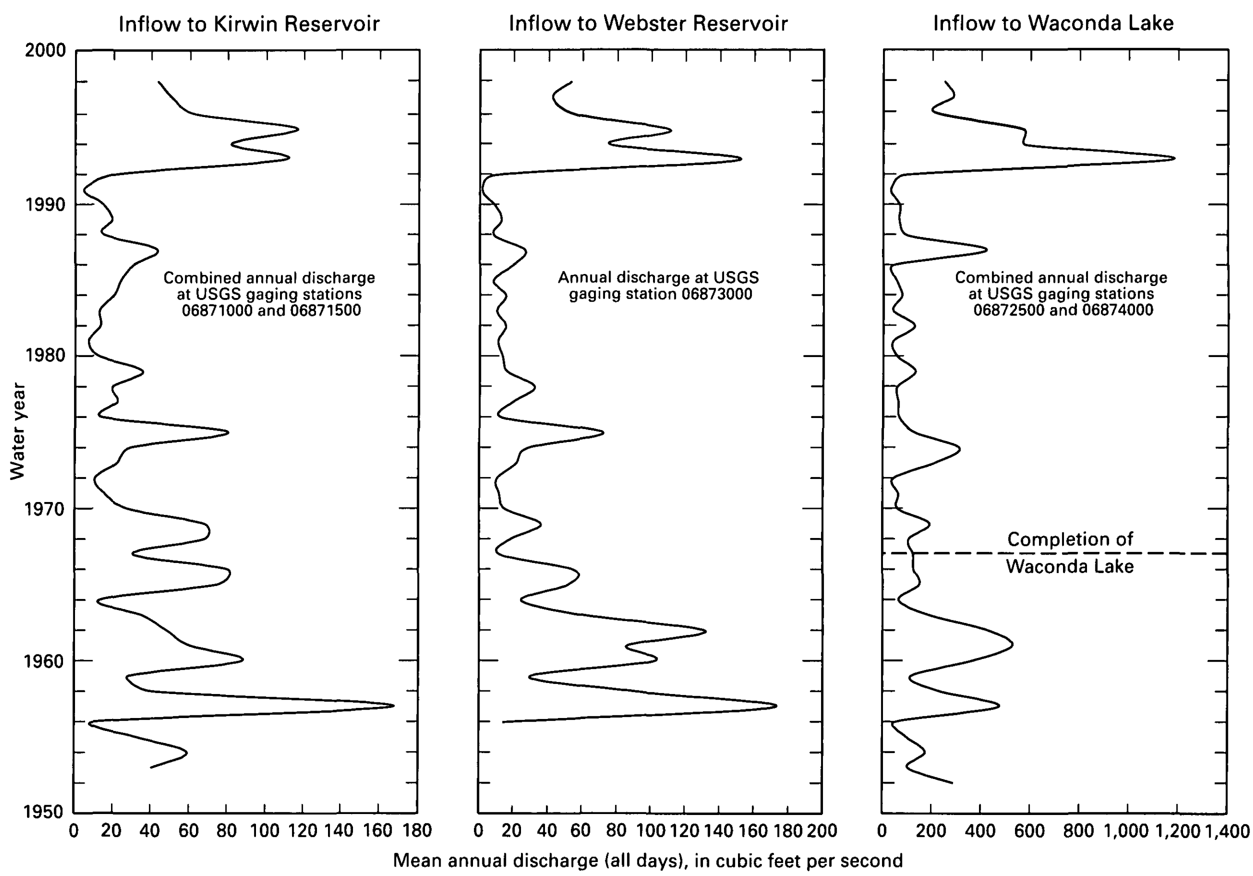


Figure 5. Historical inflows to Kirwin Reservoir, Webster Reservoir, and Waconda Lake. Data from U.S. Geological Survey (USGS) streamflow-gaging stations 06871000 and 06871500 upstream from Kirwin Reservoir, station 06873000 upstream from Webster Reservoir, and stations 06872500 and 06874000 upstream from Waconda Lake. Data on file with the U.S. Geological Survey, Lawrence, Kansas. The location of these streamflow-gaging stations is shown in figure 1.

Webster Reservoir was completed in 1956, and although the first atmospheric deposition of ^{137}Cs cannot be assigned, the 1963–64 peak is evident near the 0.5 sample interval (fig. 4). As with Kirwin Reservoir, the ^{137}Cs concentration following the 1963–64 peak shows a relatively smooth decline, indicating presumably undisturbed sediment. The top of the cores may be assigned a date of 1998 (the date of sampling). The cores from Webster Reservoir (cores WEB 1.3 and WEB 2.3, fig. 4) also showed thicker layers of sediment in the deeper samples compared to the shallower samples. Similar to data derived from cores from Kirwin Reservoir, the greater sedimentation rate of the initial deposits in Webster Reservoir may have been caused by floods in the 1957, 1960, and 1962 water years (fig. 5).

Because Waconda Lake was completed in 1967, neither the first incidence of ^{137}Cs (in 1952) nor the peak (1963–64) is evident in sediment cores WAC 1.2, WAC 2.2, and WAC 3.4 from Waconda Lake (fig. 4). The only dates that can be assigned to the cores from Waconda Lake are the date of dam completion (1967) to the bottom of the core and the sampling date (1998) to the top of the core. However, a relatively smooth decrease in ^{137}Cs concentrations is evident for the three sediment cores. This would indicate that the bottom sediment has been relatively undisturbed. Upon visual examination of the Waconda Lake cores (WAC 1.2, WAC 2.2, and WAC 3.4, fig. 4), it appears that there also was significant sedimentation in the early years of the reservoir, as indicated by a very thick sedimentation layer in the deepest core samples. This may be due to large inflows in 1969 and 1974 (fig. 5).

In addition to large inflows in the years following reservoir completion, the greater sedimentation rates observed in the three reservoirs before 1964 may be due, in part, to other factors. These include a change in sediment source, changes in land use, or the development of small-scale impoundments or reservoirs within the basin that trap sediment before it reaches Kirwin Reservoir, Webster Reservoir, and Waconda Lake.

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 trace metals (U.S. Environmental Protection Agency, 1997b). 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 concentrations presented by USEPA are referred to as the threshold-effects level (TEL) and the probable-effects level (PEL). The smaller of the two guidelines (the TEL) is assumed to represent the concentration below which toxic effects rarely occur. In the range of concentrations between the TEL and PEL, adverse effects occasionally occur. Toxic effects usually or frequently occur at concentrations above the larger guideline (the PEL).

The TEL and PEL are guidelines to be used as screening tools for possible hazardous levels of chemicals and are not regulatory criteria. The USEPA (1997b) has made this cautionary statement because, although biological-effects correlation identifies level-of-concern concentrations associated with the likelihood of adverse organism response, the procedure does not demonstrate that a particular chemical is solely responsible.

Table 7 shows a statistical summary of selected chemical constituents analyzed in bottom-sediment samples from the three Solomon River Basin reservoirs. Concentrations of selenium, arsenic, strontium, and phosphorus in samples from the additional cores collected from Webster Reservoir (coring sites WEB 3–11) are not included. The USEPA (1997b) has established TELs and PELs for eight of the constituents listed. The median arsenic and copper concentrations exceeded the TELs for samples from all three reservoirs. Cadmium concentrations exceeded the TEL in four samples from Kirwin and Webster Reservoirs. Nickel concentrations exceeded the TEL in 11 samples from Webster Reservoir. Concentrations of chromium, lead, and mercury either were not detected or did not exceed TELs in samples from any reservoir. PELs were not exceeded for any of the eight constituents in samples from any of the three reservoirs.

Increasing trends in selenium, arsenic, manganese, strontium, and phosphorus concentrations, determined using Spearman's rho correlation and Kendall's tau trend test, occurred in bottom-sediment samples from at least one reservoir (table 8). Decreasing trends in aluminum and magnesium concentrations occurred in bottom-sediment samples from Webster Reservoir. Decreasing trends in iron concentrations occurred in

Table 7. Statistical summary of selected constituent concentrations in bottom-sediment samples from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998, and comparison to sediment-quality guidelines

[mg/kg, milligrams per kilogram; --, not determined; <, less than highest detection limit for samples from that reservoir]

Constituent	Concentrations in bottom-sediment cores (mg/kg)						Sediment-quality guidelines[1]	
	Kirwin Reservoir		Webster Reservoir		Waconda Lake			
	Range	Median	Range	Median	Range	Median	TEL	PEL
			Trace metals					
Aluminum	13,500–54,300	33,400	18,300–54,200	31,300	15,000–50,900	26,100	--	--
Arsenic	4.6–10	8.0	8.0–15.1	11	5.4–13.1	10.2	7.24	41.6
Barium	216–362	303	224–333	285	155–372	276	--	--
Beryllium	<2.7	--	<3.1–4.8	--	<5.1	--	--	--
Boron	<21–37	27.5	<24–37	18	<41–47	--	--	--
Cadmium	<2.7–3.7	--	<3.0	--	<5.1	--	.68	4.21
Chromium	9–33	16	<6–26	13	<10–17	10	52.3	160
Copper	17–28	22	19–29	25	7–27	22	18.7	108
Iron	14,200–33,900	25,000	16,900–33,100	24,900	9,200–27,100	23,700	--	--
Lead	14–26	21	16–32	26	<14–25	18	30.2	112
Magnesium	4,370–10,500	7,460	5,740–10,900	7,890	2,260–7,260	5,910	--	--
Manganese	371–573	496	341–788	541	235–1,110	770	--	--
Mercury	<0.2	--	<0.2	--	<0.2	--	.13	.696
Nickel	<11–24	12	<12–30	14	<21	--	15.9	42.8
Selenium	<0.5–2.2	1.0	0.5–2.7	1.4	<0.6–3.4	1.1	--	--
Strontium	74–219	149	109–263	177	68–336	154	--	--
Vanadium	23–114	82	47–125	64	22–73	58	--	--
Zinc	59–118	93.5	76–119	98	35–137	102	124	271
			Nutrients					
Nitrogen	1,200–1,980	1,700	30.0–1,910	1,640	704–3,210	2,050	--	--
Phosphorus	422–795	616	251–692	562	281–904	652	--	--
							--	--
			Organic carbon					
Total organic carbon	8,310–13,600	11,600	10,600–16,200	12,300	3,440–19,900	16,700	--	--

[1]Sediment-quality guidelines from U.S. Environmental Protection Agency (1998):
TEL—threshold-effects level;
PEL—probable-effects level.

bottom-sediment samples from Kirwin and Webster Reservoirs. No increasing or decreasing trends occurred in concentrations of barium, beryllium, boron, cadmium, chromium, copper, lead, nickel, vanadium, zinc, nitrogen, or total organic carbon. Mercury was not detected in bottom sediment from any of the three reservoirs in the basin. Of the chemical constituents analyzed in core samples from the three reservoirs, arsenic, selenium, and strontium were the only constituents that showed an increasing trend in concentrations in samples from more than one reservoir.

