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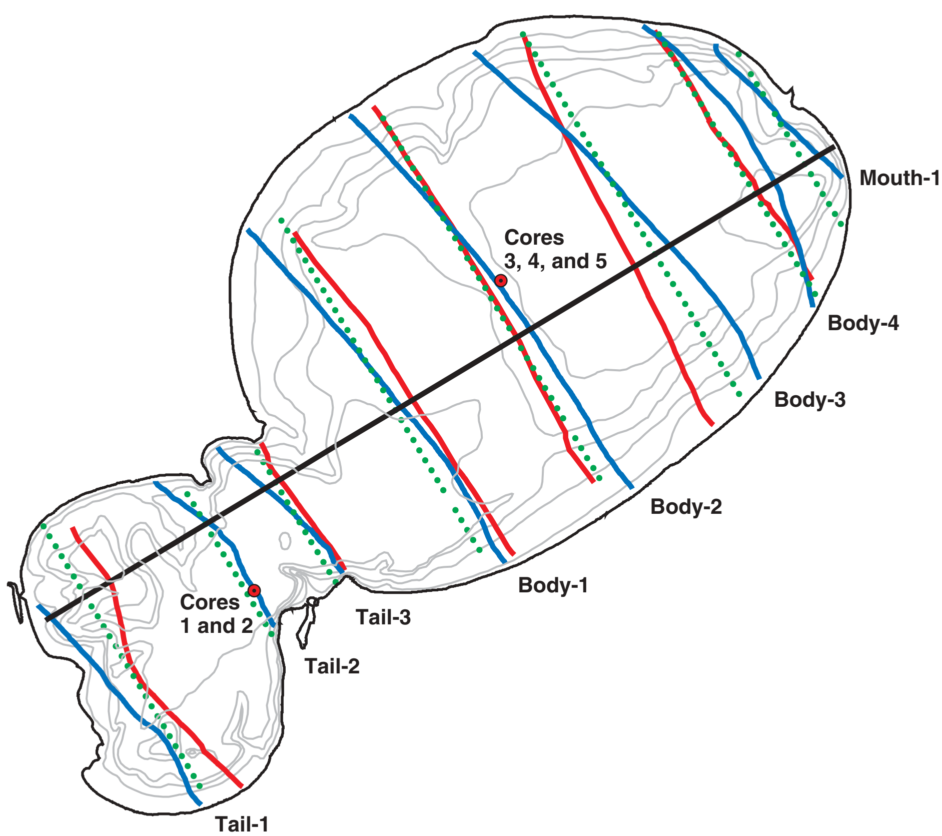
# Sediment Accumulation and Distribution in Lake Kampeska, Watertown, South Dakota

Water-Resources Investigations Report 02-4171




U.S. Department of the Interior
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**U.S. Department of the Interior**

GALE A. NORTON, Secretary

**U.S. Geological Survey**

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Rapid City, South Dakota: 2002

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## CONVERSION FACTORS, ABBREVIATIONS, AND VERTICAL AND HORIZONTAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| acre | 4,047 | square meter |
| acre | 0.4047 | hectare |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| foot (ft) | 0.3048 | meter |
| foot per day (ft/d) | 0.3048 | meter per day |
| foot per year (ft/yr) | 0.3048 | meter per year |
| gallon (gal) | 3.785 | liter |
| inch | 2.54 | centimeter |
| mile (mi) | 1.609 | kilometer |
| ton, short (2,000 lb) | 0.9072 | megagram |

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

Horizontal coordinate information is referenced to the North American Datum of 1927 (NAD27), unless otherwise noted.

# Sediment Accumulation and Distribution in Lake Kampeska, Watertown, South Dakota

*By* Bryan D. Schaap *and* Steven K. Sando

## ABSTRACT

Lake Kampeska is a natural lake of about 5,075 acres located within the city limits of Watertown, South Dakota. The lake is important as a water supply and recreational resource. Sediment accumulation has been a concern for many years, and several studies have been conducted to learn more about the sediment, including how fast it is accumulating. This study attempted to evaluate previously estimated sediment-accumulation rates and to describe the distribution of sediment in the lake.

Analysis of cesium-137 concentrations in sediment cores and changes in lake-bottom elevation over time led to the conclusion that during about the last 50 years, the sediment has been accumulating at a rate on the order of 0.01 foot per year or less. Changes in lake-bottom elevation during this time period indicate that the only significant deposition occurred in the area near the connection of Lake Kampeska to the Big Sioux River. Direct physical measurements and marine seismic surveys indicate that the flat-bottom interior part of the lake has 10 feet or more of sediment over a relatively irregular subbottom.

## INTRODUCTION

Lake Kampeska is a natural lake of about 5, 075 acres located within the city limits of Watertown, South Dakota (fig. 1). The lake has a surface-water connection to the Big Sioux River and is hydraulically connected to the Big Sioux aquifer. Almost 200,000 people live within 65 miles of the lake, which serves as a water-supply and recreational resource (Steuven and Steward, 1996). Sediment accumulation within the lake has the potential to impair these beneficial uses by making it more difficult to extract water, by adversely affecting the number of desirable fish in the lake, and by ultimately filling the lake. Previous investigations produced very different estimates of sediment-accumulation rates from each other. The consideration of various management plans, such as dredging the lake, indicated the need for a better understanding of the historical sediment-accumulation rate and the distribution of sediment within the lake.

The U.S. Geological Survey (USGS), in cooperation with the Lake Kampeska Water Project District, conducted a study of sediment accumulation and distribution in Lake Kampeska. The objectives of the study were to: (1) estimate the rate of sediment accumulation in the lake, and (2) describe the distribution of sediment in the lake. Methods and results of this study may be useful in sediment studies of other lakes in similar settings.

### Purpose and Scope

The purpose of this report is to provide information about the rate of sediment accumulation and sediment distribution within Lake Kampeska. This is accomplished by providing summaries of previous sedimentation studies and comparing the historical data to the data collected for this study.

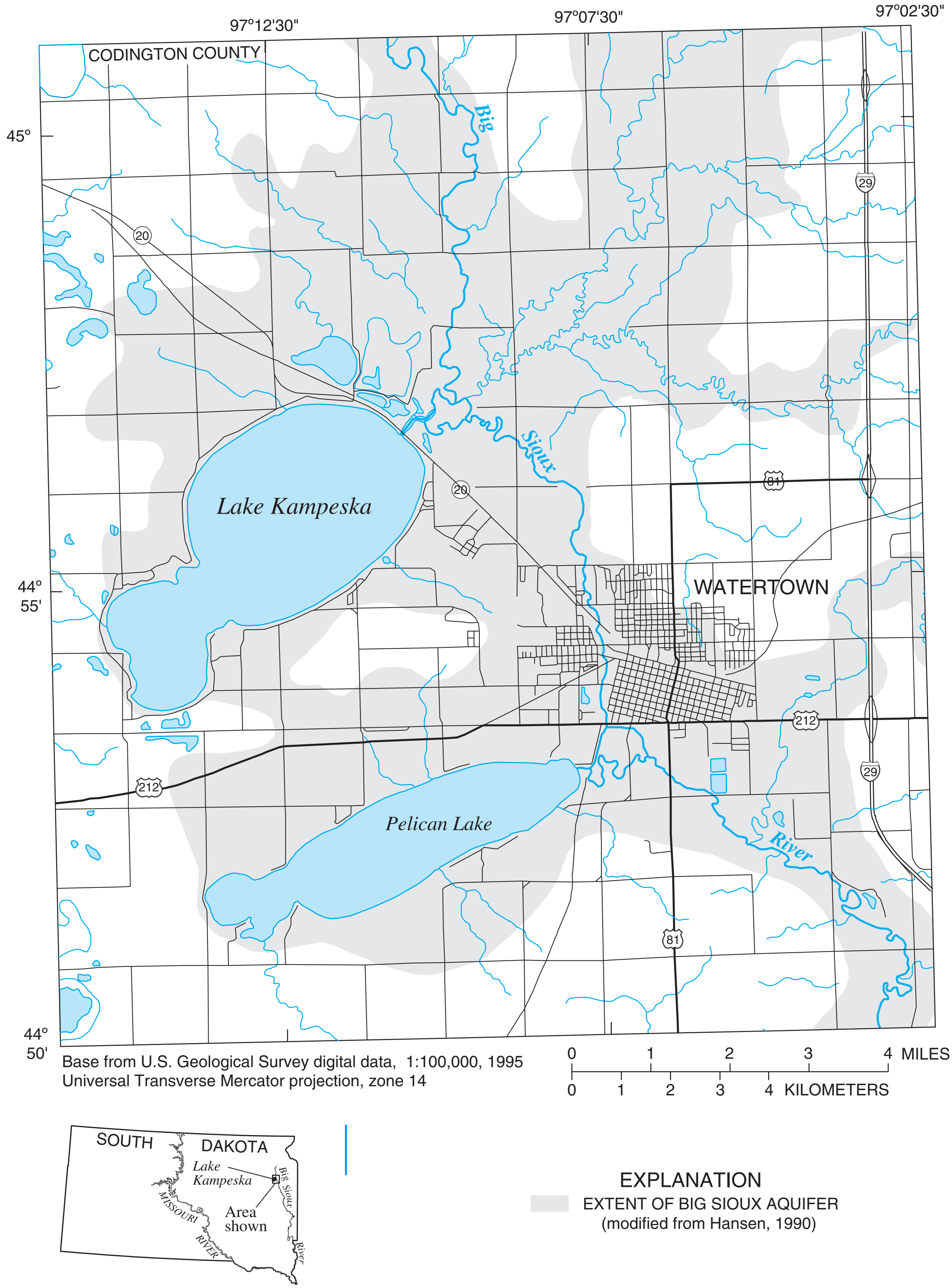


**Figure 1**. Location of Lake Kampeska.

The sediment in the lake has been studied previously using several different methods. To allow comparison of the various studies, the results from different time periods were incorporated into a geographic information system (GIS), and vertical measurements were reported relative to a common elevation. Previous studies provided information about the rate of sediment accumulation, measurements of water-depth, descriptions of lake-bottom material, and the thickness of the sediment in the lake. Collection and analysis of sediment samples for cesium-137 concentrations during October 2000 and a marine seismic survey used to collect information about water depth and sediment thickness in 2000 are described. Comparisons of the various studies are used to evaluate estimated rates of sediment accumulation. Selected information from studies conducted from 1990 through 2000 was used to create a water-depth map of the lake.

## Description of Lake Kampeska Area

Lake Kampeska is located in a geographic region known as the Prairie Hills. This broad trough includes the well-developed drainage of the Big Sioux River near its center and hummocky poorly developed drainage along the edges (Gries, 1996; Bryce and others, 1998).

The bedrock in the Lake Kampeska area consists of the Upper Cretaceous-age Niobrara Formation, Carlile Shale, and Pierre Shale. These bedrock formations, which generally do not yield water to wells, are considered to be confining beds to the overlying surficial aquifers.

The surficial deposits in the Lake Kampeska area are Quaternary-age glacial deposits, which consist primarily of till and outwash. Only the glacial-outwash deposits that are composed primarily of sand and gravel yield substantial quantities of water to wells (Hansen, 1990). The Big Sioux aquifer (fig. 1), which is one of the most important aquifers in the State, has a fluvial origin and consists of poorly to well-sorted surficial outwash ranging from medium-sized sand to medium-sized gravel (Putnam and Thompson, 1996).

Lake Kampeska was formed thousands of years ago by glacial processes (probably the melting of a remnant ice block) in a zone of glacial stagnation on the boundary between end-moraine till and outwash deposits (Steece, 1957). The composition of bed material of the lake shortly following the lake's formation probably consisted of till with overlying outwash in some parts. Because of the uncertainty concerning the specific formation processes, the extent and thickness of outwash in the original lake bed is not known.