Selenium

The USEPA has not established a threshold-effects level (TEL) or probable-effects level (PEL) for selenium. However, concentrations equal to or greater than

Table 8. Results of trend tests on concentrations of selected constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998

[--, not calculated]

Core-sample identification	Constituent	Total number of samples	Number of samples with detections	Spearman's rho (r)	Trend test at a 0.05 level of significance	Kendall's tau (τ)	Trend test at a 0.05 level of significance
			Kirwin Reservoir bottom-sediment cores (fig. 2A)				
KIR 1.3	Aluminum	12	12	0.615	increasing trend	0.364	no trend
	Arsenic	12	12	.280	no trend	.182	no trend
	Barium	12	12	-.294	no trend	.212	no trend
	Beryllium	12	1	--	--	--	--
	Boron	12	8	.638	increasing trend	.333	no trend
	Cadmium	12	0	--	--	--	--
	Chromium	12	12	.323	no trend	.167	no trend
	Copper	12	12	-.396	no trend	.348	no trend
	Iron	12	12	-.399	no trend	-.394	decreasing trend
	Lead	12	12	-.088	no trend	-.061	no trend
	Magnesium	12	12	-.378	no trend	-.364	no trend
	Manganese	12	12	.137	no trend	.015	no trend
	Mercury	12	0	--	--	--	--
	Nickel	12	9	-.539	no trend	-.379	decreasing trend
	Selenium	12	11	.749	increasing trend	.561	increasing trend
	Strontium	12	12	.958	increasing trend	.909	increasing trend
	Vanadium	12	12	.739	increasing trend	.500	increasing trend
	Zinc	12	12	-.415	no trend	-.439	decreasing trend
	Nitrogen	12	12	-.350	no trend	-.242	no trend
	Phosphorus	12	12	.846	increasing trend	.667	increasing trend
	Total organic carbon	12	12	-.259	no trend	-.212	no trend
KIR 2.2	Aluminum	12	12	-.322	no trend	-.273	no trend
	Arsenic	12	12	-.414	no trend	-.333	no trend
	Barium	12	12	-.392	no trend	-.333	no trend
	Beryllium	12	4	--	--	--	--
	Boron	12	11	-.525	no trend	-.379	decreasing trend
	Cadmium	12	3	--	--	--	--
	Chromium	12	12	-.334	no trend	-.258	no trend
	Copper	12	12	-.551	no trend	-.439	decreasing trend
	Iron	12	12	-.797	decreasing trend	-.667	decreasing trend
	Lead	12	12	-.514	no trend	-.394	decreasing trend
	Magnesium	12	12	-.818	decreasing trend	-.697	decreasing trend
	Manganese	12	12	.496	no trend	.424	increasing trend
	Mercury	12	0	--	--	--	--
	Nickel	12	10	-.234	no trend	-.182	no trend

Table 8. Results of trend tests on concentrations of selected constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Constituent	Total number of samples	Number of samples with detections	Spearman's rho (r)	Trend test at a 0.05 level of significance	Kendall's tau (τ)	Trend test at a 0.05 level of significance
			Kirwin Reservoir bottom-sediment cores (fig. 2*A*)—Continued				
KIR 2.2	Selenium	12	11	0.313	no trend	0.227	no trend
	Strontium	12	12	.657	increasing trend	.485	increasing trend
	Vanadium	12	12	.119	no trend	.091	no trend
	Zinc	12	12	-.343	no trend	-.273	no trend
	Nitrogen	12	12	.427	no trend	.303	no trend
	Phosphorus	12	12	.893	increasing trend	.692	increasing trend
	Total organic carbon	12	12	-.308	no trend	-.242	no trend
			Webster Reservoir bottom-sediment cores (fig. 2*B*)				
WEB 1.2	Aluminum	12	12	-.573	no trend	-.485	decreasing trend
	Arsenic	12	12	.641	increasing trend	.530	increasing trend
	Barium	12	12	-.420	no trend	-.333	no trend
	Beryllium	12	10	-.242	no trend	-.121	no trend
	Boron	12	10	-.222	no trend	-.197	no trend
	Cadmium	12	1	--	--	--	--
	Chromium	12	11	-.565	no trend	-.424	decreasing trend
	Copper	12	12	-.364	no trend	-.333	no trend
	Iron	12	12	-.517	no trend	-.485	decreasing trend
	Lead	12	12	.134	no trend	.015	no trend
	Magnesium	12	12	-.510	no trend	-.455	decreasing trend
	Manganese	12	12	.888	increasing trend	.788	increasing trend
	Mercury	12	0	--	--	--	--
	Nickel	12	9	-.531	no trend	-.364	no trend
	Selenium	12	12	.569	no trend	.409	increasing trend
	Strontium	12	12	.888	increasing trend	.758	increasing trend
	Vanadium	12	12	-.354	no trend	-.258	no trend
	Zinc	12	12	-.457	no trend	.348	no trend
	Nitrogen	12	12	-.112	no trend	-.364	no trend
	Phosphorus	12	12	.496	no trend	-.167	no trend
	Total organic carbon	12	12	-.196	no trend	.091	no trend
WEB 2.4	Aluminum	12	12	-.727	decreasing trend	-.576	decreasing trend
	Arsenic	12	12	.669	increasing trend	.530	increasing trend
	Barium	12	12	-.900	decreasing trend	-.773	decreasing trend
	Beryllium	12	0	--	--	--	--
	Boron	12	4	--	--	--	--

Table 8. Results of trend tests on concentrations of selected constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Constituent	Total number of samples	Number of samples with detections	Spearman's rho (r)	Trend test at a 0.05 level of significance	Kendall's tau (τ)	Trend test at a 0.05 level of significance
			Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued				
WEB 2.4	Cadmium	12	0	--	--	--	--
	Chromium	12	10	-0.711	decreasing trend	-0.515	decreasing trend
	Copper	12	12	-.664	decreasing trend	-.455	decreasing trend
	Iron	12	12	-.769	decreasing trend	-.606	decreasing trend
	Lead	12	12	-.462	no trend	-.333	no trend
	Magnesium	12	12	-.692	decreasing trend	-.318	no trend
	Manganese	12	12	.956	increasing trend	.864	increasing trend
	Mercury	12	0	--	--	--	--
	Nickel	12	7	-.687	decreasing trend	-.485	decreasing trend
	Selenium	12	12	.874	increasing trend	.697	increasing trend
	Strontium	12	12	.937	increasing trend	.848	increasing trend
	Vanadium	12	12	.042	no trend	0	no trend
	Zinc	12	12	-.585	decreasing trend	-.424	decreasing trend
	Nitrogen	12	12	-.186	no trend	-.106	no trend
	Phosphorus	12	12	.052	no trend	.136	no trend
	Total organic carbon	12	12	.021	no trend	0	no trend
			Waconda Lake bottom-sediment cores (fig. 2*C*)				
WAC 1.3	Aluminum	12	12	.594	increasing trend	.455	increasing trend
	Arsenic	12	12	.734	increasing trend	.515	increasing trend
	Barium	12	12	.400	no trend	.303	no trend
	Beryllium	12	0	--	--	--	--
	Boron	12	2	--	--	--	--
	Cadmium	12	0	--	--	--	--
	Chromium	12	10	-.407	no trend	-.273	no trend
	Copper	12	12	-.218	no trend	-.091	no trend
	Iron	12	12	.531	no trend	.394	increasing trend
	Lead	12	11	-.050	no trend	-.061	no trend
	Magnesium	12	12	.601	increasing trend	.485	increasing trend
	Manganese	12	12	.189	no trend	.136	no trend
	Mercury	12	0	--	--	--	--
	Nickel	12	5	--	--	--	--
	Selenium	12	10	.550	no trend	.364	no trend
	Strontium	12	12	.818	increasing trend	.576	increasing trend
	Vanadium	12	12	.451	no trend	.348	no trend
	Zinc	12	12	.287	no trend	.152	no trend
	Nitrogen	12	12	.063	no trend	.030	no trend

Table 8. Results of trend tests on concentrations of selected constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Constituent	Total number of samples	Number of samples with detections	Spearman's rho (r)	Trend test at a 0.05 level of significance	Kendall's tau (τ)	Trend test at a 0.05 level of significance
		Waconda Lake bottom-sediment cores (fig. 2C)—Continued					
WAC 1.3	Phosphorus	12	12	0.161	no trend	0.121	no trend
	Total organic carbon	12	12	-.322	no trend	-.182	no trend
WAC 2.1	Aluminum	12	12	-.441	no trend	-.394	decreasing trend
	Arsenic	12	12	.154	no trend	.121	no trend
	Barium	12	12	-.472	no trend	-.288	no trend
	Beryllium	12	0	--	--	--	--
	Boron	12	4	--	--	--	--
	Cadmium	12	0	--	--	--	--
	Chromium	12	11	-.733	decreasing trend	-.606	decreasing trend
	Copper	12	12	-.604	decreasing trend	-.439	decreasing trend
	Iron	12	12	-.510	no trend	-.455	decreasing trend
	Lead	12	11	-.477	no trend	-.333	no trend
	Magnesium	12	12	-.203	no trend	-.273	no trend
	Manganese	12	12	-.112	no trend	-.030	no trend
	Mercury	12	0	--	--	--	--
	Nickel	12	8	-.714	decreasing trend	-.515	decreasing trend
	Selenium	12	12	.519	no trend	.424	increasing trend
	Strontium	12	12	.854	increasing trend	.742	increasing trend
	Vanadium	12	12	-.431	no trend	-.348	no trend
	Zinc	12	12	-.685	decreasing trend	-.515	decreasing trend
	Nitrogen	12	12	.510	no trend	.303	no trend
	Phosphorus	12	12	-.196	no trend	-.106	no trend
	Total organic carbon	12	12	-.818	decreasing trend	-.576	decreasing trend
WAC 3.1	Aluminum	12	12	.412	no trend	.333	no trend
	Arsenic	12	12	.768	increasing trend	.636	increasing trend
	Barium	12	12	.448	no trend	.273	no trend
	Beryllium	12	0	--	--	--	--
	Boron	12	8	.564	increasing trend	.409	increasing trend
	Cadmium	12	0	--	--	--	--
	Chromium	12	11	.039	no trend	-.015	no trend
	Copper	12	12	.046	no trend	-.015	no trend
	Iron	12	12	.350	no trend	.303	no trend
	Lead	12	12	.042	no trend	-.015	no trend
	Magnesium	12	12	.434	no trend	.333	no trend

Table 8. Results of trend tests on concentrations of selected constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Constituent	Total number of samples	Number of samples with detections	Spearman's rho (r)	Trend test at a 0.05 level of significance	Kendall's tau (τ)	Trend test at a 0.05 level of significance
			Waconda Lake bottom-sediment cores (fig. 2C)—Continued				
WAC 3.1	Manganese	12	12	.718	increasing trend	.591	increasing trend
	Mercury	12	0	--	--	--	--
	Nickel	12	2	--	--	--	--
	Selenium	12	11	.874	increasing trend	.727	increasing trend
	Strontium	12	12	.238	no trend	.197	no trend
	Vanadium	12	12	.656	increasing trend	.545	increasing trend
	Zinc	12	12	.196	no trend	.061	no trend
	Nitrogen	12	12	.895	increasing trend	.758	increasing trend
	Phosphorus	12	12	.860	increasing trend	.727	increasing trend
	Total organic carbon	12	12	.049	no trend	0	no trend

4.0 mg/kg (milligrams per kilogram) in sediment are a concern because of the potential for bioaccumulation in fish and wildlife (Lemly and Smith, 1987).

In Kirwin Reservoir, selenium concentrations in samples from bottom-sediment cores ranged from less than 0.3 to 2.2 mg/kg (table 11 in "Supplemental Information" section). A significant increasing trend (p=0.006) was evident in only one of the two Kirwin cores (core KIR 1.3, fig. 6). In Webster Reservoir, the selenium concentrations in bottom-sediment cores ranged from 0.3 to 4.0 mg/kg (table 11). A significant increasing trend (p=0.001 and p=0.035) occurred in both Webster bottom-sediment cores. In Waconda Lake, selenium concentrations in samples from bottom-sediment cores ranged from less than 0.4 to 3.4 mg/kg (table 11). Significant increasing trends were evident in two of the three cores (cores WAC 2.1, p=0.031, and WAC 3.1, p=0.001). Core WAC 1.3 had a p value slightly higher than the specified criteria (p=0.052).

Arsenic

Arsenic has been used in the past as a compound in pesticides and also may be the result of some industrial activities (Pais and Jones, 1997). Because arsenic is believed to be carcinogenic, the USEPA (1997b) has established a threshold-effects level (TEL) of 7.24 mg/kg and a probable-effects level (PEL) of 41.6 mg/kg.

In Kirwin Reservoir, arsenic concentrations in samples from bottom-sediment cores ranged from 4.6 to 10 mg/kg (table 11 in "Supplemental Information" section). In Webster Reservoir, arsenic concentrations in bottom-sediment cores ranged from 8.0 to 15.1 mg/kg (table 11). In Waconda Lake, arsenic concentrations in bottom-sediment cores ranged from 5.4 to 13.1 mg/kg (fig. 7, table 11). A significant increasing trend in arsenic concentrations was not evident in the Kirwin cores. There was, however, an increasing trend in the cores from Webster Reservoir (core WEB 1.2, p=0.010, and core WEB 2.4, p=0.010) and Waconda Lake (core WAC 1.3, p=0.012, and core WAC 3.1, p=0.002).

Strontium

Strontium is common in the lithosphere, and its geochemical and biochemical characteristics are similar to calcium (Pais and Jones, 1997). There are no TEL and PEL guidelines for strontium.

Strontium concentrations in core samples from Kirwin Reservoir ranged from 74 to 219 mg/kg (table 11 in "Supplemental Information" section) and showed a significant increasing trend in both cores (p=0 and p=0.017) (fig. 8). Strontium concentrations ranged from 109 to 263 mg/kg in cores WEB 1.2 and WEB 2.4 from Webster Reservoir (table 11) and showed a significant increasing trend (p=0). Strontium concentrations in Waconda cores WAC 1.3, WAC 2.1,

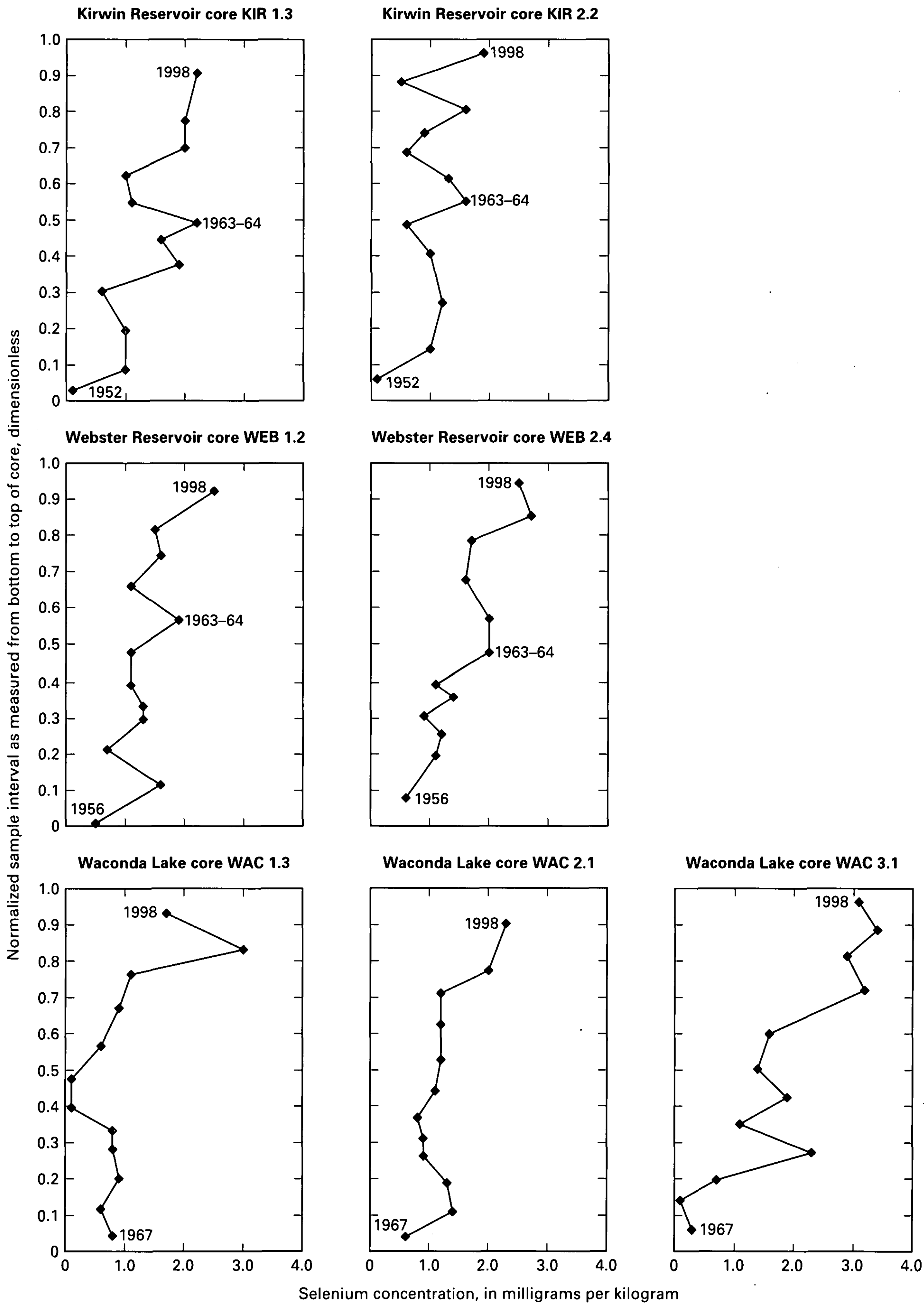


Figure 6. Depth-normalized selenium concentration profiles in selected bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake.

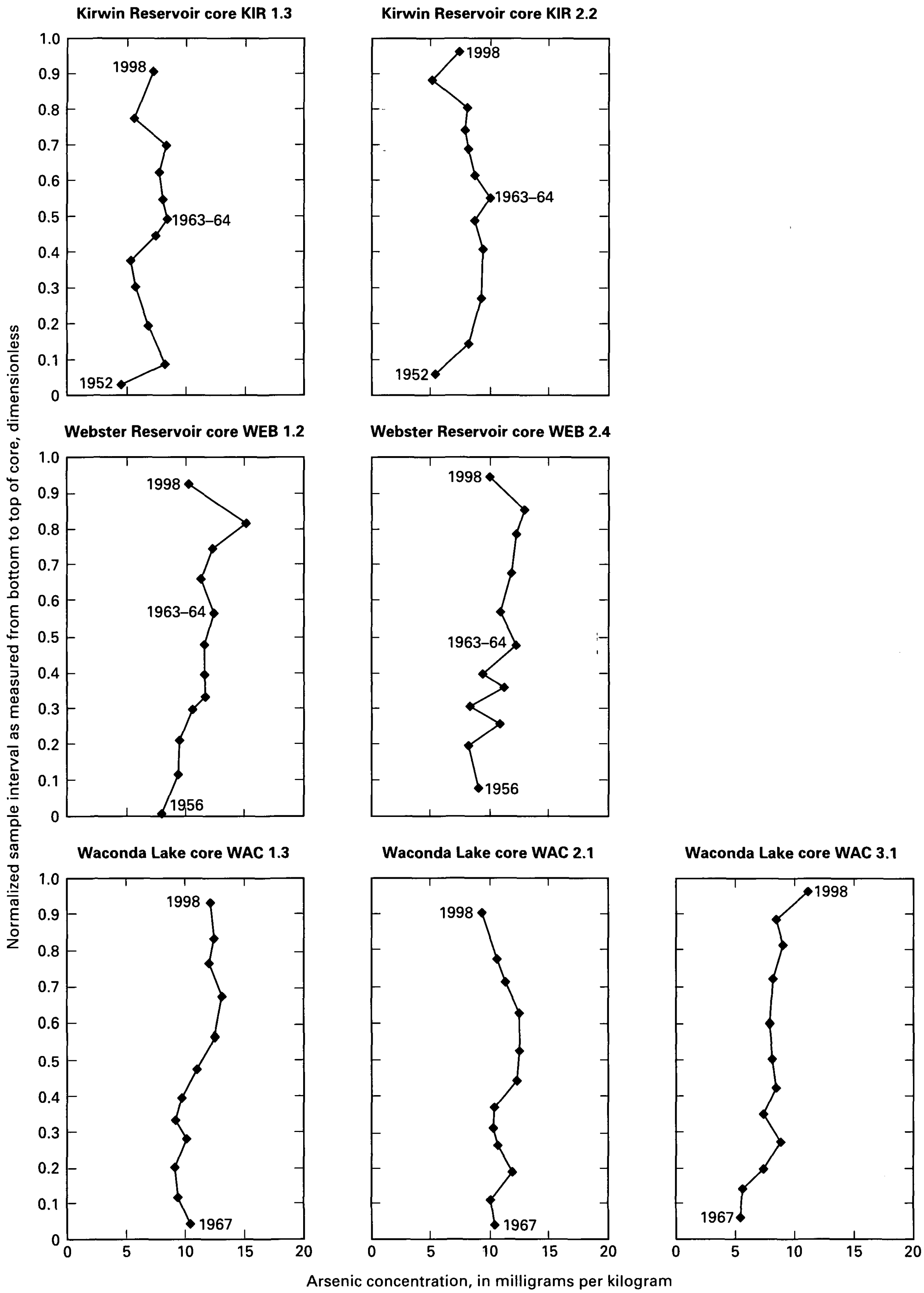


Figure 7. Depth-normalized arsenic concentration profiles in selected bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake.

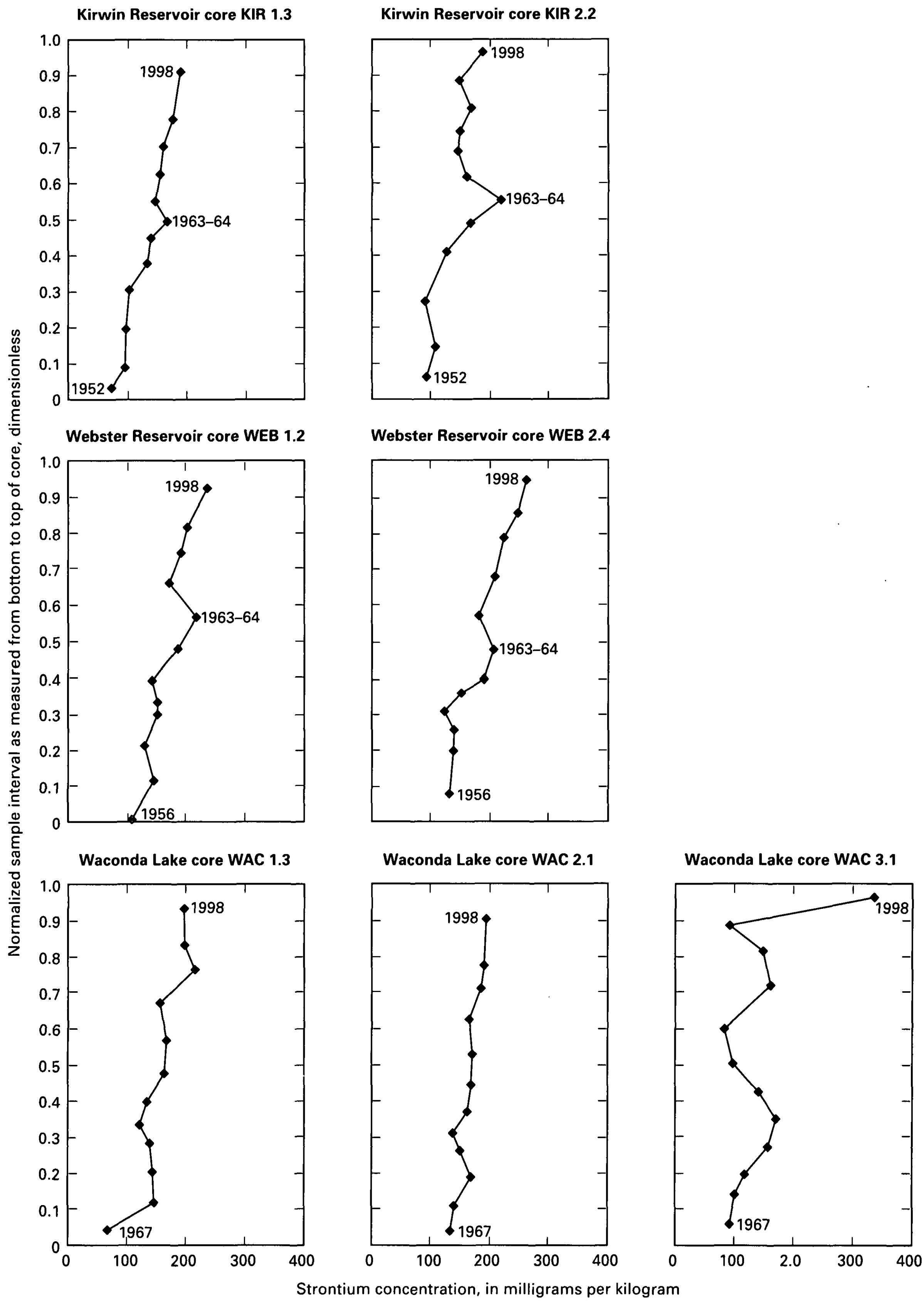


Figure 8. Depth-normalized strontium concentration profiles in selected bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake.

and WAC 3.1 ranged from 68 to 336 mg/kg (table 11). Two of the three bottom-sediment cores from Waconda Lake had significant increasing trends (core WAC 1.3, p=0.005, and core WAC 2.1, p=0.001).