There is a direct connection between the Big Sioux River and Lake Kampeska. Near Lake Kampeska, the Big Sioux River has a meandering channel, and relief in the area is only a few feet. It is possible that the Big Sioux River and Lake Kampeska were naturally connected early in their history and that surface connection may have been reduced or eliminated as the Big Sioux River deposited sands and gravels along the northeast side of the lake. The modern history of the connection is uncertain, but some connection, at least when the Big Sioux River was at flood stages, probably occurred since the late 1800's based on old newspaper accounts. In the 1930's, the surface-water connection between the river and the lake was channelized (Madison, 1994); however, this channelization may have been an enhancement of a connection that had been in existence for some time based on historical information (Watertown Public Opinion, 1969). Since the 1940's, the inlet also has served as the outlet after the original outlet along the southeastern part of the lake was blocked during the construction of an airport (Madison, 1994).

The Big Sioux River and Lake Kampeska are hydraulically connected to the Big Sioux aquifer (Barari, 1971; Hansen, 1990; Putnam and Thompson, 1996). Information presented in Putnam and Thompson (1996, p. 4) indicates that the thickness of the Big Sioux aquifer around Lake Kampeska is extremely variable, with a range of 6 to 47 feet and an average of 20 feet for eight test holes surrounding the lake. The elevation of the bottom of the Big Sioux aquifer is about 1,680 feet above sea level in the Lake Kampeska area (Putnam and Thompson, 1996, p. 6). Recharge can occur from infiltration of precipitation and from the Big Sioux River and lakes in the area when surface-water levels are higher than adjacent ground-water levels. Ground-water levels can be reduced by evapotranspiration and pumping. Ground-water flow generally is parallel to the flow in the Big Sioux River and is from north-northwest to south-southeast in the vicinity of the lake (Hansen, 1990; Putnam and Thompson, 1996).

More than 96 percent of the land in the lake subbasin primarily is used for agriculture, and most of this is used as cropland rather than pasture (Madison, 1994). The Lake Kampeska subbasin has an area of about 17,278 acres, and the contributing Big Sioux

River Basin from the headwaters downstream to and including the Lake Kampeska subbasin has an area of about 223,006 acres (U.S. Department of Agriculture, 2000). If the 5,075 acres of Lake Kampeska are subtracted, then the remaining portion of the Lake Kampeska subbasin is about 5.5 percent of the contributing area to this part of the river basin.

## Nomenclature

In this report, the data sets provided by various organizations and researchers are described, then comparisons are made among the common components from the various studies. It was necessary to provide a common basis for comparison, and basic information often is presented in terms of elevation, in feet above sea level. In some instances, comparisons are made to an elevation of 1,717.8 feet, which has been defined by the State of South Dakota as the normal lake elevation and is the assumed reference elevation for "above normal" and "below normal" conditions at Lake Kampeska.

The term "sediment" is used throughout most of this report to refer to the fine-grained sediment that was deposited in Lake Kampeska after its glacial origin. This same material was referred to as "silt" in some of the previous studies, and that term is used when referring to maps or literal descriptions of notes from those studies. The term "subbottom" refers to the lowest extent of the fine-grained material, and "sediment thickness" refers to the distance from the top of the sediment to the subbottom. This is an important distinction because the methods described in this report were not used to determine the bottom of the sediment in the sense of defining the interface between sediment and bedrock, but rather were used to define the interface between fine-grained material and the assumed underlying glacial deposits from the time of the lake's origin.

Lake Kampeska, in map view, is shaped generally like a fish, and the terms "mouth," "body," and "tail" can be useful descriptors for general areas of the lake. The mouth of the lake is in the northeast end of the lake, approximately at the Big Sioux River inlet. The body of the lake is the ovoid, flat-bottomed, steep-sided area to the southwest of the mouth and is the largest part of the lake. The area to the southwest of the body, including the narrows, is referred to as the tail. The lake is about 4.7 miles long from mouth to tail, and the width varies from about 0.7 mile to about 2.3 miles.

## Previous Studies

Lake Kampeska has been the subject of considerable interest and study over the years. Some studies have been general and examined the role of the lake in the hydrologic system, and others have examined specific issues directly or indirectly related to sediment in the lake.

The South Dakota Geological Survey has published several reports describing the geology of Lake Kampeska and the factors affecting lake levels (Rothrock, 1933; Steece, 1958a, 1958b). In a comprehensive report describing the hydrology of the lake, Barari (1971) concluded that in addition to the direct surface-water connection, the Big Sioux River is hydraulically connected to Lake Kampeska by the Big Sioux aquifer, and therefore, water levels in the river and the lake are affected by water levels in the aquifer.

A study based on many factors, including land use and soil types, reported that an estimated 4,052 tons of sediment were deposited annually in Lake Kampeska, and that more than 30 percent of this sediment came from lake-shore erosion (South Dakota Department of Water and Natural Resources, 1985). This corresponds to an average reduction of about 0.006 foot per year in lake depth, assuming that the 4,052 tons were deposited uniformly throughout the lake. Based on analysis of water samples, Madison (1994) concluded that most of the suspended solids coming into the lake did so during flood stages of the Big Sioux River, and that the sediment in the lake settles out of the water column quickly.

During the winters of 1990 and 1991, the Kampeska Chapter of the Izaak Walton League of America undertook an all-volunteer study to measure water depth and sediment thickness at more than 2,000 locations on the lake (Jim Madsen, Izaak Walton League, written commun., 2000). The methods and results of that study are described in more detail later in this report.

The USGS conducted a study of the water resources, including Lake Kampeska, of Codington and Grant Counties (Hansen, 1990). A digital model of ground-water flow in the Big Sioux aquifer for an area that included Lake Kampeska was described by Putnam and Thompson (1996).

Suspended sediment samples collected at the Big Sioux River inlet during an April 1997 flood led to estimates that from October 1, 1996, through September 30, 1997, the net increase in Lake Kampeska sediment was 28,800 tons, and from

October 1, 1993, through September 30, 1997, the net increase in Lake Kampeska sediment was 61,700 tons (John R. Little, Lake Kampeska Water Project District, written commun., 2000). These estimates correspond to sediment-accumulation rates of about 0.0025 foot per year and about 0.0013 foot per year, respectively, during these 1-year and 4-year time periods.

Day and Butler (1998) studied lead-210 and chironomid (aquatic insects) trends in sediment cores to determine a correlation between sediment accumulation and the lake environment in the past. Sediment cores were collected from the southwestern part of the lake "approximately 100 feet SW of the rock pile" in the tail part of the lake, well away from the mouth or the connection with the Big Sioux River. The core was described as homogeneous, consisting primarily of a very fine silty mud, and the only visible difference with greater depth was an increase in shells and organic matter. Lead-210 is a naturally occurring isotope that decays with time (half-life of 22.3 years), and the amount of lead-210 decreases with increasing sediment depth in undisturbed deposits. The lead-210 analyses from sub-samples of the core were used to estimate the age of the sediment at 20-centimeter intervals. The average sediment-accumulation rate from 1918 through 1998 was about 0.04 foot per year (3.28 feet cumulative), and the average sediment-accumulation rate from 1989 through 1998 was about 0.08 foot per year (Day and Butler, 1998). The chironomid analysis was for the purpose of assessing the environmental conditions during the time of sediment deposition and was not used to provide any information about the time of sediment deposition.

A study by the Natural Resources Conservation Service was designed to provide information about sediment and nutrients in the Upper Big Sioux River Basin. Computer simulation models indicated that the Lake Kampeska subbasin is contributing about 5.3 percent of the total sediment load contributed by the basin from the headwater areas downstream to and including Lake Kampeska (U.S. Department of Agriculture, 2000).

As part of a fish-movement study, Blackwell (2001) collected information about Lake Kampeska during 1995-96 including the lake boundary, bottom materials, and water depth. This information is described more fully later in this report.

## Acknowledgments

The authors gratefully acknowledge the efforts of all those who provided information and guidance. Many people provided valuable information about the history of Lake Kampeska and the many observations of lake conditions that have been made over the years. Jim Madsen, one of the volunteers, was particularly helpful in providing information about the 1990-91 survey by the Kampeska Chapter of the Izaak Walton League of America to measure water depth and sediment thickness in the lake. John R. Little, a technical advisor to the Lake Kampeska Water Project District, provided summaries of information about the hydrology of the Upper Big Sioux River and Lake Kampeska. Brian Blackwell provided information about conditions in the lake during 1995-96 from his doctoral dissertation. The authors also wish to acknowledge the Watertown Community Foundation and Watertown Municipal Utilities for their assistance.

# GENERAL METHODS OF INVESTIGATION

The historical sediment-accumulation rate was evaluated using two methods. One method used trends observed in sediment cores based on cesium-137 values to age-date the sediment. The other method involved the comparison of water-depth information collected over a span of several decades. Both methods are described further in this section of the report.

The distribution of the sediment in the lake was based on three sources of data: (1) probing data collected by the Kampeska Chapter of the Izaak Walton League of America, (2) samples collected and evaluated by Blackwell (2001), and (3) marine seismic surveys by the USGS for this study. Specific details for the collection of sediment distribution data are provided later in this report.

## Age-Dating of Sediment

One way to estimate the rate of sediment accumulation at a specific location is to collect samples of the sediment and to correlate changes with depth to events known to have occurred on specific dates. This method is based on the assumption that the sediment has not been affected by excavation, wind-caused mixing, biological activity, or other forces that might have disrupted the relative age sequence of the sediment as originally deposited.

Sediment samples from various depths often are obtained by collecting a vertical core of lake deposits and selecting samples from various intervals. These cores can be several feet long and can include sediment deposited over a period of many years. Depending on many factors including collection conditions and the method used, the core can be shorter than the known distance of penetration into the sediment. This can be caused by compression of the sediment and loss of sediment. The effects of compression may not be evenly distributed throughout the length of the core, and this can hinder efforts to determine the absolute depth of the sediment before it was collected. Precautions are taken to prevent the sediment from leaving the top or the bottom of the coring tube once it has entered the tube, but some sediment may be dispersed by the downward movement of the coring tube and not enter the tube.

Samples of the uppermost few tenths of a foot of the sediments can be obtained by using a bottom sampler. When the bottom sampler is lowered slowly to the lake bottom, a small stainless steel rotary scoop on the bottom of the sampler is activated when the weight of the sampler is supported by the sediment and not by the suspension cable. The bottom sampler also may disperse some sediment and the sampler may settle slightly into the sediment before the scoop is activated. Samples collected this way can be compared to the samples from the upper part of the core. Specific details for the collection of sediment samples during 2000 for this study are provided later in this report.

Several different methods can be used to estimate the rate of sediment accumulation based on changes with depth. The selected method generally is based on many factors, including the time interval of interest and the constituents likely to be found within the sediment during that time interval. Studies of sediment accumulation within the past few tens to hundreds of years can use techniques based on constituents introduced by human activity, such as cesium-137, or naturally occurring isotopes, such as lead-210. Additional details of the cesium-137 methods are provided later in this report.

Sediment may not accumulate uniformly throughout a lake, and analysis of sediment from a few selected locations can be used only to estimate an average rate of sediment accumulation. These results can be used to develop a qualitative relation between the factors outside the lake and the amount of sediment deposited in the lake. In the case of Lake Kampeska, the most interest is in relating factors from the last several decades rather than from the thousands of years since its origin. Factors such as the development of intensive row crop agriculture in the Big Sioux River Basin upstream of the lake, human manipulation of the surface connection between the Big Sioux River and Lake Kampeska, and development along the lake shore may affect the rate of sediment accumulation within the lake.