Nutrients and Total Organic Carbon

Nutrients, such as nitrogen and phosphorus, are necessary for growth and reproduction of plants. In general, major sources of nutrients include fertilizer application, livestock production, and sewage-treatment plants. There are no TEL and PEL 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). There are no TEL and PEL guidelines for TOC.

The median nitrogen concentration in core samples from Kirwin Reservoir was 1,700 mg/kg, compared to 1,640 mg/kg in samples from Webster Reservoir and 2,050 mg/kg in samples from Waconda Lake. Core WAC 3.1 was the only core from the three reservoirs that showed an increasing trend with respect to nitrogen.

The median phosphorus concentration was 616 mg/kg in core samples from Kirwin Reservoir, compared to 562 and 652 mg/kg in samples from Webster Reservoir and Waconda Lake, respectively. The only reservoir with core samples showing an increasing trend in phosphorus concentration was Kirwin.

The median TOC concentration in core samples from Kirwin Reservoir was 11,600 mg/kg, compared to 12,300 mg/kg in samples from Webster Reservoir and 16,700 mg/kg in samples from Waconda Lake. None of the core samples from the three reservoirs showed an increasing trend for TOC.

Bottom-Sediment Volume and Mass in Webster Reservoir

Additional sediment cores were collected from seven sites (WEB 3 through WEB 11, fig. 2*B*) in Webster Reservoir to estimate the mass of bottom sediment. Of the three reservoirs in the Solomon River Basin, complete bathymetric data were available only for Webster Reservoir. An extensive sedimentation survey of Webster Reservoir was completed by the Bureau in 1996. This survey showed very little sediment deposition in Webster Reservoir given the size of its drainage area (Ferrari, 1997). Previous surveys by the Bureau in 1968 and 1979 verify the small accumulation of sediment. In addition, during this study, several attempts to collect sediment outside the original channel bed failed because there was no sediment or there was too little sediment for analysis, confirming findings of previous bathymetric surveys. The 1996 survey estimated that a total of 1,267 acre-ft of sediment has accumulated since dam closure in May 1956; approximately 81 percent of the sediment was deposited in the original channel bed (Ferrari, 1997). As with previous surveys, the 1996 survey showed very little sediment deposition outside of the original channel bed, except for some accumulation near the north bank due to bank erosion.

The sediment volume determined by the Bureau's 1996 sedimentation survey of Webster Reservoir was used to estimate the 1998 volume and mass of sediment for the reservoir. The Bureau's estimated annual loss in storage capacity was 31.7 acre-ft per year; therefore 31.7 acre-ft was added to the 1996 sediment volume to estimate 1997 volume, and 31.7 acre-ft was added to the 1997 volume for 1998. The final estimated sediment accumulation in the reservoir for 1998 was 1,330 acre-ft.

Bulk density, the weight per unit volume of the oven-dried bottom sediment, was calculated for all sites in Webster Reservoir using methods described by Guy (1969). Bulk density generally was higher for the out-of-channel cores; the mean out-of-channel bulk density was 91.0 lb/ft^3 (samples containing original material were not included), and the mean in-channel bulk density was 48.9 lb/ft^3. Because of the differences in bulk density, mass was calculated separately for in-channel and out-of-channel components. On the basis of the Bureau's estimate that 81 percent of sediment accumulation was in the original channel bed, 1,080 acre-ft of sediment was multiplied by the mean bulk density of all in-channel samples (sites WEB 1–5, fig. 2*B*) to estimate the in-channel sediment mass. Similarly, the remaining 253 acre-ft of sediment accumulation was multiplied by the mean out-of-channel bulk density to estimate the out-of-channel sediment mass. These two components were summed to arrive at the total mass of sediment accumulation in Webster Reservoir since dam closure in 1956 of 3,300 million lb. It is important to recognize that the core-shortening phenomenon may affect bulk-density calculations and thus the calculation for total mass. The mass calculation presented here has not been corrected for core shortening.

Mean annual sediment deposition was calculated by dividing the total mass of sediment accumulation by 42 (the number of years since dam closure). Mean annual sediment deposition was calculated as 78,600,000 lb/yr. This estimate does not reflect probable differences in sedimentation from year to year. In addition, because mean bulk density was used in the calculation, mean annual sediment deposition may be understated if the core-shortening phenomenon discussed previously was due to a loss of sediment in the core.

Selenium, Arsenic, and Strontium Loads in Webster Reservoir

To estimate the loads of selenium, arsenic, and strontium transported into Webster Reservoir, the in- and out-of-channel components were calculated separately and then summed. The mean concentration for all in-channel cores was multiplied by in-channel mass to provide an estimate of the total mass in the original channel bed. Similarly, the mean out-of-channel concentration was multiplied by the out-of-channel mass. Sample intervals that contained original channel-bed material or land-surface material were not included in the calculations. Mean annual loads of selenium, arsenic, and strontium transported into Webster Reservoir and accumulated as bottom sediment were estimated by dividing the total mass of each constituent by 42 years.

The average in-channel selenium concentration was 1.5 mg/kg. On the basis of this concentration, the estimated total in-channel selenium mass was 3,450 lb for May 1998. The average out-of-channel concentration of selenium was 0.6 mg/kg. The estimated out-of-channel mass of selenium was 601 lb. The average selenium concentration is larger for the in-channel component. Selenium is strongly sorbed to fine-grained particle sizes, such as are present in the original channel. The original channel bed receives fine-grained sediment from channel erosion, irrigation runoff, and runoff due to floods. The out-of-channel component is mainly the recipient of sediment from bank erosion, which would naturally contain larger grain sizes and thus contain smaller selenium concentrations. The total estimated mass of selenium in Webster Reservoir was 4,050 lb in May 1998. The annual load of selenium was estimated as 96.4 lb.

The average arsenic concentration for in-channel coring sites was 9.3 mg/kg; therefore, the estimated total in-channel mass of arsenic was 21,400 lb for May 1998. The average out-of-channel arsenic concentration was 4.6 mg/kg; therefore, the estimated total out-of-channel mass of arsenic was 4,610 lb for May 1998. The average in-channel arsenic concentration is more than twice the average out-of-channel arsenic concentration. This probably is due to the larger percentage of sand in the out-of-channel cores and the fact that arsenic is associated with smaller grain sizes that occur in the channel. This stresses the importance of calculating in- and out-of-channel components separately and determining the percentage of silt and clay. The total mass of arsenic in Webster Reservoir was estimated as 26,000 lb. The annual load of arsenic was calculated as 619 lb.

The average in-channel strontium concentration from Webster Reservoir was 159 mg/kg. Therefore, the estimated total in-channel mass of strontium was 366,000 lb for May 1998. The average out-of-channel strontium concentration was 186 mg/kg. On the basis of this concentration, the estimated total out-of-channel mass of strontium in Webster Reservoir was 186,000 lb. The total estimated strontium mass in Webster Reservoir was 552,000 lb. The annual load of strontium into the reservoir was estimated as 13,100 lb. Unlike selenium and arsenic, average strontium concentrations are larger outside of the original channel, indicating that strontium is not as strongly associated with the smaller grain sizes within the channel. The larger out-of-channel strontium concentrations may be due to replacement of calcium in common rock minerals associated with larger grain sizes

COMPARISON OF DEPOSITIONAL TRENDS TO IRRIGATION AND CONSTITUENT LOADS

The possible effect of irrigation on selenium, arsenic, and strontium concentrations in bottom sediment was assessed first by comparing the annual change in irrigated acres in Kirwin and Webster Irrigation Districts (fig. 9) to selenium, arsenic, and strontium concentration profiles in cores from Waconda Lake (figs. 6–8), which receives water from these Bureau-operated irrigation districts. The amount of land irrigated with water from Kirwin and Webster Irrigation Districts, which depend on available water supply, has not consistently increased through the

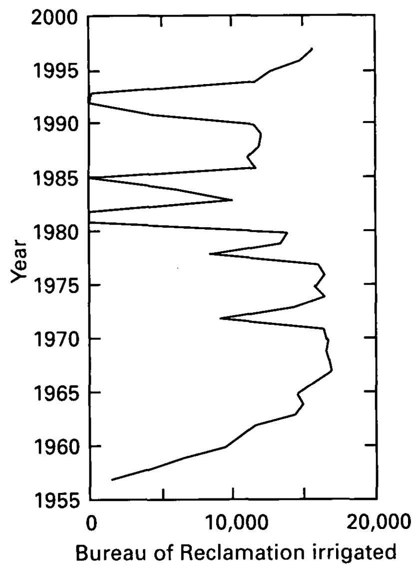


Figure 9. Irrigated acres in Kirwin and Webster Irrigation Districts, 1957–97.

years. The concentrations of selenium, arsenic, and strontium in reservoir bottom sediment, however, have increased since completion of Waconda Lake in 1967. Therefore, constituent concentrations in Waconda Lake bottom sediment cannot be explained entirely by Bureau irrigation.

To further assess the effect of Bureau irrigation, the mean concentrations of selenium, arsenic, and strontium in bottom sediment from Waconda Lake, which receives inflow from both Bureau- and non-Bureau-irrigated areas, were compared to mean concentrations in bottom sediment from Kirwin and Webster Reservoirs, which do not receive inflow from Bureau-irrigated areas. When comparing bottom-sediment constituent concentrations in Kirwin and Webster Reservoirs to Waconda Lake, it is important to consider the difference in geology between the reservoirs. The geology changes from primarily Quaternary and Tertiary strata upstream from Kirwin and Webster Reservoirs to primarily Cretaceous strata downstream from these two reservoirs (fig. 1). In addition, the only outcrop of Pierre Shale, a known source for selenium, in the Solomon River Basin is in a small area upstream from Webster Reservoir. Another important consideration in comparing bottom-sediment concentrations is the difference in the source of irrigation water, which is ground water upstream from Kirwin and Webster Reservoirs and surface water upstream from Waconda Lake.

The median selenium concentration in core samples from Waconda Lake is less than the median concentration in samples from Kirwin Reservoir and equal to the median concentration in samples from Webster Reservoir (table 7). The median arsenic and strontium concentrations in core samples from Waconda Lake are larger than the median arsenic and strontium concentrations in samples from Kirwin Reservoir and smaller than the median concentrations in samples from Webster Reservoir. Because constituent concentrations in bottom sediment from Waconda Lake are not generally larger or smaller than constituent concentrations in bottom sediment from Kirwin and Webster Reservoirs, Bureau irrigation, which occurs upstream from Waconda Lake, does not entirely explain increasing trends in selenium, arsenic, and strontium concentrations in bottom sediment from Waconda Lake.