The rate of sediment accumulation can be estimated by associating times with depths and dividing the change in depth, associated with the sediment thickness, by the change in time. In addition to analytical results, other information can be used to associate a time to a depth. The top of the core is associated with the time of collection. Lower in the core, changes in vegetation, soil horizons, or sediment type can be associated with known periods of change, such as droughts, floods, or dam construction.

### Water-Depth Data

Changes in water depth over time also can be used to estimate an average sediment-accumulation rate. Assuming that no processes, such as isostatic rebound, subsidence, erosion, or dredging, have affected the lake bottom, any decrease in water depth over time would be associated with an increase in sediment thickness. Because the lake surface may be at different elevations when water-depth measurements are made, comparisons between measurements can only be made when the water depths are compared relative to a common elevation.

## EVALUATION OF SEDIMENT-ACCUMULATION RATES AND DISTRIBUTION

Information from previous studies and information collected for this study is used to evaluate sediment accumulation rates and distribution in Lake Kampeska. Previous studies have provided information regarding water depth, sediment thickness, lake-bottom material, and the lake boundary. Information collected for this study includes trends in cesium-137 concentration with sediment depth obtained from sediment samples and water depth and sediment thickness obtained during two marine seismic surveys. The various information from different sources and times is compared in cross sections at selected transects of the lake.

## Information from Previous Studies

Selected information from the previous studies described earlier is presented in this section of the report. This information includes data collected during surveys in 1951 (Barari, 1971), 1990-91 by the Izaak Walton League, and 1995-96 (Blackwell, 2001).

### 1951 Water-Depth Survey

The South Dakota Department of Game, Fish and Parks produced a water-depth map of Lake Kampeska (fig. 2) based on data collected during March 1951 and a lake boundary from an air photo taken during 1958 (Barari, 1971). According to the Watertown Public Opinion (1969), the water-depth measurements were made through hundreds of holes drilled through the ice. The lines of equal water depth start at a depth of 5.0 feet with intervals of 2.5 feet and were drawn during 1964, 13 years after the water-depth measurements were made. Versions of this map have been published in several publications (Watertown Public Opinion, 1969; Barari, 1971; Madison, 1994; Steuven and Stewart, 1996). Although the lines of equal water depth were consistent from publication to publication, the reference elevation was stated as 1,720 feet above

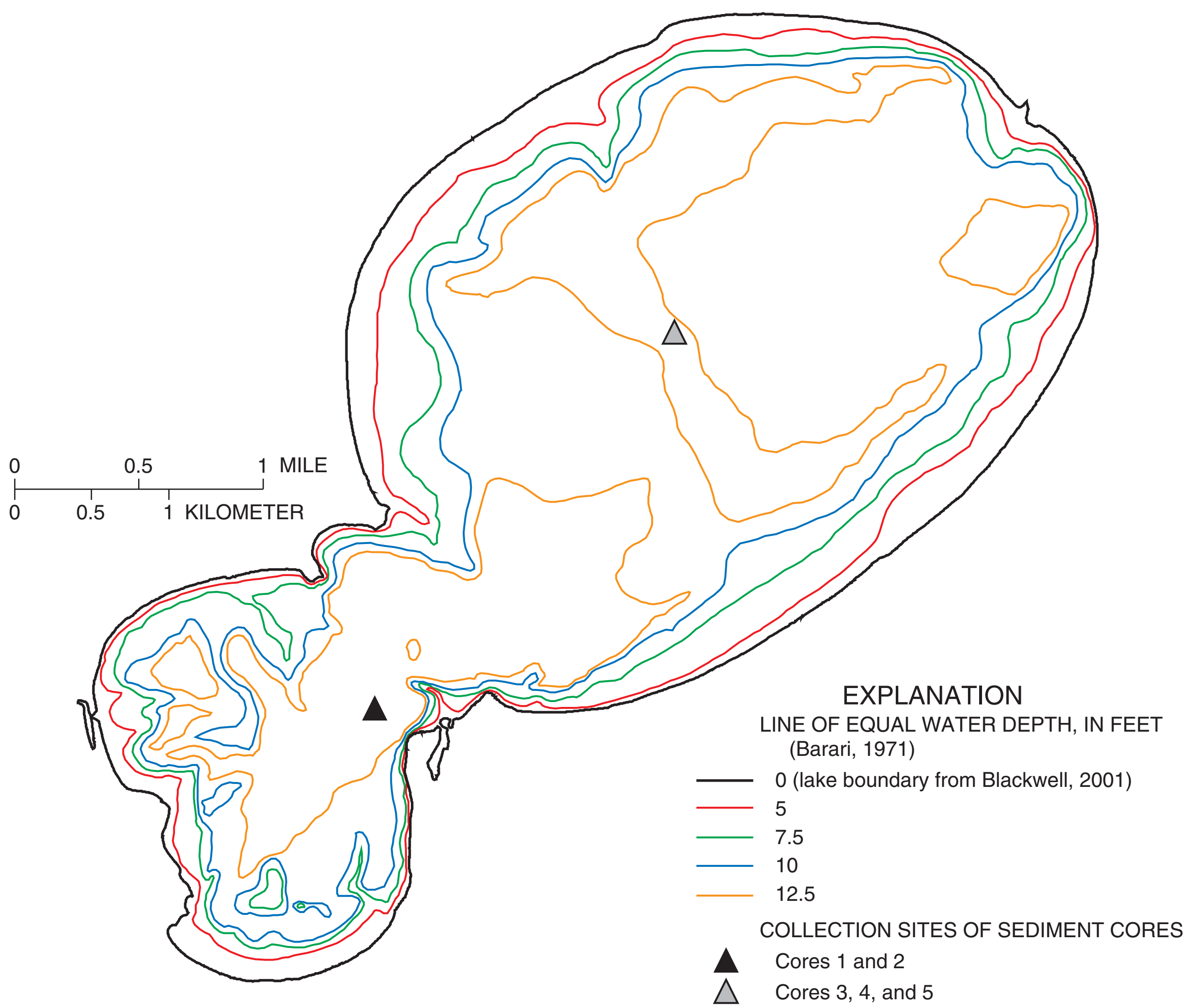


**Figure 2**. Water depth in 1951 and collection sites of sediment cores in 2000.

mean sea level in Barari (1971) and stated as 1,725 feet above sea level in Steuven and Stewart (1996). Several individuals associated with various agencies were contacted in an effort to determine the true reference elevation for this map, but the discrepancy could not be resolved without making comparisons to more recently collected water-depth data.

A GIS version of the 1951 water-depth map was created for this report (fig. 2) by digitizing the map from Barari (1971, p. 5). The use of the lake boundary from Blackwell (2001) (described in a following section) required slight modifications of some of the lines of equal water depth with smaller values in a few places, but the orientation and shape of the lines fit fairly well within the high-resolution lake boundary. The GIS version of the 1951 water-depth map appears to adequately represent the information in the published paper version.

In order for data from the 1951 survey to be comparable with data from other studies, the reference elevation for the 1951 data had to be resolved. Comparisons to water-depth data collected during surveys in 1990-91 and 2000 (described later in this report) indicated that neither the 1,720-foot nor 1,725-foot reference elevation could be correct unless the lake has been getting deeper since 1951. This can be shown by observing that the 10-foot line of equal water depth would correspond to a lake-bottom elevation of 1,710 feet if the reference elevation were 1,720 feet, and would correspond to a lake-bottom elevation of 1,715 feet if the reference elevation were 1,725 feet. Comparisons with more recently collected data consistently indicated lake-bottom elevations well below 1,710 feet in these areas. If the lake is not getting deeper at these locations, then the reference elevation for the 1951 water-depth map must be less than 1,720 feet.

Several comparisons between the lines of equal water depth based on the 1951 survey and the water-depth measurements made during the 1990-91 survey indicated that the appropriate reference elevation for the 1951 water-depth map should be about 1,715.2 feet. This estimate was based on the assumptions that little deposition had occurred in the southwestern part of the lake during the intervening years and that the elevation of the lake bottom in this area was about the same in 1951 as it was in 1990-91. These assumptions are based on the hypotheses that most of the sediment is coming into the lake from the inlet/outlet on the opposite end of the lake (Madison, 1994), and that any additional deposition would more likely be composed of the fine-grained sediment found in the middle of the lake and not the sand, rock, or gravel described in the notes from the 1990-91 survey done by the Lake Kampeska Chapter of the Izaak Walton League.

The 1,715.2-foot elevation was used to estimate the lake-bottom elevations throughout the lake associated with the water-depth map shown in Barari (1971). Considering the technology used in 1951 and the interpretations inherent in creating lines of equal water depth from water-depth point data, the transect comparisons indicate that the 1951 values, based on the 1,715.2 reference elevation, match the more recent lake-bottom elevations fairly well in areas where little or no deposition is believed to have occurred, such as the sandy shores along the northwestern and southeastern sides of the body. If the true reference elevation was significantly higher or lower, then comparisons with more recent information from the entire lake would show a pattern of unexpected increases or decreases in the lake-bottom elevation, which was not the case.

### 1990-91 Survey

During February 1990 and January to February 1991, the Kampeska Chapter of the Izaak Walton League of America organized volunteers to measure water depth and sediment thickness in Lake Kampeska. More than 2,000 holes were drilled through the ice, and measurements were made of water depth and sediment thickness. Observations were made regarding the type of lake-bottom material. A summary of the study and available copies of the field notes (Jim Madsen, Izaak Walton League, written commun., 2000) were used to input the information into a GIS.

The field work for the 1990-91 survey included establishing where the holes should be drilled, drilling the holes, making the water-depth measurements, making the sediment-thickness measurements, and recording the results. Sixty-two different people assisted with these tasks at some time during the survey. The measuring teams typically consisted of 3 or 4 people, and each person of the team was responsible for a specific task at each site.

A grid system was established by defining two reference lines across the lake. The first reference line was defined by connecting the points along the eastern side of the narrow part of the lake at what might be considered the dividing line between the body and the tail.

The second reference line was defined as a perpendicular to the first reference line where the first line intersected the southeastern lake shore. All of the other lines in the grid system were established in 300-foot increments from these two lines. The first part of a two-part label for transects from this survey are identified with "1990," the first year data were collected. The second part is a line number for those transects parallel to the second reference line. For those transects parallel to the first reference line, the second part of the label indicates the distance in feet and direction from the first reference line.

For this report, a GIS version of the data was created by generating an orthogonal set of points with 300-foot intervals. Then the entire set was rotated and shifted until it matched as closely as possible the description of the reference lines and points used for the survey, and the points outside the lake were deleted. Figure 3A shows the locations of the measuring sites during the two field seasons. No measurements were made at some near-shore locations because of open water. During 1990, data collection in the eastern part of the lake was hindered by a fracture in the ice and subsequent differential movement along the fracture. Some locations in the fracture area were measured in both 1990 and 1991; the 1991 values were used for this report.

#### Water Depth

Water-depth measurements were made with a 20-foot section of 2-inch PVC pipe calibrated in tenths of a foot. In those areas where sediment was on the lake bottom, 0.5 foot was subtracted from the measured value to compensate for the difficulty in determining the top of the soft sediment. When the measurements were made in 1990, the lake level was described as 2 feet below normal (approximately an elevation of 1,715.8 feet), and when measurements were made in 1991, the lake level was described as 3 feet below normal (approximately an elevation of 1,714.8 feet). Water-level records from the Watertown Utilities Department (John R. Little, Lake Kampeska Water Project District, written commun., 2000) reported similar values for these time periods and indicate that the lake level typically does not vary by more than a few tenths of a foot during winter.

The water-depth data at specific locations are not shown in this report, but water-depth measurements were used in the calculation of the lake-bottom elevation and sediment-bottom elevation points shown in the comparative cross sections presented later in this report. For example, during the 1990 field season, a water depth of 10.0 feet and a sediment thickness of 14.8 feet might have been recorded for a specific location. The lake-bottom elevation would be calculated as 1,705.8 feet (1,715.8 feet minus 10 feet). The sediment-bottom elevation would be calculated as 1,691.0 feet (1,705.8 feet minus 14.8 feet).

#### Sediment Thickness

Sediment-thickness measurements were made with a 5/8-inch-thick steel probe with a handle welded to the top. In most instances, a 25-foot probe was used. The probe was pushed through the soft silt, and the greater resistance encountered at the subbottom was easily detected. At a few locations where the 25-foot probe was unable to reach the bottom of the sediment, a 30-foot probe was used, but it also was unable to reach the bottom of the sediment.

At almost 40 percent of the nearly 2,200 measurement locations, the sediment thickness was greater than the maximum measuring capability of the probe. For example, at such a location, the water depth might have been 10 feet, and the sediment thickness would have been more than 15 feet. Because the lake level was 1 foot higher during the 1990 field season than during the 1991 field season, the maximum thickness of sediment that could be measured was 1 foot less during 1990 than during 1991.

Figure 3B shows a map of measured sediment thickness in three general categories: 0 foot (no sediment); greater than 0 foot and less than 10 feet, and equal to or greater than 10 feet. The result is a concentric-type pattern similar to the water-depth pattern where the sediment thickness of zero generally occurs around the exterior of the lake. Sediment thickness from 0 to 10 feet was measured at a few locations closer to the interior of the lake, and sediment thickness greater than 10 feet was measured in most of the rest of the interior of the lake. The locations where the sediment was so thick that the subbottom could not be measured also are shown in figure 3B. As previously described, the bottom of the sediment is assumed to be the interface between the fine-grained sediment or silt and the underlying deposits of sand, gravel, or till from the time of the lake's origin.

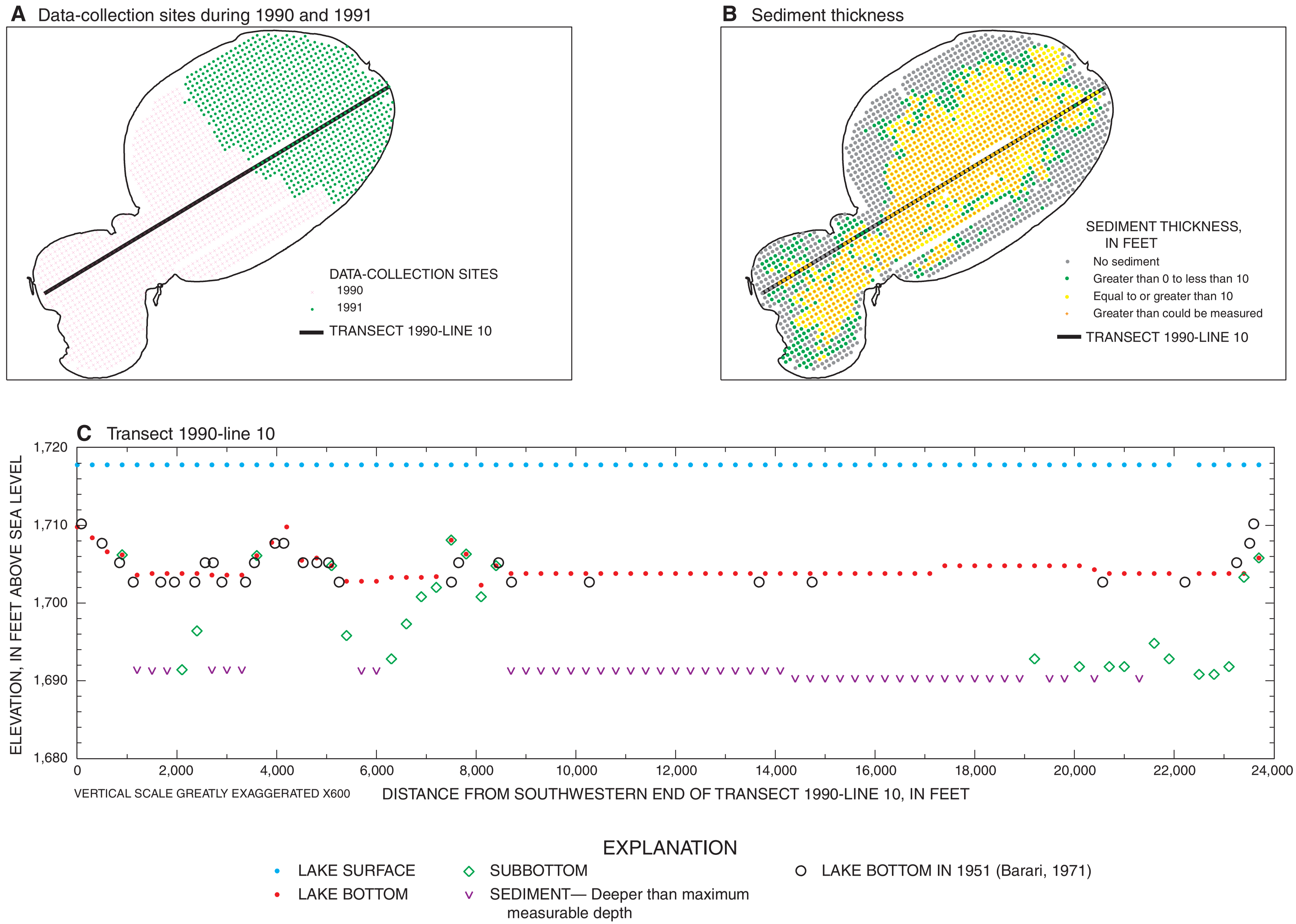


**Figure 3**. Maps showing (A) data-collection sites and (B) sediment thickness; and a cross section showing (C) transect 1990-line 10 across Lake Kampeska, 1990-91 (based on data collected by the Kampeska Chapter of the Izaak Walton League).

### Lake-Bottom Material

The nature of the lake-bottom material was determined by feel and sound during the measurement process, but there was no defined set of terms used consistently by the volunteers. A standard form was used throughout the 1990-91 survey, but it appears that different teams used slightly different methods for describing the bottom material. Figure 4 shows three maps of the lake-bottom material as recorded in the field forms. Figure 4A shows those locations where "sand" appeared in the "BOTTOM/COMMENTS" column of the field form. Such locations described as "sand," "sand/gravel," "gravel/sand," "sand-rock," "mud and sand," "sand-clay," "mud/sand," "sandy," and "sand/rocks" are included. In the same way, figure 4B shows those locations where "gravel" appeared as part of the description, and figure 4C shows those locations where "rock" appeared as part of the description. This approach means that some locations appear in more than one of these three maps. Also, more than 60 percent of the locations did not have a comment of any type. The lake bottom was sediment at many of these locations, but that description probably became so common that some teams failed to record it, and some may have assumed that it was evident that the bottom was sediment if there was a sediment thickness recorded for that location.

This qualitative characterization of the lake bottom lacks the systematic approach and rigorous definitions used by Blackwell (2001), but it has the advantage of having about 20 times as many sampling sites. This information is included in this report in part to provide a published description of the 1990-91 survey by the Izaak Walton League. In addition, the estimation of the reference elevation for the water-depth map produced by the South Dakota Department of Game, Fish and Parks (Barari, 1971) was based on the assumption of little sediment deposition in some areas of the lake. The locations where the 1990-91 survey reported coarse-grained sediments are shown in figure 4.

### Cross Section

Figure 3C shows a cross section of the transect 1990-line 10 from southwest to northeast across Lake Kampeska. This transect extends from southwest to northeast across the entire length of the lake, approximately in the middle of the lake from northwest to southeast, and has few locations where measurements were not made.

Figures 3B and 3C show that there is little or no sediment in the shallow areas on the southwestern end of the transect, the narrows at the northeastern end of the tail, and the northeastern end of the transect. The intervening areas of deep water have a flat bottom and greater than 10 feet of sediment.

These data also provide the opportunity to compare the 1951 lake-bottom elevation contours to the 1990-91 lake-bottom point measurements. The 1951 elevations were calculated so that they matched the 1990-91 elevations in the southwestern part of the lake, so it is not surprising that the results should be similar near the beginning of transect 1990-line 10. Farther along the transect, it appears that lake-bottom elevations from the two sources are usually within 1 foot of each other. So many measurements were made during the 1990-91 survey that a measurement often was made near the intersection of the 1951 lake-bottom elevation contours and 1990-line 10. A visual comparison of these two different data sets indicates that there has been little change in the lake-bottom elevation during the 40-year period. The primary source of any differences may be due to the conversion of the 1951 point data to contour lines and the interpretation inherent in such a process.

## 1995-96 Survey

Selected information collected for a survey during 1995-96 by Blackwell (2001) is presented in this section of the report. Information on the lake boundary was collected during 1995, and information on water depth and lake-bottom material was collected during 1996.

### Lake Boundary

During 1995, the lake boundary was mapped by walking along the edge of the lake with a hand-held GPS (global positioning system) unit and recording the location every 3 seconds (Blackwell, 2001). Based on this new information, the lake area is considered to be about 5,075 acres or about 5 percent more than the 4,817 acres determined using a planimeter (Barari, 1971). This digital lake boundary (fig. 2) was transmitted to the USGS as an ArcInfo export file. This was considered to be the most accurate lake boundary available and is used throughout this report to provide a common lake boundary for all maps.

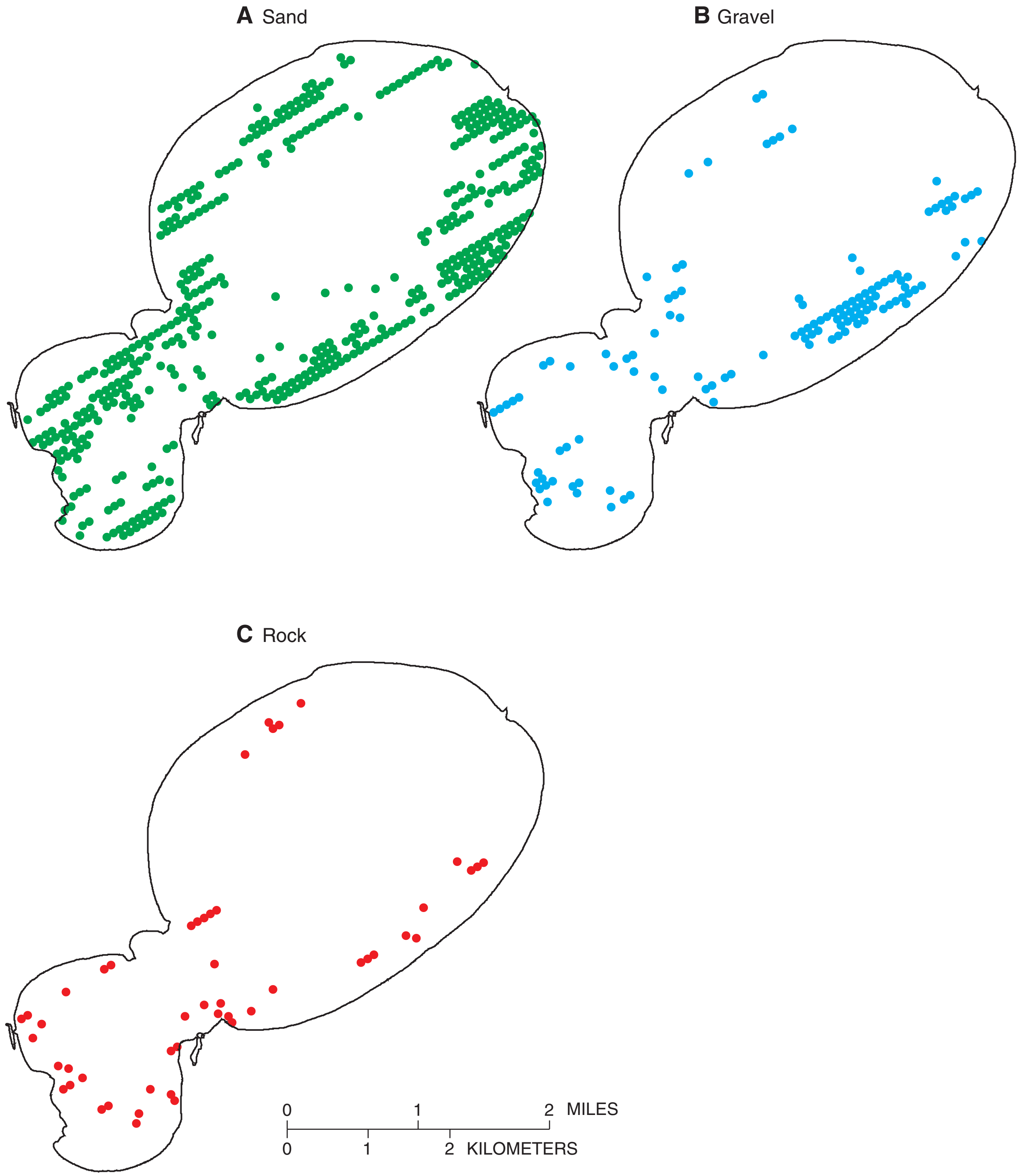


**Figure 4**. Coarse-grained lake-bottom material showing (A) sand, (B) gravel, and (C) rock, 1990-91 (based on data collected by the Kampeska Chapter of the Izaak Walton League).