The effect of total (Bureau and non-Bureau) irrigation on selenium, arsenic, and strontium concentrations was assessed by comparing background constituent concentrations (before 1963–64) to constituent concentrations after 1964 (post background) for Kirwin and Webster Reservoirs. Background concentrations for selenium, arsenic, and strontium were represented in bottom-sediment samples from Kirwin and Webster Reservoirs, which were constructed prior to the major period of irrigation development in the Solomon River Basin (early to mid-1960's). Background concentrations could not be calculated for Waconda Lake because of its 1967 completion date. ^{137}Cs results indicated sample intervals from Kirwin and Webster sediment cores that were deposited prior to 1963–64 and thus are representative of background conditions.

Mean post-background selenium, arsenic, and strontium concentrations in core samples from Kirwin and Webster Reservoirs were larger than background concentrations in those reservoirs (fig. 10*A*, 10*B*, and 10*C*). Because there are no Bureau-irrigated acres upstream from Kirwin and Webster Reservoirs, Bureau irrigation is not affecting the concentrations of selenium, arsenic, and strontium in bottom sediment from these reservoirs. However, other irrigation (non-Bureau) activities in the basin may be contributing to the trend to larger post-background constituent concentrations. Without sufficient historical irrigation data in the Solomon River Basin, this is difficult to verify.

Although selenium, arsenic, and strontium concentrations have increased in reservoir-bottom sedi-

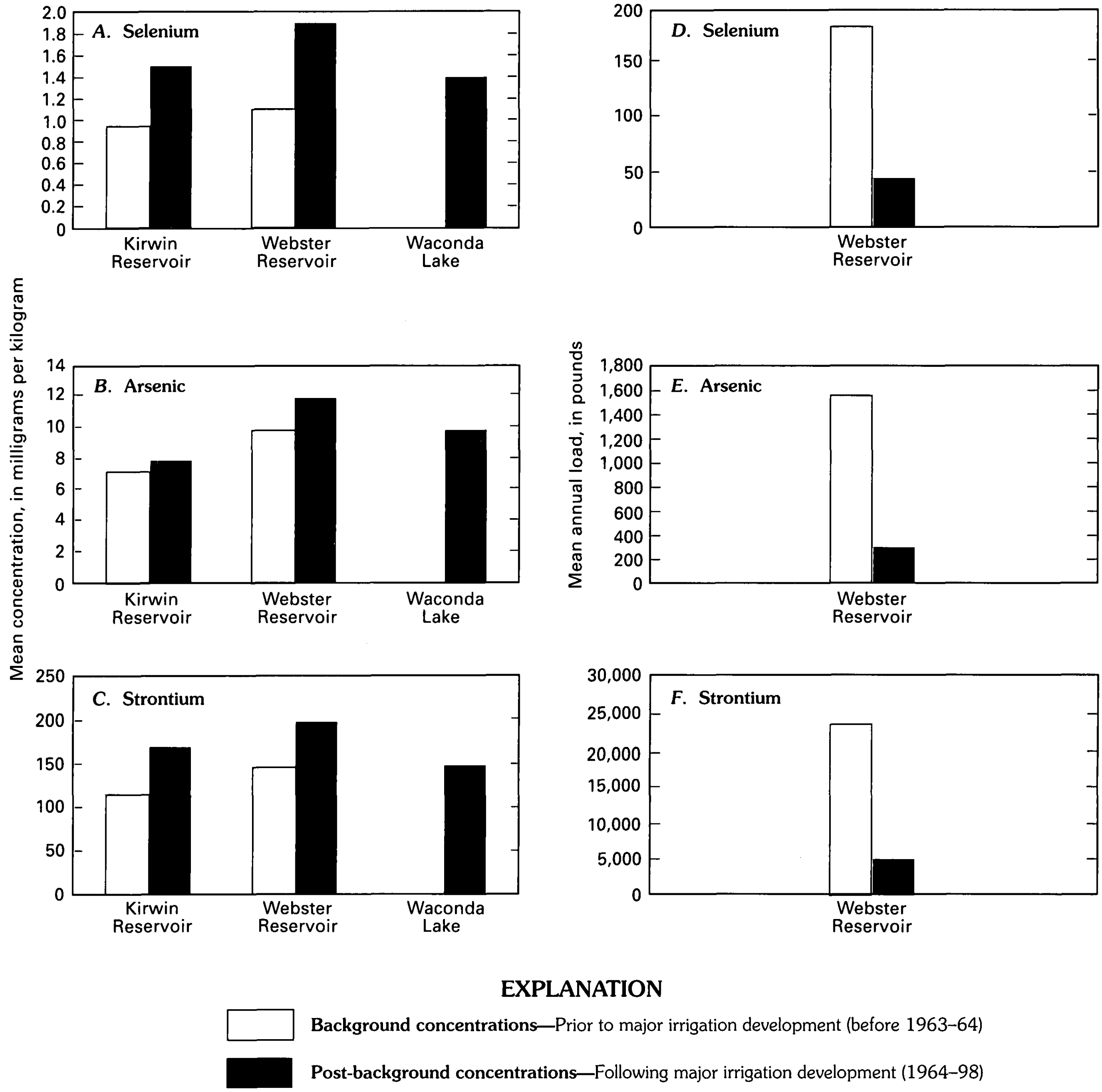


Figure 10. Background and post-background *(A)* selenium, *(B)* arsenic, and *(C)* strontium concentrations in bottom sediment from Kirwin Reservoir, Webster Reservoir, and Waconda Lake and estimated background and post-background *(D)* selenium, *(E)* arsenic, *(F)* strontium annual loads in Webster Reservoir.

ment in the Solomon River Basin, the total mass of selenium, arsenic, and strontium transported per year (annual load) to the reservoirs is also important to consider. Background and post-background mean annual loads were calculated for Webster Reservoir (fig. 10*D–F*). The post-background annual loads for selenium, arsenic, and strontium are smaller than background annual loads. In contrast, constituent concentrations have increased with time. Annual load calculations are affected by bulk-density calculations, which may be affected by the core-shortening phenomenon. It is not known whether most of the core shortening occurs in the shallow or the deep layers of a core or whether the shortening phenonmenon is due to the loss of sediment. If there is a loss of sediment in the shallow layers, mass and annual load calculations would be positively biased towards post-background annual loads (given the fact that bulk density increases with depth).

Differences in constituent loads with time may be due to several factors, including changes in streamflow, precipitation, land use, source and type of irrigation, and land-management practices. Background and post-background mean annual streamflow was examined to determine how much of the difference in background and post-background loads were due to changes in streamflow (fig. 11). For Webster Reservoir, decreases in mean annual streamflow and selenium, arsenic, and strontium loads are in agreement. However, the relative difference in background compared to post-background constituent loads is greater than the difference in background compared to post-background mean annual streamflow. Therefore, the larger constituent loads after 1964 are not completely due to changes in streamflow. Although consitutent loads were not calculated for Kirwin Reservoir and Waconda Lake, these reservoirs also had larger mean annual streamflows prior to 1964, and it is reasonable to assume that constituent loads also would be larger prior to 1964.

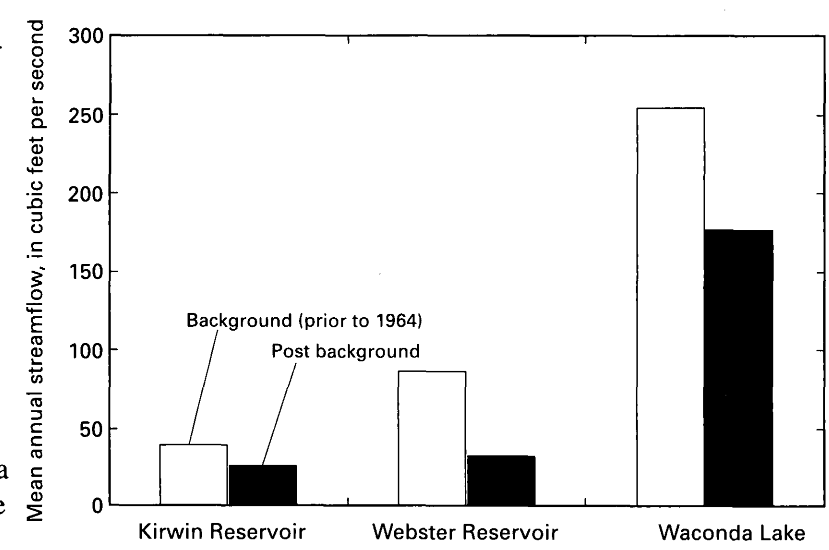


Figure 11. Background and post-background mean annual streamflow into Kirwin Reservoir, Webster Reservoir, and Waconda Lake.

SUMMARY

The Solomon River Basin extends across parts of 17 counties in north-central Kansas and drains about 6,840 mi^2 of mainly agricultural land. Sediment quality of the three reservoirs in the basin is a concern because sediment quality reflects the quality of the overlying water. The Solomon River Basin is underlain by marine strata, and irrigation return flow in areas underlain by these rocks may contain concentrations of selenium that, when introduced into a lake, reservoir, or wetland area, may bioaccumulate to levels toxic to aquatic organisms, predatory species, or potentially could affect human health through consumption of contaminated organisms.

Public Law 99–294, National Environmental Policy Act (NEPA) of 1986, requires that the Bureau of Reclamation (Bureau), U.S. Department of the Interior, investigate soil characteristics that may result in toxic or hazardous irrigation return flows. The Bureau, in response, has begun a Resource Management Assessment (RMA) of the Solomon River Basin to provide the necessary data for NEPA compliance before renewal of long-term water-service contracts with irrigation districts in the basin.

The study described in this report was begun in the spring of 1998 by the U.S. Geological Survey in cooperation with the Bureau to determine if irrigation by the Bureau was increasing selenium concentrations in the basin. The primary purpose of this report was to document baseline conditions and trends in deposition of selenium and other constituents in three reservoirs of the Solomon River Basin.

Approximately 3 to 4 percent of the Solomon River Basin is irrigated. Water for irrigation in the basin comes primarily from ground water upstream from Kirwin and Webster Reservoirs, and primarily from surface water downstream from Kirwin and Webster Reservoirs. On the basis of 1995 irrigation data, approximately 48 percent of the total irrigated acres downstream from Kirwin, Webster, and Waconda are supplied water from Bureau-operated irrigation districts. However, no Bureau irrigation water is used upstream from Kirwin and Webster Reservoirs, making Bureau-irrigated acres only 12.1 percent of the total number of irrigated acres in the Solomon River Basin.

Reservoir bottom-sediment cores collected during this study were analyzed for selected physical properties, total recoverable metals, nutrients, ^{137}Cs, and total organic carbon. The cores collected from within the original river channel and near the dam of each reservoir generally had a percentage of silt and clay of more than 99 percent. Bulk-density values were generally larger in the deeper samples from the cores than in the shallower samples. Percentage of moisture was generally larger in the shallower samples than in the deeper samples from the cores. ^{137}Cs, a by-product of nuclear weapons testing, was used to help date the cores and to determine if the sediment had been disturbed. Kirwin and Webster Reservoirs were built before the 1963–64 peak in atmospheric ^{137}Cs concentrations, making it possible to assign a 1963–64 date to the cores in these two reservoirs. The ^{137}Cs concentration following the peak shows a smooth decline in concentration for all cores, which would indicate that the sediment has been relatively undisturbed by biological activity, inflows or outflows, human activity, or wind-induced currents.

Spearman's rho and Kendall's tau were calculated to determine if there were significant increasing trends in sediment constituent concentrations for the cores collected near the dam of each reservoir. Of the total recoverable metals analyzed in core samples from the three reservoirs, only three metals (selenium, arsenic, and strontium) showed an increasing trend in samples from at least two of the three reservoirs. None of the samples from reservoir-bottom sediment had increasing trends of nitrogen, phosphorus, or total organic carbon, except for the increase in phosphorus in cores from Kirwin Reservoir.

Additional samples were collected from Webster Reservoir to determine bottom-sediment thickness, volume, and mass. Using the Bureau's 1996 sedimentation survey and information on the length of cores collected for this study, the estimated volume of sediment accumulated in Webster Reservoir was 1,330 acre-ft. The total mass of sediment accumulation in Webster Reservoir since dam closure in 1956 was calculated as 3,300 million lb.

To further analyze the effect of selenium, arsenic, and strontium on reservoir-bottom sediment, total mass and annual loads of each constituent transported into Webster Reservoir were calculated. The total estimated mass of selenium in Webster Reservoir was 4,050 lb. This corresponds to an annual load of about 96.4 lb. The total estimated mass of arsenic in Webster Reservoir was 26,000 lb. The annual load of arsenic was calculated as 619 lb. The total estimated strontium mass in Webster Reservoir was estimated as 552,000 lb, and the annual load transported into the reservoir was about 13,100 lb.

The possible effect of irrigation on selenium, arsenic, and strontium concentrations was assessed in several ways. First, the annual change in irrigated acres in Kirwin and Webster Irrigation Districts was compared to selenium, arsenic, and strontium concentration profiles in cores from Waconda Lake which receives water from these Bureau-operated irrigation districts. There appears to be no relation. Next, the median concentrations of selenium, arsenic, and strontium in bottom sediment from Waconda Lake were compared to mean concentrations in bottom sediment from Kirwin and Webster Reservoirs. Concentrations were not significantly larger in Waconda Lake and thus increases in median selenium, arsenic, and strontium concentrations in reservoir-bottom sediment can not be totally explained by Bureau irrigation.

Finally, the effect of total (Bureau and non-Bureau) irrigation on selenium, arsenic, and strontium concentrations was assessed by comparing background (before 1963–64) constituent concentrations to post-background (after 1964) constituent concentrations for sediment cores from Kirwin and Webster Reservoirs. Mean post-background selenium concentrations in cores from Kirwin and Webster Reservoirs were larger than background concentrations in cores from those reservoirs. The same is true of both arsenic and strontium concentrations. Because there are no Bureau-irrigated acres upstream from Kirwin and Webster Reservoirs, it is clear that Bureau irrigation is not affecting the concentrations of selenium, arsenic, and strontium in bottom sediments from these reservoirs. However, other irrigation activities in the basin may be causing these trends. Without sufficient historical irrigation data for the Solomon River Basin, this is difficult to verify.

Background and post-background annual loads were calculated for selenium, arsenic, and strontium in bottom sediment from Webster Reservoir. Background selenium, arsenic, and strontium annual loads were significantly larger than post-background loads. An examination of background and post-background mean annual streamflows indicated that streamflow was not the only factor affecting differences in constituent loads. Differences in constituent loads with time may be due to several other factors including changes in precipitation, land use, source and type of irrigation, and land-management practices.

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SUPPLEMENTAL INFORMATION

Table 9. Core length, estimated sediment thickness, and recovery percentage for multiple cores from sediment coring sites in Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998

[core length and sediment thickness have not been corrected for original material thickness or core shortening. ft, feet; --, not determined]

Core-sample identification	Core length (ft)	Estimated sediment thickness (ft)	Recovery percentage
Kirwin Reservoir bottom-sediment cores (fig. 2*A*)			
KIR 1.1	7.0	10.8	65
KIR 1.2	6.4	9.5	68
KIR 1.3	8.0	11.3	71
KIR 1.4	7.9	11.3	70
KIR 2.1	3.2	6.9	46
KIR 2.2	4.3	7.4	57
KIR 2.3	5.3	7.4	71
KIR 2.4	4.7	7.4	64
Webster Reservoir bottom-sediment cores (fig. 2*B*)			
WEB 1.1	7.0	9.5	74
WEB 1.2	7.1	9.7	73
WEB 1.3	7.0	9.7	72
WEB 2.1	7.2	11.0	65
WEB 2.2	6.9	9.7	71
WEB 2.3	7.3	12.0	61
WEB 2.4	7.3	12.0	61
WEB 3.1	2.8	3.7	76
WEB 3.2	2.8	3.1	90
WEB 3.3	2.8	3.7	74
WEB 3.4	2.5	3.5	71
WEB 4.1	2.9	4.5	64
WEB 4.2	2.9	5.0	58
WEB 5.1	4.2	4.0	105
WEB 5.2	4.4	6.0	74
WEB 5.3	4.0	4.0	100
WEB 6.1	2.8	3.6	76
WEB 6.2	3.0	3.6	83
WEB 6.3	3.0	3.6	83
Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued			
WEB 7.1	1.8	1.0	180
WEB 7.2	1.8	1.0	175
WEB 8.1	no sample	.1	--
WEB 8.2	no sample	0	--
WEB 8.3	no sample	0	--
WEB 9.1	no sample	--	--
WEB 9.2	no sample	--	--
WEB 9.3	no sample	--	--
WEB 10.1	1.6	4.8	33
WEB 10.2	2.5	4.8	52
WEB 10.3	2.5	4.8	52
WEB 11.1	1.4	3.4	41
WEB 11.2	1.4	3.1	45
WEB 11.3	1.4	3.3	43
Waconda Lake bottom-sediment cores (fig. 2*C*)			
WAC 1.1	6.1	16.0	38
WAC 1.2	6.4	17.0	38
WAC 1.3	6.8	17.3	39
WAC 1.4	6.0	17.3	35
WAC 2.1	7.3	15.0	48
WAC 2.2	7.3	15.0	48
WAC 3.1	7.8	12.2	64
WAC 3.2	7.0	12.2	57
WAC 3.3	7.0	12.7	55
WAC 3.4	7.3	12.0	61

Table 10. Results of analyses of selected physical properties for bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake

[ft, feet; lb/ft^3, pounds per cubic foot]

Core-sample identification	Sample interval (ft)	Percentage of silt and clay	Percentage of sand	Bulk density (lb/ft^3)	Percentage of moisture
		Kirwin Reservoir bottom-sediment cores (fig. 2*A*)			
KIR 1.4	6.5–7.9 (top)	98.9	1.1	27.5	65.5
	5.9–6.5	97.7	2.3	38.1	60.0
	5.5–5.9	98.8	1.2	38.2	58.5
	4.7–5.5	99.7	.3	34.7	61.4
	4.2–4.7	98.8	1.2	44.2	54.2
	3.9–4.2	99.7	.3	41.7	56.1
	3.5–3.9	100.0	0	42.6	54.3
	2.7–3.5	99.9	.1	45.4	52.0
	2.2–2.7	99.8	.2	44.2	52.6
	0.92–2.2	100.0	0	44.5	46.9
	0.46–0.92	100.0	0	43.5	49.6
	0–0.46 (bottom)	99.9	.1	42.7	53.0
KIR 2.1	2.7–3.2 (top)	99.4	.6	30.9	63.1
	2.5–2.7	99.8	.2	37.0	57.3
	2.2–2.5	98.9	1.1	34.1	58.8
	1.9–2.2	98.9	1.1	33.0	60.3
	1.5–1.9	99.6	.4	35.8	59.3
	1.3–1.5	99.7	.3	40.2	54.5
	1.0–1.3	99.9	.1	35.4	57.6
	0.5–1.0	99.9	.1	42.8	54.1
	0–0.5 (bottom)	99.3	.7	50.4	46.8
		Webster Reservoir bottom-sediment cores (fig. 2*B*)			
WEB 1.1	5.6–6.7 (top)	99.2	.8	27.3	63.7
	5.2–5.6	99.2	.8	31.8	61.7
	4.6–5.2	99.4	.6	35.1	57.1
	3.9–4.6	100.0	0	40.9	57.0
	3.2–3.9	99.8	.2	32.0	61.9
	2.7–3.2	100.0	0	35.4	57.0
	2.2–2.7	100.0	0	31.7	58.0
	1.9–2.2	100.0	0	34.2	56.1
	1.7–1.9	100.0	0	33.9	57.8
	0.71–1.7	99.8	.2	38.0	54.3
	0.42–0.71	100.0	0	35.3	56.3
	0.21–0.42 (bottom)	99.9	.1	48.6	46.6
WEB 2.1	6.7–7.2 (top)	98.9	1.1	21.1	72.9
	6.0–6.7	99.3	.7	29.4	66.6

Table 10. Results of analyses of selected physical properties for bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake—Continued

Core-sample identification	Sample interval (ft)	Percentage of silt and clay	Percentage of sand	Bulk density (lb/ft^3)	Percentage of moisture
	Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued				
WEB 2.1	5.5–6.0	99.8	0.2	25.6	65.6
	4.5–5.5	99.8	.2	35.0	61.6
	4.2–4.5	100.0	0	34.1	60.9
	3.2–4.2	99.9	.1	37.5	60.4
	3.0–3.2	100.0	0	37.5	55.9
	2.8–3.0	99.9	.1	36.0	63.8
	2.2–2.8	100.0	0	45.4	53.6
	2.0–2.2	100.0	0	35.1	61.8
	1.4–2.0	100.0	0	39.8	55.3
	0–1.4 (bottom)	100.0	0	41.1	56.2
WEB 3.3	1.8–2.8 (top)	99.2	.8	25.1	67.8
	1.1–1.8	99.8	.2	33.7	62.1
	0.8–1.1	83.9	16.1	48.0	50.8
	0.3–0.8	41.8	58.2	101.9	20.6
	0–0.3* (bottom)	4.0	96.0	115.0	13.9
WEB 4.1	2.7–2.9 (top)	10.2	89.8	92.7	10.2
	2.0–2.7	3.9	96.1	120.2	10.6
	1.2–2.0	1.0	99.0	141.8	15.3
	0.6–1.2	1.9	98.1	129.2	14.3
	0–0.6* (bottom)	33.0	67.0	95.2	19.6
WEB 5.2	3.5–4.4 (top)	99.5	.5	75.9	44.3
	2.5–3.5	88.7	11.3	63.5	45.6
	1.4–2.5	100.0	0	51.7	53.8
	0.5–1.4	100.0	0	43.7	55.8
	0–0.5 (bottom)	100.0	0	40.6	56.5
WEB 6.1	2.2–2.8 (top)	6.9	93.1	133.3	15.0
	1.7–2.2	4.6	95.4	125.2	15.1
	1.2–1.7	5.8	94.2	121.6	16.1
	0.6–1.2	21.3	78.7	110.6	19.0
	0–0.6 (bottom)	21.9	78.1	97.1	17.8
WEB 7.2	1.2–1.8 (top)	98.6	1.4	46.0	42.9
	0.8–1.2	98.4	1.6	60.7	33.7
	0.3–0.8	95.0	5.0	63.8	33.6
	0.2–0.3	26.9	73.1	82.1	28.2
	0–0.2 (bottom)	93.5	6.5	72.8	26.9
WEB 10.1	1.0–1.6 (top)	32.4	67.6	93.1	23.7

Table 10. Results of analyses of selected physical properties for bottom-sediment cores collected in May 1998 from Kirwin Reservoir, Webster Reservoir, and Waconda Lake—Continued

Core-sample identification	Sample interval (ft)	Percentage of silt and clay	Percentage of sand	Bulk density (lb/ft^3)	Percentage of moisture
	Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued				
WEB 10.1	0.5–1.0	46.8	53.2	94.8	23.7
	0–0.5 (bottom)	57.1	42.9	96.1	22.6
WEB 11.3	0.8–1.4 (top)	70.7	29.3	76.3	26.9
	0–0.8* (bottom)	89.4	10.6	75.7	27.7
	Waconda Lake bottom-sediment cores (fig. 2*C*)				
WAC 1.1	5.8–6.1 (top)	99.8	.2	27.3	62.4
	5.4–5.8	99.8	.2	29.8	62.5
	4.9–5.4	99.8	.2	27.1	63.4
	4.1–4.9	99.9	.1	26.8	65.5
	3.4–4.1	99.8	.2	29.3	62.7
	2.9–3.5	99.9	.1	27.7	64.3
	2.4–2.9	99.9	.1	29.7	65.8
	2.1–2.4	99.8	.2	29.9	60.7
	1.7–2.1	99.9	.1	32.0	59.9
	1.0–1.7	99.8	.2	41.4	53.6
	0.71–1.0	99.8	.2	42.5	52.9
	0–0.71 (bottom)	99.1	.9	47.0	45.1
WAC 3.2	6.4–7.0 (top)	99.9	0.1	21.6	73.1
	5.8–6.4	99.9	.1	25.0	68.6
	5.1–5.8	99.8	.2	29.2	67.0
	4.7–5.1	100.0	0	27.8	67.5
	4.1–4.7	100.0	0	22.0	67.7
	3.6–4.1	99.9	.1	30.0	66.9
	3.0–3.6	99.9	.1	33.6	63.5
	2.4–3.0	100.0	0	28.9	67.2
	1.8–2.4	99.9	.1	22.0	64.5
	1.2–1.8	99.9	.1	35.9	59.3
	0.92–1.2	99.9	.1	30.1	57.3
	0–0.92 (bottom)	100.0	0	43.7	46.3

*Sample intervals containing original channel-bed or soil-surface material.