### Water Depth

During 1996, water depths were recorded at 112 locations, primarily based on a 500-by-500-meter grid. This information was used to create a water-depth map (Blackwell, 2001). This information was transmitted to the USGS as an ArcInfo export file and is presented in figure 5 (metric units retained). This map shows the generalized concentric form of the transition from the shallow exterior to the relatively deep, flat interior of the lake. These data are not used later in the report for the comparison of lake-bottom elevations at various times, primarily because of the relatively short time interval between 1996 and 1994 when the USGS collected water-depth and marine seismic data.

### Lake-Bottom Material

During 1996, an Ekman dredge was used to collect lake-bottom samples at the 112 locations where water depths were measured. The samples were classified visually by Blackwell (2001) as follows: (1) silt, less than 0.059 millimeter in diameter; (2) sand, 0.06 to 1 millimeter in diameter; (3) gravel, 2 to 15 millimeters in diameter; or (4) rock, greater than 16 millimeters in diameter. Based on this information, silt covered about 73 percent of the lake, sand covered about 26 percent of the lake, and gravel and rock covered less than 1 percent of the lake (Blackwell, 2001). This map showing bottom material type was transmitted to the USGS as an ArcInfo export file and is presented without modification in this report (fig. 5). The pattern is similar to that for the lines of equal water depth, with the sand, gravel, and rock on the exterior part of the lake and the silt in the interior part.

# Information Collected for this Study

Sediment samples were collected and two marine seismic surveys were conducted for this study. These efforts were designed to provide information about trends in sediment accumulation and to provide additional information about the thickness of the sediment.

## Sediment Samples

On October 17, 2000, five sediment cores were collected from two locations within the lake (fig. 2). Table 1 provides details about the core collection and the analytical results. The coordinates of the collection sites were determined using a hand-held GPS unit. The cores were collected using a Benthos gravity corer mounted on a pontoon boat. The cores were collected in a cellulose acetate butyrate transparent tube, with an inside diameter of 2.625 inches. Every effort was made to keep the entire sample in the tube, and there was no evidence that these efforts were not successful. A sediment catcher, which acts as a one-way trap door, was placed in the bottom of the tube, and a plunger was used to seal the top of the tube once the corer had stopped moving downward. The depth of penetration for each core was determined by measuring the distance that the corer traveled after starting with the nose of the corer at water level and subtracting the measured depth of water. For example, the corer dropped a total of 22.0 feet during the collection of core 1 and the water-depth at the site was 12.3 feet, so the corer was calculated to have penetrated 9.7 feet of sediment. The length of each recovered core was less than the penetration depth; this difference is assumed to be caused by compression of the sediment during collection. Cores 1 and 2 were collected in the tail part of the lake near the site described by Day and Butler (1998). Cores 3, 4, and 5 were collected near the center of the body of the lake in an area that represented the deepest part of the lake based on the 1951 water-depth map (Barari, 1971) (fig. 2).

The samples from the cores were analyzed for cesium-137 concentrations. Cesium-137 is a radioactive isotope that was distributed in the Earth's atmosphere by thermonuclear activity, including nuclear weapons testing. The deepest sediment with a measurable cesium-137 concentration above background levels would have been deposited during about 1952. At the depth where the maximum cesium-137 concentration is found, the sediment would have been deposited during about 1963-64. Since 1964, the amount of cesium-137 released into the atmosphere has decreased as above-ground nuclear testing has decreased (Holmes, 1998). Several studies have used the cesium-137 method to produce age-dating results that have been consistent with reservoir histories and pesticide concentration trends (Kalkhoff and Van Metre, 1997; Pope, 1998; Christensen, 1999; Christensen and Juracek, 2001). A study in North Carolina (Weaver, 1994) found similar sediment-accumulation rates from sediment cores using the cesium-137 method and the lead-210 method, which was the method used by Day and Butler (1998). A study in Devils Lake Basin of North Dakota found that the cesium-137 and lead-210 methods produced similar results for some lakes, but different results for others, and these differences were attributed to biological and physical mixing (Lent and Alexander, 1997).

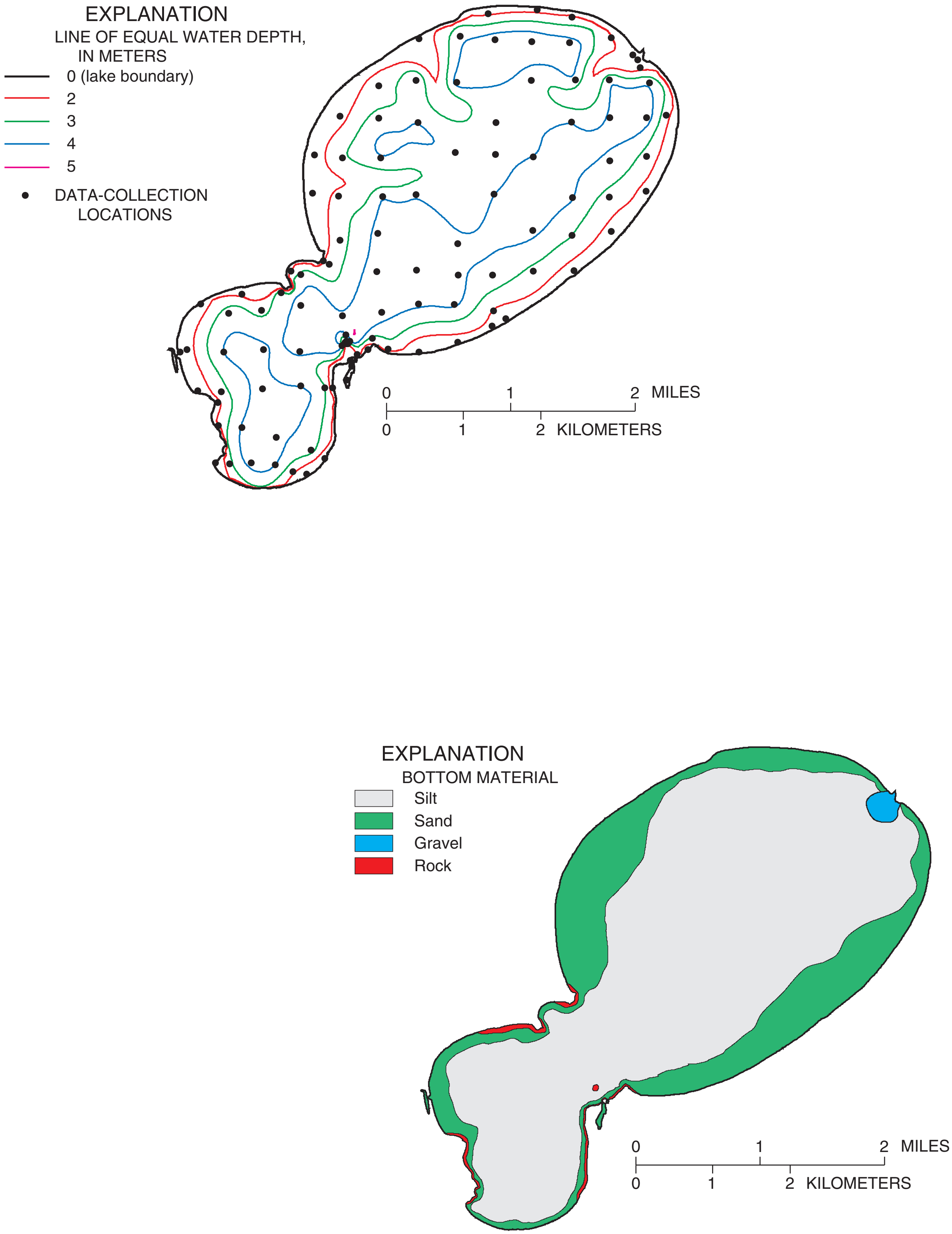


**Figure 5**. Water depth and bottom material in 1996 (from Blackwell, 2001).

**Table 1**. Sediment cores for cesium-137 analysis collected at Lake Kampeska on October 17, 2000

[dd-mm-ss.ss; degrees-minutes-seconds.decimal seconds; --, not applicable]