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998

[mg/kg, milligrams per kilogram; <, less than; --, not determined]

Core-sample identification	Sample interval as measured from bottom to top of core (feet)	Aluminum (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Iron (mg/kg)
Kirwin Reservoir bottom-sediment cores (fig. 2*A*)										
KIR 1.3	7.54–8.00	33,200	7.3	294	<2.7	26	<2.7	13	20	23,700
	7.08–7.54	32,200	5.7	279	<2.2	25	<2.2	13	21	23,500
	5.83–7.08	34,100	8.4	284	<1.9	27	<1.9	15	21	24,000
	5.33–5.83	33,500	7.8	292	<2.5	28	<2.4	13	21	24,100
	4.67–5.33	36,900	8.1	283	<2.1	30	<2.1	16	21	24,700
	4.21–4.67	50,300	8.5	335	<2.6	37	<2.6	22	27	31,400
	3.92–4.21	29,700	7.5	305	<2.2	18	<2.2	10	25	25,700
	3.33–3.92	31,700	5.4	313	<2.4	<19	<2.4	12	25	27,300
	2.71–3.33	32,600	5.8	307	2.0	19	<1.9	13	25	27,000
	2.12–2.71	31,400	6.9	301	<2.6	<21	<2.6	15	25	26,800
	1.50–2.12	31,800	8.3	327	<2.4	<19	<2.4	13	27	27,800
	0–1.50	13,500	4.6	255	<2.3	<18	<2.3	9	19	14,200
KIR 2.2	3.75–4.25	35,300	7.4	283	<2.5	21	<2.5	17	20	21,600
	3.54–3.75	18,500	5.1	216	<1.9	<15	<1.9	13	17	14,900
	2.67–3.54	43,400	8.1	326	<2.7	28	<2.7	33	22	24,100
	2.37–2.67	50,900	7.9	333	<2.2	31	<2.2	20	22	22,800
	2.00–2.37	38,600	8.2	294	<2.3	27	<2.3	18	22	25,300
	1.83–2.00	35,800	8.7	287	<2.0	26	3.7	16	21	23,800
	1.46–1.83	39,600	10	311	<2.3	27	2.7	20	27	27,900
	1.21–1.46	47,700	8.7	336	2.4	35	<2.1	25	28	31,600
	1.00–1.21	43,000	9.4	310	<2.3	32	<2.3	21	24	28,400
	0.67–1.00	54,300	9.3	337	2.4	36	2.1	27	28	33,700
	0.33–0.67	49,900	8.2	362	2.5	33	<1.8	25	28	33,900
	0–0.33	34,900	5.4	264	1.8	24	<1.6	17	20	24,600
Webster Reservoir bottom-sediment cores (fig. 2*B*)										
WEB 1.2	6.45–6.66	18,300	10.3	224	<2.6	<20	<2.6	<5	20	16,900
	6.08–6.45	20,900	15.1	226	<2.5	<20	<2.5	6	20	18,300
	5.08–6.08	28,900	12.3	245	3.9	20	<2.4	8	22	22,500
	4.87–5.08	41,100	11.3	274	4.2	27	<2.2	18	25	27,000
	4.58–4.87	44,500	12.4	317	4.7	31	<2.5	17	25	27,600
	4.00–4.58	49,800	11.6	309	4.8	35	<2.4	22	29	30,900
	3.41–4.00	48,100	11.6	324	4.6	31	<2.2	21	27	31,900
	2.75–3.41	50,600	11.7	322	4.8	33	<2.5	22	27	32,100
	2.08–2.75	54,200	10.6	333	4.4	37	<2.0	26	28	33,100
	1.54–2.08	45,800	9.5	301	4.1	28	<1.9	21	27	30,500
	1.08–1.54	46,200	9.4	297	4.1	27	2.1	20	27	30,800
	0–1.08	34,200	8.0	244	2.9	18	<1.5	13	19	20,600
WEB 2.4	6.20–7.33	23,300	10	235	<3.1	<24	<3.0	<6	21	19,200
	5.58–6.20	20,700	12.9	226	<2.5	<20	<2.5	<5	20	18,400

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Sample interval as measured from bottom to top of core (feet)	Aluminum (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Iron (mg/kg)
Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued										
WEB 2.4	5.33–5.58	24,800	12.2	258	<2.6	<21	<2.6	5	22	21,300
	4.83–5.33	27,000	11.8	259	<2.6	<21	<2.6	7	21	21,900
	4.58–4.83	31,100	10.9	272	<2.3	<19	<2.3	13	26	24,500
	4.29–4.58	25,100	12.2	281	<2.2	<18	<2.3	7	25	21,700
	3.41–4.29	34,900	9.4	281	<2.0	23	<2.0	14	28	26,400
	2.91–3.41	26,600	11.2	295	<2.5	<20	<2.5	8	24	23,500
	1.83–2.91	30,000	8.3	302	<2.1	18	<2.1	13	26	25,200
	1.33–1.83	31,400	10.8	304	<2.3	21	<2.3	13	26	26,000
	0.83–1.33	28,600	8.2	299	<2.1	<17	<2.1	11	26	24,400
	0–0.83	31,800	9.0	289	<2.0	17	<1.9	13	25	25,900
WEB 3.3	2.46–2.75	--	9.2	--	--	--	--	--	--	--
	2.00–2.46	--	10.2	--	--	--	--	--	--	--
	1.62–2.00	--	9.7	--	--	--	--	--	--	--
	1.00–1.62	--	2.4	--	--	--	--	--	--	--
	0–1.00	--	.8	--	--	--	--	--	--	--
WEB 4.1	2.3–2.9	--	2.2	--	--	--	--	--	--	--
	1.6–2.3	--	1.5	--	--	--	--	--	--	--
	0.9–1.6	--	.9	--	--	--	--	--	--	--
	0.2–0.9	--	1.1	--	--	--	--	--	--	--
	0–0.2	--	2.9	--	--	--	--	--	--	--
WEB 5.2	3.9–4.4	--	8.2	--	--	--	--	--	--	--
	3.0–3.9	--	9.9	--	--	--	--	--	--	--
	1.9–3.0	--	10.2	--	--	--	--	--	--	--
	0.9–1.9	--	10.2	--	--	--	--	--	--	--
	0–0.9	--	8.8	--	--	--	--	--	--	--
WEB 6.1	2.2–2.8	--	1.9	--	--	--	--	--	--	--
	1.6–2.2	--	1.3	--	--	--	--	--	--	--
	1.1–1.6	--	1.4	--	--	--	--	--	--	--
	0.6–1.1	--	2.6	--	--	--	--	--	--	--
	0–0.6	--	1.9	--	--	--	--	--	--	--
WEB 7.2	1.6–1.8	--	7.5	--	--	--	--	--	--	--
	1.5–1.6	--	9.3	--	--	--	--	--	--	--
	1.0–1.5	--	9.2	--	--	--	--	--	--	--
	0.6–1.0	--	8.5	--	--	--	--	--	--	--
	0–0.6	--	2.7	--	--	--	--	--	--	--
WEB 10.1	0–1.6	--	4.1	--	--	--	--	--	--	--
WEB 11.3	0–1.4	--	3.0	--	--	--	--	--	--	--

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Sample interval as measured from bottom to top of core (feet)	Aluminum (mg/kg)	Arsenic (mg/kg)	Barium (mg/kg)	Beryllium (mg/kg)	Boron (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Iron (mg/kg)
				Waconda Lake bottom-sediment cores (fig. 2*C*)						
WAC 1.3	6.17–6.75	29,300	12.1	276	<3.5	<28	<3.5	<7	23	25,100
	5.75–6.17	27,800	12.4	296	<3.7	47	<3.7	10	22	23,800
	5.04–5.75	25,800	12.0	272	<3.3	<27	<3.3	<7	22	23,700
	4.67–5.04	30,300	13.1	280	<3.8	<30	<3.7	15	25	26,500
	4.33–4.67	25,500	12.5	279	<2.8	<22	<2.8	10	25	24,100
	3.83–4.33	27,500	11.0	275	<3.2	<26	<3.2	13	25	24,900
	3.25–3.83	26,400	9.7	270	<3.0	<24	<3.0	14	24	24,000
	2.62–3.25	25,700	9.2	271	<2.6	<21	<2.6	13	23	23,000
	1.83–2.62	31,700	10.1	297	<2.9	<23	<2.9	17	25	27,100
	1.37–1.83	24,400	9.1	276	<2.5	<20	<2.4	10	23	22,300
	0.92–1.37	25,200	9.4	268	<2.5	20	<2.4	11	23	23,000
	0–0.92	24,900	10.4	272	<3.0	<24	<3.0	11	24	22,800
WAC 2.1	6.67–7.25	23,000	9.3	247	<3.0	<24	<3.0	7	15	21,400
	6.25–6.67	26,700	10.6	251	<3.0	<25	<3.0	9	17	23,000
	5.54–6.25	22,100	11.3	245	<3.5	<28	<3.5	<7	17	21,200
	5.17–5.54	24,600	12.5	268	<3.7	<29	<3.7	9	18	23,200
	4.83–5.17	25,700	12.5	266	<2.8	<23	<2.8	9	26	23,700
	4.33–4.83	26,300	12.3	320	<3.1	27	<3.1	10	25	24,400
	3.75–4.33	28,600	10.4	305	<2.7	24	<2.8	11	24	25,000
	3.12–3.75	27,100	10.3	305	<2.7	28	<2.7	11	23	24,000
	2.33–3.12	30,300	10.7	288	<2.6	22	<2.6	12	24	25,700
	1.87–2.33	32,500	11.9	306	<2.7	<22	<2.7	13	25	26,500
	1.42–1.87	25,400	10.1	267	<2.3	<18	<2.3	9	22	22,900
	0–1.42	25,400	10.4	265	<3.0	<24	<3.0	11	25	23,500
WAC 3.1	6.83–7.75	50,900	11.1	372	<5.1	<41	<5.1	<10	27	24,400
	6.50–6.83	26,100	8.4	286	<3.0	26	<3.0	6	15	22,800
	5.96–6.50	26,100	9.0	288	<3.6	<29	<3.6	8	19	24,400
	5.33–5.96	26,800	8.2	300	<3.5	30	<3.5	9	18	24,300
	4.75–5.33	23,300	7.9	261	<3.5	<28	<3.5	9	18	22,000
	4.17–4.75	23,300	8.1	327	<4.0	37	<4.0	11	21	22,400
	3.54–4.17	29,600	8.4	335	<3.1	34	<3.1	13	16	25,200
	2.67–3.54	28,700	7.4	339	<3.8	42	<3.8	11	19	24,100
	1.67–2.67	23,200	8.8	305	<2.6	26	<2.6	7	22	21,800
	1.21–1.67	18,700	7.4	255	<1.9	19	<1.9	6	19	18,400
	0.58–1.21	30,800	5.6	264	<1.7	16	<1.7	15	22	25,400
	0–0.58	15,000	5.4	155	<1.4	<11	<1.4	4	7	9,200

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Lead (mg/kg)	Magnesium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Strontium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)	Total nitrogen (mg/kg)	Total phosphorus (mg/kg)	Total organic carbon (mg/kg)
Kirwin Reservoir bottom-sediment cores (fig. 2*A*)												
KIR 1.3	20	7,130	552	<0.2	<11	2.2	191	80	83	1,740	754	13,600
	19	6,970	473	<.2	<9	2.0	179	76	83	1,450	780	10,300
	21	7,200	498	<.2	9	2.0	162	78	87	1,740	795	10,300
	19	7,090	503	<.2	<10	1.0	157	82	87	1,710	755	10,200
	14	7,280	446	<.2	9	1.1	149	85	89	1,750	716	10,900
	23	9,590	509	<.2	12	2.2	169	106	112	1,830	630	12,900
	22	7,640	463	<.2	13	1.6	141	54	92	1,860	611	12,100
	26	8,000	553	<.2	11	1.9	135	53	95	1,980	719	13,000
	23	8,080	489	<.2	13	.6	104	55	93	1,800	625	12,700
	16	7,810	490	<.2	15	1.0	99	50	95	1,780	546	13,000
	16	8,250	492	<.2	12	1.0	98	53	96	1,780	621	12,500
	21	5,060	492	<.2	10	<.5	74	23	59	1,720	603	12,100
KIR 2.2	16	6,490	518	<.2	12	1.9	188	87	82	1,710	688	11,500
	16	4,370	496	<.2	<8	.5	149	42	76	1,360	631	9,290
	25	6,940	573	<.2	15	1.6	170	106	105	1,600	644	10,400
	20	6,590	567	<.2	19	.9	151	114	113	1,510	564	11,000
	17	7,550	471	<.2	<9	.6	146	88	94	1,360	589	10,100
	19	7,070	495	<.2	11	1.3	161	86	90	1,550	598	10,800
	25	8,050	553	<.2	12	1.6	219	96	108	1,690	598	11,600
	22	9,760	542	<.2	24	.6	168	99	114	1,350	502	12,200
	23	8,650	490	<.2	14	1.0	128	92	104	1,560	533	11,800
	24	10,300	538	<.2	14	1.2	91	103	118	1,380	422	12,000
	24	10,500	423	<.2	14	1.0	108	82	110	1,420	458	11,500
	22	7,380	371	<.2	12	<.3	94	63	79	1,200	501	8,310
Webster Reservoir bottom-sediment cores (fig. 2*B*)												
WEB 1.2	24	5,740	636	<.2	<10	2.5	237	47	76	1,690	682	12,300
	25	6,100	555	<.2	<10	1.5	202	48	79	1,400	639	10,600
	27	7,210	539	<.2	<10	1.6	192	70	92	1,190	640	11,500
	26	8,760	536	<.2	16	1.1	172	95	104	1,850	644	11,900
	26	9,100	682	<.2	13	1.9	218	112	104	1,910	692	12,300
	28	10,200	543	<.2	19	1.1	187	125	116	1,730	556	12,100
	17	10,500	516	<.2	17	1.1	143	97	116	1,690	582	13,100
	28	10,300	511	<.2	19	1.3	153	114	115	1,780	671	12,500
	16	10,900	495	<.2	30	1.3	152	119	119	1,460	557	12,900
	16	9,600	509	<.2	17	.7	130	96	110	1,400	487	12,000
	29	9,900	432	<.2	16	1.6	146	95	111	1,700	668	12,300
	20	6,280	341	<.2	11	.5	109	62	79	1,740	486	11,800
WEB 2.4	21	6,320	788	<.2	<12	2.5	263	59	88	521	463	16,200
	22	6,180	642	<.2	<10	2.7	248	51	80	30.0	251	13,400
	25	7,160	692	<.2	<10	1.7	224	57	90	1,710	692	12,300
	23	7,110	640	<.2	<10	1.6	209	60	91	1,720	633	13,400
	27	7,850	587	<.2	13	2.0	182	65	101	1,720	536	11,100
	31	6,820	626	<.2	14	2.0	207	60	88	1,540	556	12,100
	32	8,500	551	<.2	19	1.1	191	83	106	1,180	606	12,200
	26	7,110	543	<.2	<10	1.4	152	58	90	940	495	13,700

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Lead (mg/kg)	Magnesium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Strontium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)	Total nitrogen (mg/kg)	Total phosphorus (mg/kg)	Total organic carbon (mg/kg)
Webster Reservoir bottom-sediment cores (fig. 2*B*)—Continued												
WEB 2.4	29	8,190	519	<0.2	15	0.9	124	53	98	1,020	467	13,600
	28	7,930	509	<.2	18	1.2	140	65	101	1,710	567	14,000
	28	7,660	505	<.2	17	1.1	139	53	97	1,450	520	12,800
	22	8,040	519	<.2	16	.6	133	57	98	1,600	463	13,100
WEB 3.3	--	--	--	--	--	4.0	278.5	--	--	--	98.9	--
	--	--	--	--	--	2.3	172.6	--	--	--	352	--
	--	--	--	--	--	2.0	134.8	--	--	--	403	--
	--	--	--	--	--	.6	67.6	--	--	--	219	--
	--	--	--	--	--	.4	18.9	--	--	--	69.4	--
WEB 4.1	--	--	--	--	--	.7	74.8	--	--	--	159	--
	--	--	--	--	--	.2	45.1	--	--	--	67.5	--
	--	--	--	--	--	<.2	41.1	--	--	--	54.8	--
	--	--	--	--	--	.2	57.8	--	--	--	57.9	--
	--	--	--	--	--	.8	198.9	--	--	--	91.1	--
WEB 5.2	--	--	--	--	--	2.1	185.9	--	--	--	314	--
	--	--	--	--	--	2.1	153.5	--	--	--	116	--
	--	--	--	--	--	2.3	155.0	--	--	--	58.7	--
	--	--	--	--	--	1.5	131.6	--	--	--	63.3	--
	--	--	--	--	--	1.3	118.5	--	--	--	118	--
WEB 6.1	--	--	--	--	--	<.2	114.6	--	--	--	97.8	--
	--	--	--	--	--	<.2	111.0	--	--	--	107	--
	--	--	--	--	--	<.2	120.2	--	--	--	609	--
	--	--	--	--	--	<.2	148.3	--	--	--	166	--
	--	--	--	--	--	<.2	131.9	--	--	--	246	--
WEB 7.2	--	--	--	--	--	.3	190.7	--	--	--	112	--
	--	--	--	--	--	3.9	374.0	--	--	--	351	--
	--	--	--	--	--	.7	265.1	--	--	--	384	--
	--	--	--	--	--	<.3	208.0	--	--	--	337	--
	--	--	--	--	--	<.3	171.5	--	--	--	<50	--
WEB 10.1	--	--	--	--	--	.4	214.8	--	--	--	311	--
WEB 11.3	--	--	--	--	--	0.3	108.8	--	--	--	370	--
Waconda Lake bottom-sediment cores (fig. 2*C*)												
WAC 1.3	<14	6,390	789	<.2	<14	1.7	197	66	119	2,180	719	17,300
	17	6,220	736	<.2	<15	3.0	199	65	137	2,520	771	18,100
	18	5,900	767	<.2	<13	1.1	216	60	103	2,340	744	16,700
	19	6,650	841	<.2	<15	.9	157	67	104	2,070	701	16,400
	20	5,980	987	<.2	13	.6	168	58	94	1,580	568	16,100
	19	6,270	863	<.2	<13	<.6	164	64	133	1,700	558	16,000
	16	5,970	749	<.2	<12	<.6	134	59	95	2,040	641	17,400
	17	5,800	745	<.2	11	.8	122	57	101	2,050	690	18,200

Table 11. Results of analyses of sediment-quality constituents in bottom-sediment cores collected from Kirwin Reservoir, Webster Reservoir, and Waconda Lake, May 1998—Continued

Core-sample identification	Lead (mg/kg)	Magnesium (mg/kg)	Manganese (mg/kg)	Mercury (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Strontium (mg/kg)	Vanadium (mg/kg)	Zinc (mg/kg)	Total nitrogen (mg/kg)	Total phosphorus (mg/kg)	Total organic carbon (mg/kg)
Waconda Lake bottom-sediment cores (fig. 2*C*)—Continued												
WAC 1.3	19	6,710	807	<0.2	14	0.8	139	69	110	2,210	658	19,600
	17	5,530	812	<.2	10	.9	145	57	112	1,720	618	18,000
	18	5,580	767	<.2	13	.6	147	57	125	2,370	785	18,400
	17	5,440	639	<.2	<12	.8	68	62	91	2,180	710	16,500
WAC 2.1	13	5,660	704	<.2	<12	2.3	195	54	76	2,280	451	16,600
	15	5,860	670	<.2	<12	2.0	192	62	82	2,020	281	14,900
	<14	5,200	861	<.2	<14	1.2	186	49	84	3,210	843	15,900
	22	5,810	777	<.2	<15	1.2	166	54	107	2,160	646	14,800
	16	5,840	903	<.2	12	1.2	172	57	91	2,380	740	17,600
	24	6,150	905	<.2	14	1.1	169	58	109	1,780	589	16,700
	18	6,260	774	<.2	15	.8	163	62	102	1,190	506	19,100
	18	6,010	745	<.2	16	.9	139	58	101	1,540	621	17,800
	21	6,430	791	<.2	18	.9	151	64	100	1,460	475	17,600
	19	6,660	871	<.2	15	1.3	169	73	124	1,880	589	17,200
	19	5,500	766	<.2	15	1.4	141	58	98	2,050	600	19,600
	17	5,620	731	<.2	15	.6	134	56	128	1,890	680	19,400
WAC 3.1	24	7,260	1,110	<.2	<21	3.1	336	64	108	2,630	885	16,100
	15	5,780	678	<.2	<12	3.4	93	61	92	2,550	904	13,700
	15	5,920	786	<.2	<14	2.9	150	59	96	2,220	812	15,700
	16	6,100	874	<.2	<14	3.2	162	60	98	2,180	771	14,800
	19	5,570	793	<.2	<14	1.6	84	54	80	2,100	726	14,800
	19	5,590	741	<.2	<16	1.4	99	52	111	2,150	673	16,100
	17	6,270	767	<.2	<12	1.9	142	64	117	1,610	483	16,000
	20	6,010	786	<.2	<15	1.1	171	66	131	1,760	544	17,900
	25	5,260	744	<.2	<10	2.3	157	52	125	1,800	565	19,900
	19	4,520	556	<.2	<8	.7	119	45	85	1,910	661	17,300
	16	6,680	372	<.2	13	<.4	102	51	88	1,620	533	10,300
	7	2,260	235	<.2	6	.3	93	22	35	704	526	3,440

V. G. Christensen—DEPOSITION OF SELENIUM AND OTHER CONSTITUENTS IN RESERVOIR BOTTOM SEDIMENT OF THE SOLOMON RIVER BASIN, NORTH-CENTRAL KANSAS,—USGS/WRIR 99–4230

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