| Site number | Core | Latitude (NAD27) (dd-mm-ss.ss) | Longitude (NAD27) (dd-mm-ss.ss) | Water depth (feet) | Penetration into sediment (feet) | Core length (feet) | Sample interval from top (feet) | Cesium-137[1] concentration (picocuries per gram) |
|---|---|---|---|---|---|---|---|---|
| 445436097134700 | 1 | 44-54-35.75 | 97-13-46.78 | 12.3 | 9.7 | 6.53 | -- | -- |
| | | | | | | | 0.05 - 0.15 | 1.45 +-/ 0.299 |
| | | | | | | | 0.20 - 0.30 | 0.598 +/- 0.143 |
| | | | | | | | 0.35 - 0.45 | 0.0162 +/- 0.0541 |
| 445436097134700 | 2 | 44-54-35.75 | 97-13-46.78 | 12.3 | 9.7 | -- | -- | No analysis done |
| 445553097121600 | [2]3 | 44-55-53.08 | 97-12-16.06 | 10.7 | 8.8 | 6.25 (frozen) | -- | -- |
| | | | | | | | 0.00 - 0.10 | 1.83 +/- 0.275 |
| | | | | | | | 0.10 - 0.20 | 1.67 +/- 0.224 |
| | | | | | | | 0.20 - 0.30 | 1.48 +/- 0.212 |
| | | | | | | | 0.30 - 0.40 | 1.20 +/- 0.181 |
| | | | | | | | 0.40 - 0.50 | 0.831 +/- 0.151 |
| | | | | | | | 0.50 - 0.60 | 0.338 +/- 0.0915 |
| | | | | | | | 0.60 - 0.70 | 0.198 +/- 0.0956 |
| | | | | | | | 0.70 - 0.80 | -0.00873 +/- 0.046 |
| | | | | | | | 0.80 - 0.90 | 0.0248 +/- 0.0467 |
| | | | | | | | 0.90 - 1.00 | 0.0136 +/- 0.0536 |
| | | | | | | | 1.00 - 1.10 | -0.0424 +/- 0.0488 |
| | | | | | | | 1.10 - 1.20 | 0.00897 +/- 0.0462 |
| | | | | | | | 1.20 - 1.30 | -0.0641 +/- 0.0718 |
| | | | | | | | 1.30 - 1.40 | -0.0209 +/- 0.0466 |
| | | | | | | | 1.40 - 1.50 | -0.00929 +/- 0.0409 |
| | | | | | | | 1.50 - 1.60 | -0.0292 +/- 0.0384 |
| | | | | | | | 1.60 - 1.70 | 0.00129 +/- 0.0467 |
| | | | | | | | 1.70 - 1.80 | -0.0446 +/- 0.0422 |
| | | | | | | | 1.80 - 1.90 | 0.0155 +/- 0.0445 |
| | | | | | | | 1.90 - 2.00 | -0.0284 +/- 0.0430 |
| 445553097121600 | 4 | 44-55-53.08 | 97-12-16.06 | 10.7 | 8.8 | 5.83 | -- | -- |
| | | | | | | | 0.05 - 0.15 | 1.84 +/- 0./326 |
| | | | | | | | 0.20 - 0.30 | 1.670 +/- 0.247 |
| | | | | | | | 0.35 - 0.45 | 0.962 +/- 0.190 |
| | | | | | | | 0.50 - 0.60 | 0.238 +/- 0.115 |
| | | | | | | | 0.65 - 0.75 | 0.0135 +/- 0.0571 |
| | | | | | | | 0.80 - 0.90 | 0.0245 +/- 0.0539 |
| | | | | | | | 0.95 - 1.05 | 0.0590 +/- 0.0706 |
| 445553097121600 | 5 | 44-55-53.08 | 97-12-16.06 | 10.7 | 8.8 | 5.67 | -- | -- |
| | | | | | | | 0.05 - 0.15 | 1.90 +/- 0.283 |
| | | | | | | | 0.20 - 0.30 | 1.85 +/- 0.267 |
| | | | | | | | 0.35 - 0.45 | 0.215 +/- 0.0951 |

[1]Cesium-137 analysis is done in comparison to standards. At very low levels, slight differences between the environmental sample and the standard may produce analytical results with negative numbers. The cesium-137 concentration in the environmental sample is not negative, but at these very low levels, it had a lower concentration than the standard.

[2]Core 3 was frozen to allow continuous sub-sampling without intervals between samples.

Cores 1, 4, and 5 were prepared for sampling by draining the water from the top of the tube, securing a wooden plug into place at the top of the core, setting the tube on its side, and cutting away a strip the length of the tube about one-third the circumference of the tube. Each of the cores had about 0.02 foot of light gray silt on top, about 0.15 foot of darker gray silt below that, and the remaining several feet consisted of a uniform black silt with some shell material (snails and bivalves) sparsely scattered throughout. The sediment in the core was distinctly more dense from top to bottom in the top few tenths of a foot and was gradually more dense after that. There was no sign of vegetation remains and no appearance of sand or any other variation in stratigraphy that indicated any major change in depositional environment or major disturbance.

Individual samples were collected from the core using a strategy based on the assumption that the Day and Butler (1998) findings were correct and that the highest cesium-137 values would be detected about 2.1 feet from the top of the core and background levels would be encountered about 2.5 feet from the top of the core. Therefore, as many samples as possible were collected from the upper 3 feet of each of these cores. Each sample interval had to include about 0.10 foot of the core to produce the 50 grams needed for the cesium-137 analysis, and a 0.05-foot interval was left between sample intervals to allow sampling of distinct intervals in the soft sediment. For each of the cores, the top of the core was not sampled because that was assumed to represent the date of collection, so the first sample was from 0.05 foot through 0.15 foot from the top of the core, the 0.15-foot through 0.20-foot interval was skipped and left in the tube, the second sample was from 0.20 foot through 0.30 foot, and so on. In this manner, 20 samples were collected for the upper 3 feet of each core, and below 3 feet, the skipped interval was increased to 0.10 foot. For cores, 1, 4, and 5, a total of 37, 34, and 34 samples were collected, respectively.

The samples were submitted for analyses to STL Richland in Richland, Washington, with the instruction that analysis for each core should begin with the sample from the uppermost part of the core and continue in sequence with samples from lower in the core until background cesium-137 levels had been encountered. Then one more sample should be analyzed. For cores 1, 4, and 5, the highest cesium-137 concentrations were found in the uppermost samples submitted; concentrations at or below background levels were found after the second or third sample from the top (table 1).

In an effort to confirm these analytical results and get the most information from the sediment cores, samples from core 3 were collected using a slightly different method. Core 3 was frozen before the samples were collected so that no interval would be needed to maintain the separation between sampling intervals. The sampling started from the top of the core and continued down to 2 feet. There was some expansion in the length of the core when it was frozen, but this was on the order of a few percent and would not have affected the relative position of the cesium-137 within the core. A total of 20 samples were submitted for analysis. The results (table 1 and fig. 6A) have the same pattern as those for the other cores, with the sample from the uppermost part of the core having the highest cesium-137 concentration. The lack of any peaks at depth indicates that the upper 2 feet of the core had not been affected by episodic processes that led to the removal, addition, or mixing of the sediment after it had been deposited. Samples below 2 feet were not analyzed because there does not appear to be any likely series of events that could have produced this decreasing trend with depth of the cesium-137 results and produced a secondary peak nearer the depth predicted by Day and Butler (1998). The age-dating results presented by Day and Butler (1998) show gradually decreasing lead-210 concentrations with depth at 20-centimeter intervals throughout a 1-meter core (fig. 6B).

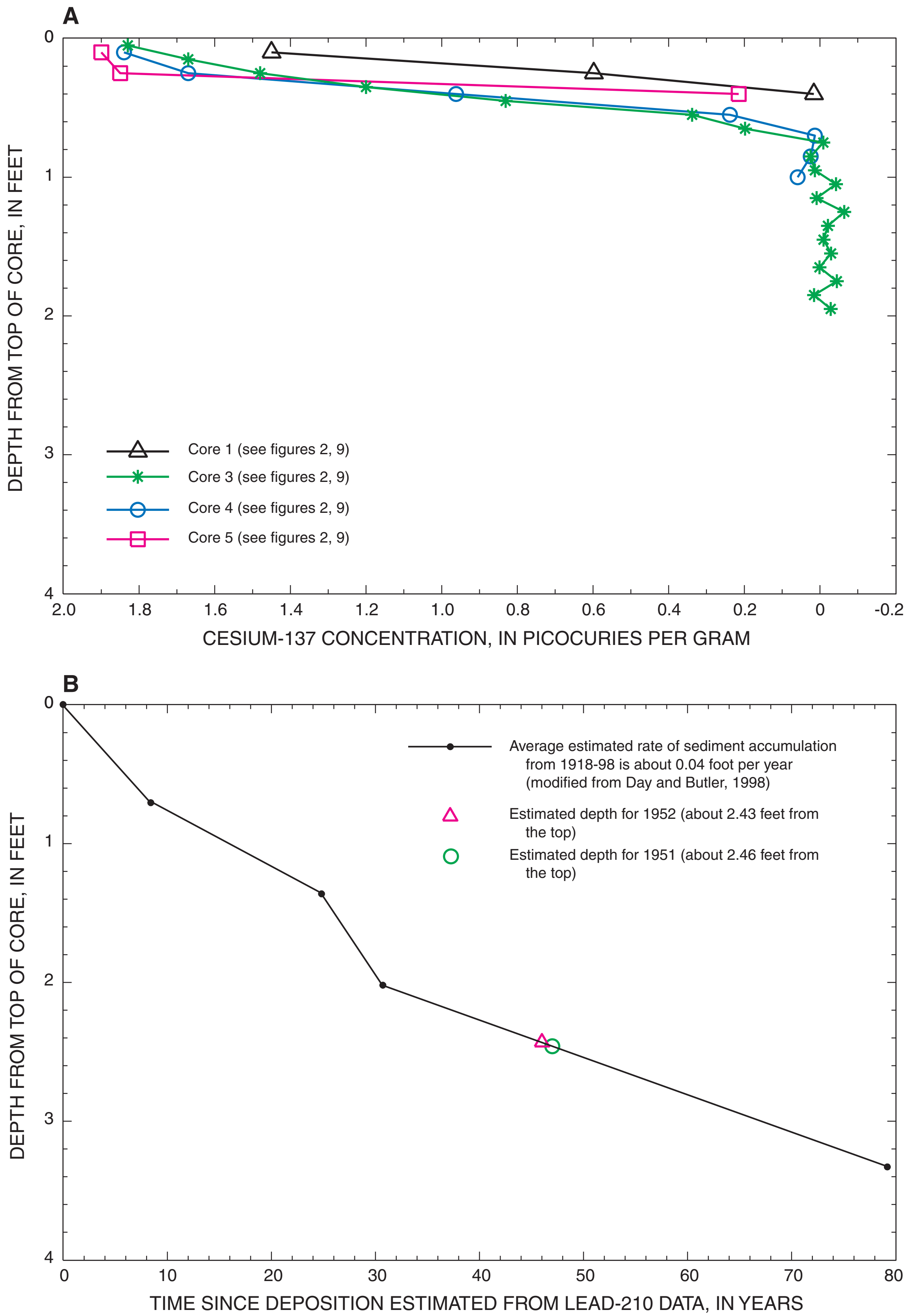


**Figure 6**. Profiles in bottom-sediment cores of (A) cesium-137 concentrations collected during October 2000, and (B) time since deposition estimated from lead-210 data collected during 1998.

Because the largest cesium-137 values in the sediment cores were found in the uppermost intervals and the penetration of about 10 feet of sediment produced cores of about 6 feet in length, there was some concern that some of the sediment might have been lost during the collection of the cores. If, for example, the upper 4 feet of the sediment was missing and the sediment in the cores was actually from 4 to 10 feet below the lake bottom, then the largest cesium-137 concentrations might have been within the missing 4 feet and closer to the depth predicted by the Day and Butler (1998) results. There was also some concern that perhaps the apparent compression of the sediment might have occurred almost exclusively in the upper part of the cores. If this had happened, then the apparent depths in the upper part of the cores would have been considerably less than the true depths. In either case, the overall effect would be that the uppermost part of the collected sediment cores would not provide a true representation of the uppermost sediment deposits. On November 20, 2001, a GPS unit was used to locate the approximate sites where the core samples were collected, and a bed sampler (US BMH-60) was used to collect surficial sediment samples. Two samples, one from each site, were submitted for cesium-137 analysis, and the results of 1.38 picocuries per gram (near cores 1 and 2) and 1.57 picocuries per gram (near cores 3, 4, and 5) are comparable to the results from a depth of about 0.25 foot from the cores. This indicates that the tops of the cores do represent the uppermost sediment at these locations.

Based on the cesium-137 results, it appears that the sediment-accumulation rate is very low but considering the various elements of uncertainty involved with the method, it is not appropriate to report a precise rate. Each sample was from a 0.10-foot segment of a core, and the assumed compression may not have been proportional throughout the length of the core. If the distance from the top of the core to the cesium-137 concentrations associated with 1964 or 1952 had been on the order of several feet, then it would have been appropriate to divide the distance by 36 or 48 years to calculate an approximate rate of sediment accumulation.

The cesium-137 profiles shown in figure 6A may simply show the effects of low-level nearly constant mixing on a low rate of sediment accumulation. Wetzel (1983) reported that even deepwater sediments of many lakes are disturbed to the depths from millimeters to centimeters by resuspension and redeposition caused by wind. Such a process could smooth a cesium-137 peak associated with 1964 and produce the gradual decrease observed in all of the cores. If this occurred, then the first deposition of cesium-137 above background levels in 1952 would be at a depth of less than 0.4 foot for core 1, which was collected in the southwestern part of the lake. The true depth associated with 1952 would be affected by the depth of mixing and the compression of the sediment during the collection of the core. The true depths associated with 1952 would be at less than 0.7 foot for cores 3, 4, and 5, which were collected about 2 miles closer to the mouth than core 1. Based on the findings of Day and Butler (1998), deposition during 1952 in the southwestern part of the lake should have been at a depth of about 2.43 feet (fig. 6B), and the average rate of sediment accumulation from 1952 through 1998 would have been about 0.05 foot per year. An interpretation of the cesium-137 data, based on the assumptions that the cores were complete and the profiles were affected by mixing, indicates that the average rate of sediment accumulation was much less than this and closer to the rates of less than 0.01 foot per year indicated by other studies.

### Marine Seismic Surveys

The USGS conducted two marine seismic surveys of Lake Kampeska. The first was a reconnaissance-level survey performed along six transects (fig. 7) during June 1994 with a high-frequency (7 kilohertz), continuous seismic-reflection system. During October 2000, the second survey used a swept frequency (2-10 kilohertz), continuous seismic-reflection system along more than 30 transects (fig. 8). During both surveys a GPS was used to monitor horizontal position. An electronic strip-chart fathometer and a digital fathometer were used to record water depth. During the windier days, the vertical movement of the boat may have been on the order of plus or minus 1 foot from the lake level at the time.

During the surveys, the GPS base station receiver and antenna were located at a U.S. Coast and Geodetic Survey topographic station disk about 2 miles southeast of Lake Kampeska. The rover receiver and antenna were on the boat with the antenna positioned above the seismic transducer. The GPS information was processed using differential-correction techniques to determine the horizontal position during the surveys. During the 1994 survey, the GPS horizontal positions were related to the seismic and water-depth records by periodically (approximately every minute) marking the seismic thermal chart and the fathometer chart and recording an associated GPS clock time. During the

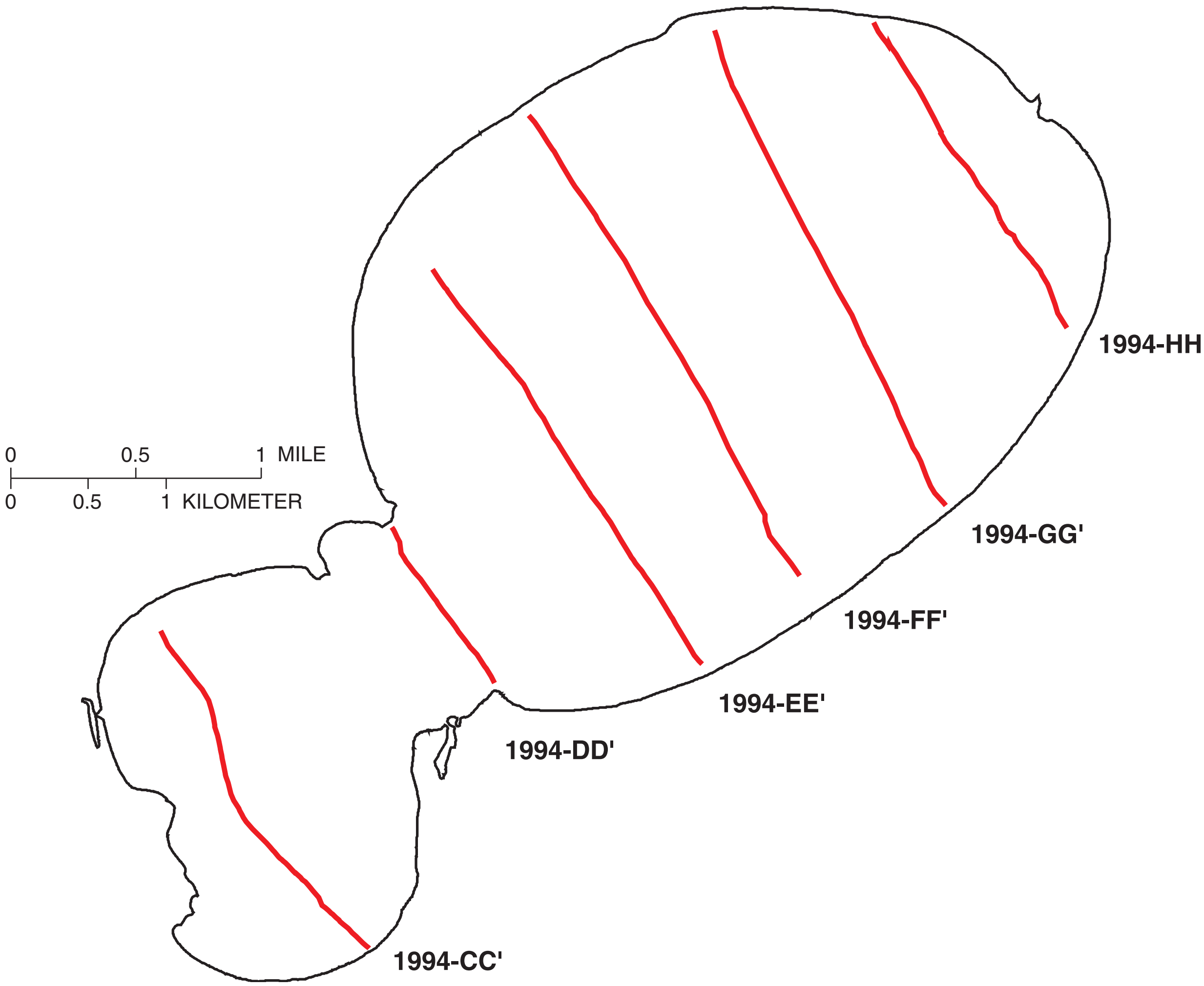


**Figure 7**. Transects of a marine seismic survey during June 1994.

2000 survey, the GPS coordinates were recorded every 10 seconds on the receiver and every second as part of the digital seismic record. During tests conducted as part of the 1994 survey, the GPS horizontal-position coordinates had an average error of 3.5 feet. GPS coordinates may have been slightly more accurate during the 2000 survey because the quality of the satellite signals had improved, but no additional tests were conducted.

The transects do not extend to the lake shore because the boat had limited maneuverability at low speeds, with the heavy and expensive seismic transducer being towed alongside the boat. The six transects of the 1994 survey were designed to provide a general overview of the lake bottom and subbottom and evaluate the effectiveness of the technique. The names for these transects all start with “1994” and the last part of the name is a letter code based on the relative position of the transect, southwest to northeast. The most southwestern of the six transects is 1994-CC′, and the most northeastern of the transects is 1994-HH′ (fig. 7). The transects of the 2000 survey were designed to provide a comprehensive data set describing the lake bottom and subbottom. The names for the transects all start with “2000” and end with a transect code (fig. 8). The transect codes are based on the number of the transect from 1 through 28 and sometimes a letter A or B. Some transects were not completed during the first attempt because of high wind, rain, or equipment malfunctions. If more than one attempt was needed for a transect, an “A” is used to designate the path of the first attempt and a “B” is used to designate the path of the second attempt.

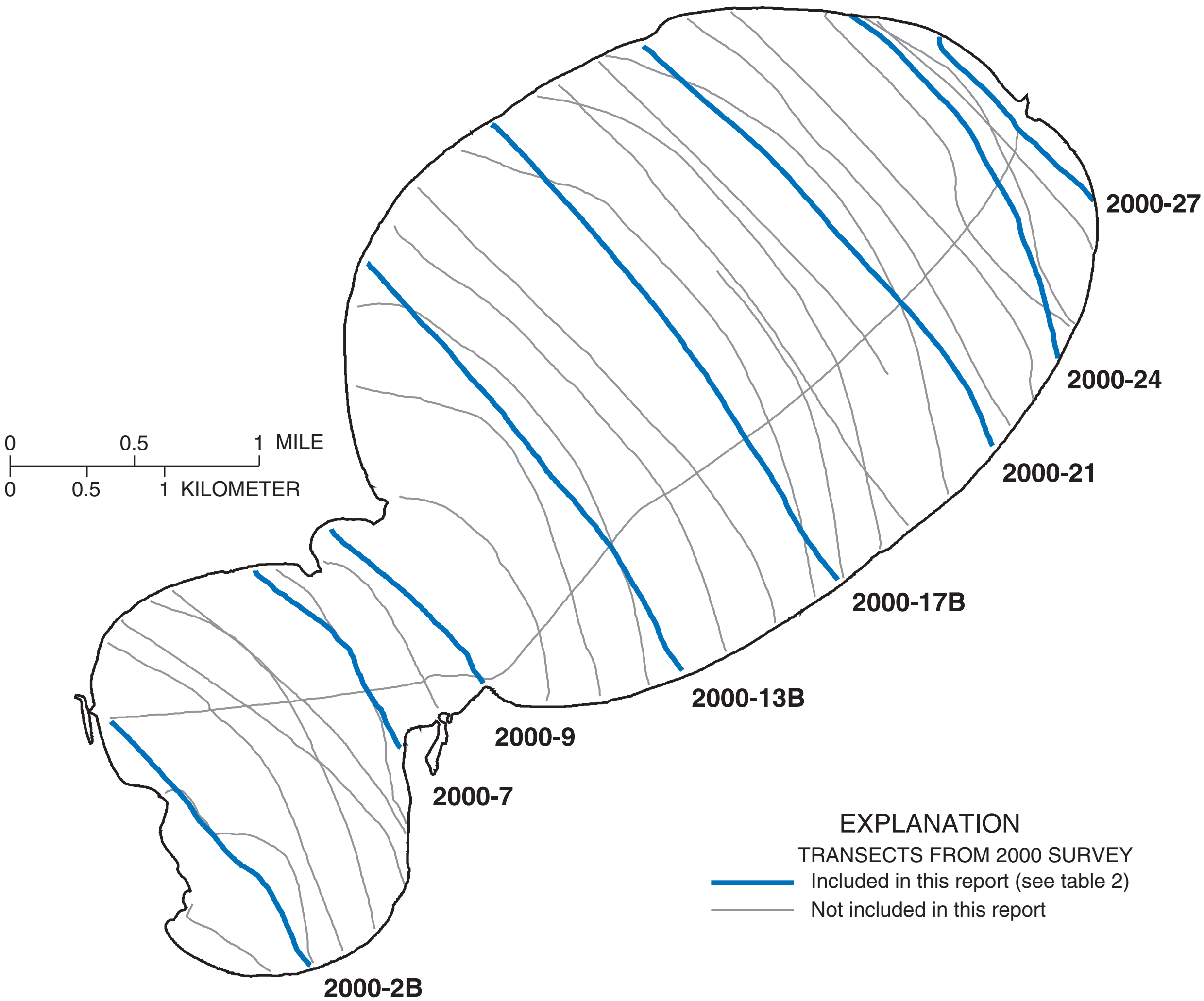


**Figure 8**. Transects of a marine seismic survey during October 2000.

Continuous seismic-reflection systems transmit and receive high-energy acoustic signals through the water column and the subsurface. When the signal encounters layers of different acoustical properties (primarily dependent on material density), part of the signal is reflected back to the receiver at the water surface and part penetrates farther into the sediment. The strength of the reflection primarily is dependent on the contrast in density between two adjoining layers. In general, the more dense the lower layer, the more the signal will tend to be reflected and the less the signal will tend to travel into the lower layer. The average velocity of sound in pure water and saturated sediments—approximately 5,000 cubic feet per second (Gorin and Haeni, 1988)—was used in determining the thickness of the sediment based on the seismic record. During the surveys of Lake Kampeska, the greatest interest was in the reflection at the bottom of the sediment and what is assumed to be the original lake bottom (subbottom). In general, higher frequencies provide better resolution but poorer penetration of the sediment, and lower frequencies provide poorer resolution but better penetration of the sediment. Pre-survey testing conducted on Lake Kampeska during 1994 and 2000 was used to choose the best frequency options, but neither survey was very successful in defining the subbottom of the lake.

The depth of penetration by the marine seismic signal is affected by the type of sediment encountered. The fine-grained sediment in Lake Kampeska is not easily penetrated by the signal. The ineffectiveness of the seismic system in some areas probably was due to the presence of gas from the decomposition of organic material in the sediments. Accumulated gas can act as a strong reflector of the acoustic signal and result in multiple signals that obscure deeper reflectors in the seismic record (Sando, 1996). The areas where the seismic system was ineffective may be associated with greater accumulation of organic material and gas production. The swept-frequency system has the advantage of using a multi-frequency signal to increase the possibility of penetrating the sediment of interest, and it has been used in other studies around the United States to define subbottom structure at depths of tens to hundreds of feet (Eric A. White, U.S. Geological Survey, written commun., 2000). The 1994 and 2000 surveys of Lake Kampeska had limited success defining the subbottom, with what appears to be a maximum penetration depth of less than 20 feet. It is unknown if the subbottom was not detected in some areas because the signal penetration depth was severely limited or because thicker sediment inhibited the return of the seismic signal.

#### 1994 Water Depth and Sediment Thickness

A standard electronic strip-chart water-depth fathometer was used to determine water depth. Accuracy of the water-depth record was determined by comparison to a second concurrently operated digital water-depth fathometer and also by comparison to water depth indicated in the seismic record. Comparison of the strip-chart fathometer record with the concurrently operated digital fathometer generally indicated agreement within 0.3 foot. The individual transects are described in a later section, but, in general, they present water-depth data and the same basic lake-bottom shape as the other data sets from the other studies.

A strong, undulating reflector was apparent in some of the seismic record, especially in the southwestern part of the lake, and was interpreted to be the subbottom. The subbottom is most completely defined along transects 1994-CC′ and 1994-DD′ (fig. 7).

#### 2000 Water Depth and Sediment Thickness

During the 2000 marine seismic survey, the digital fathometer usually recorded the water depth every 2 to 3 seconds during which time the boat might have traveled about 4 to 6 feet on the surface of the lake. The lake bottom was digitized in the seismic record. Using time as a common variable, the two data sets were merged, and the depths recorded by the digital fathometer were assigned to locations digitized from the seismic record. Some editing was done to reduce the variability associated with vertical movement of the boat during windy days and to interpolate where there were gaps in the merged data set.

Because the 2000 water-depth data were considered to be the most accurate data available from 1990-2000, these data provided the primary data used to generate a modern water-depth map of the lake. This map is described and presented in the Supplemental Information section at the end of this report.

Reflectors identified below the lake bottom were digitized in the seismic record, and these distances were subtracted from the lake-bottom data set described above. Like the 1994 survey, the method was the most effective in the southwestern part of the lake and along the near-shore areas.

## Comparison of Information from Various Sources and Times

The water-depth and sediment-thickness information from the previously described studies was put into a GIS. Calculations were performed to determine the associated elevations, and this elevation information was used to create cross sections across Lake Kampeska showing the water depth and sediment thickness. These cross sections provide the opportunity to make comparisons of data collected from various times and to look for trends related to the deposition of sediment in the lake over the time span of the studies. The location of selected transects used for comparison along with the locations of sediment cores and 1951 lake-bottom-elevation contours are shown in figure 9.

Cross sections along selected transects (table 2, fig. 9) are presented in figures 10-17. The selected transects are organized first by group (tail, body, and mouth) and then by subgroup. Although care was taken to select transects that were close to each other for each subgroup, the transects from the different studies are not coincident so they cannot be compared directly to each other. However, each of the selected transects does cross the lake-bottom-elevation contours based on the water-depth map shown in Barari (1971), and these elevations are shown on each of the cross sections and provide a common basis for comparison.

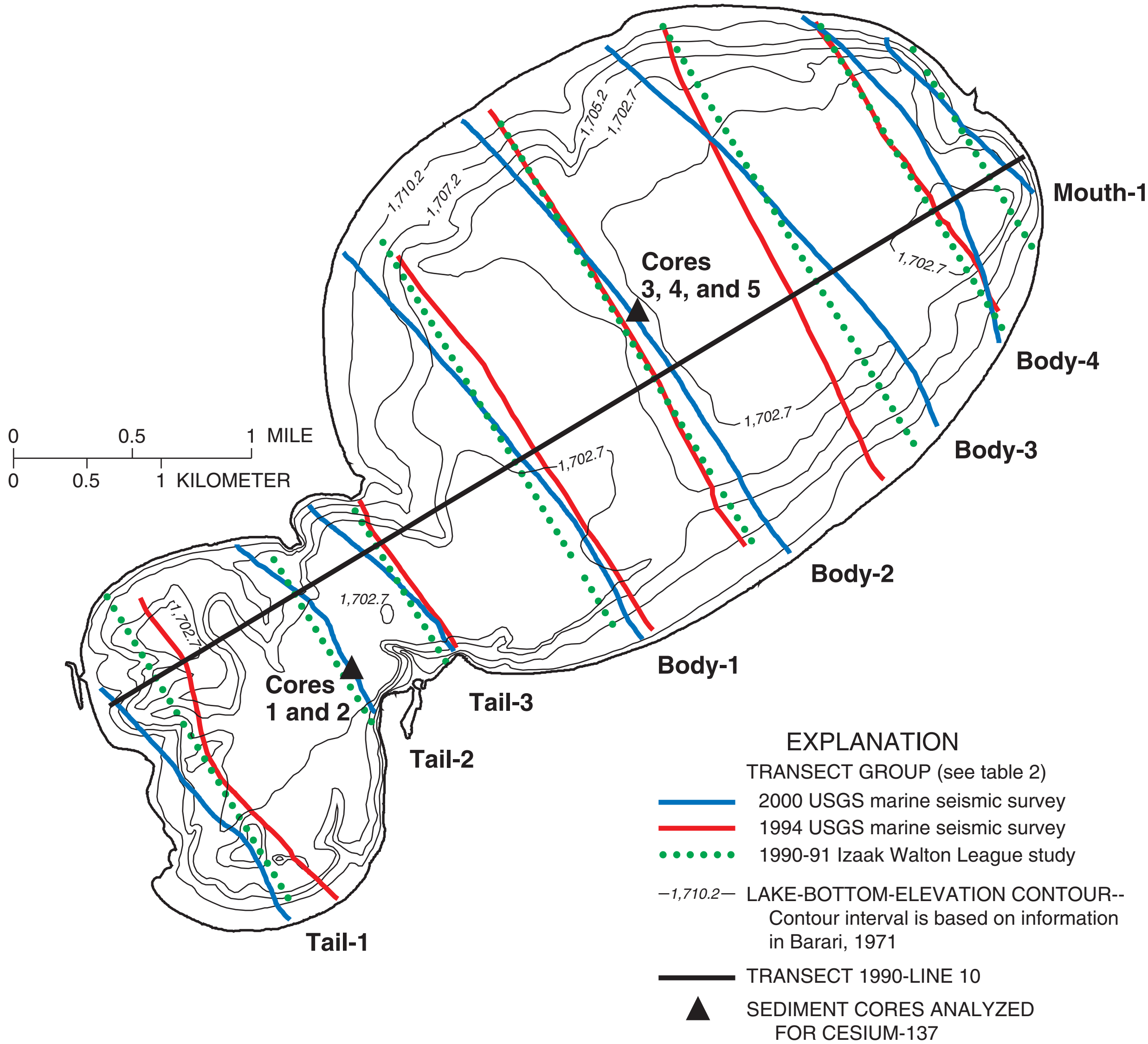


**Figure 9**. Selected transects used for comparisons between studies. Sediment core locations and 1951 lake-bottom-elevation contours also are shown.

**Table 2.** Selected transects used for comparisons of cross sections across Lake Kampeska

| Group | Subgroup | Name | Transects during 2000 | Transects during 1994 | Transects during 1990-91 |
|---|---|---|---|---|---|
| Tail | 1 | Tail-1 | 2000-2B | 1994-CC′ | 1990-6000W |
| Tail | 2 | Tail-2 | 2000-7 | None | 1990-2400W |
| Tail | 3 | Tail-3 | 2000-9 | 1994-DD′ | 1990-300W |
| Body | 1 | Body-1 | 2000-13B | 1994-EE′ | 1990-3300E |
| Body | 2 | Body-2 | 2000-17B | 1994-FF′ | 1990-6900E |
| Body | 3 | Body-3 | 2000-21 | 1994-GG′ | 1990-11100E |
| Body | 4 | Body-4 | 2000-24 | 1994-HH′ | 1990-14100E |
| Mouth | 1 | Mouth-1 | 2000-27 | None | 1990-15600E |

The subgroups of selected transects are numbered, starting in the southwest part of the lake. Most subgroups consist of a transect from the 2000 marine seismic survey, a transect from the 1994 marine seismic survey, and a transect from the 1990-91 Izaak Walton League survey. Subgroups tail-2 and mouth-1 do not include a transect from the 1994 marine seismic survey. The cross sections for each subgroup are presented in figures 10-17, each with the cross section from the 2000 marine seismic survey on top, the cross section from the 1990-91 Izaak Walton study on the bottom, and the cross section from the 1994 marine seismic survey, if one is included, in the middle. The order from top to bottom is based on the amount of elapsed time between the data collection for the three studies and the water-depth data collected in 1951 (Barari, 1971). The greatest opportunity to observe any increase in sediment accumulation and lake-bottom elevation since 1951 should be in comparison to the high-resolution lake bottom defined by the 2000 marine seismic survey.

For each cross section, the horizontal location is reported as the distance to the northwest or southeast of transect 1990-line 10 (fig. 9). The transects do not follow common paths, do not have common endpoints, and do not have common lengths, but they do all cross 1990-line 10. Using 1990-line 10 as a common reference line makes it easier to compare transect to transect within the subgroup and from group to group than if distances had been reported relative to the northwest end of the transect or from some other reference line.

The cross sections in figures 10-17 all have the same horizontal and vertical scale, which is the same horizontal and vertical scale used for the 1990-line 10 graph (fig. 3). The horizontal scale was limited by the space needed for the 1990-line 10 graph. The vertical scale ranges from 1,720 feet, a little more than the normal lake level of 1,717.8 feet, to 1,680 feet, an estimate of the bottom elevation of the Big Sioux aquifer based on drill-hole data from around the lake (Putnam and Thompson, 1996, p. 6).

## Tail

Three subgroups of selected transects are used to examine the tail part of the lake (fig. 9). The transects of tail-1 cross the wide part of the tail, and the transects of tail-2 and tail-3 cross the narrow part of the tail.

The transects of tail-1 (2000-2B, 1994-CC′, 1990-6000W) are not very close to each other and they cross the part of the lake with the most variable lake-bottom elevation (fig. 10), which makes comparisons of the transects difficult. It appears that the three transects match the 1951 data fairly well, although some of the relatively abrupt changes in lake-bottom elevation seen in the high-density data of the transects are associated with smoothed, less abrupt changes in the 1951 lake-bottom elevation.

This group of transects shown in figure 10 covered the area of the lake where the seismic surveys and the Izaak Walton League study were best able to penetrate the sediment and define the subbottom. These graphs provide relatively complete examples of a pattern that is seen less clearly in transects from the rest of the lake. They show a relatively steep-sided lake with a relatively flat, featureless lake bottom, but they also reveal that the flat areas are sediment-filled troughs with a relatively irregular subbottom.

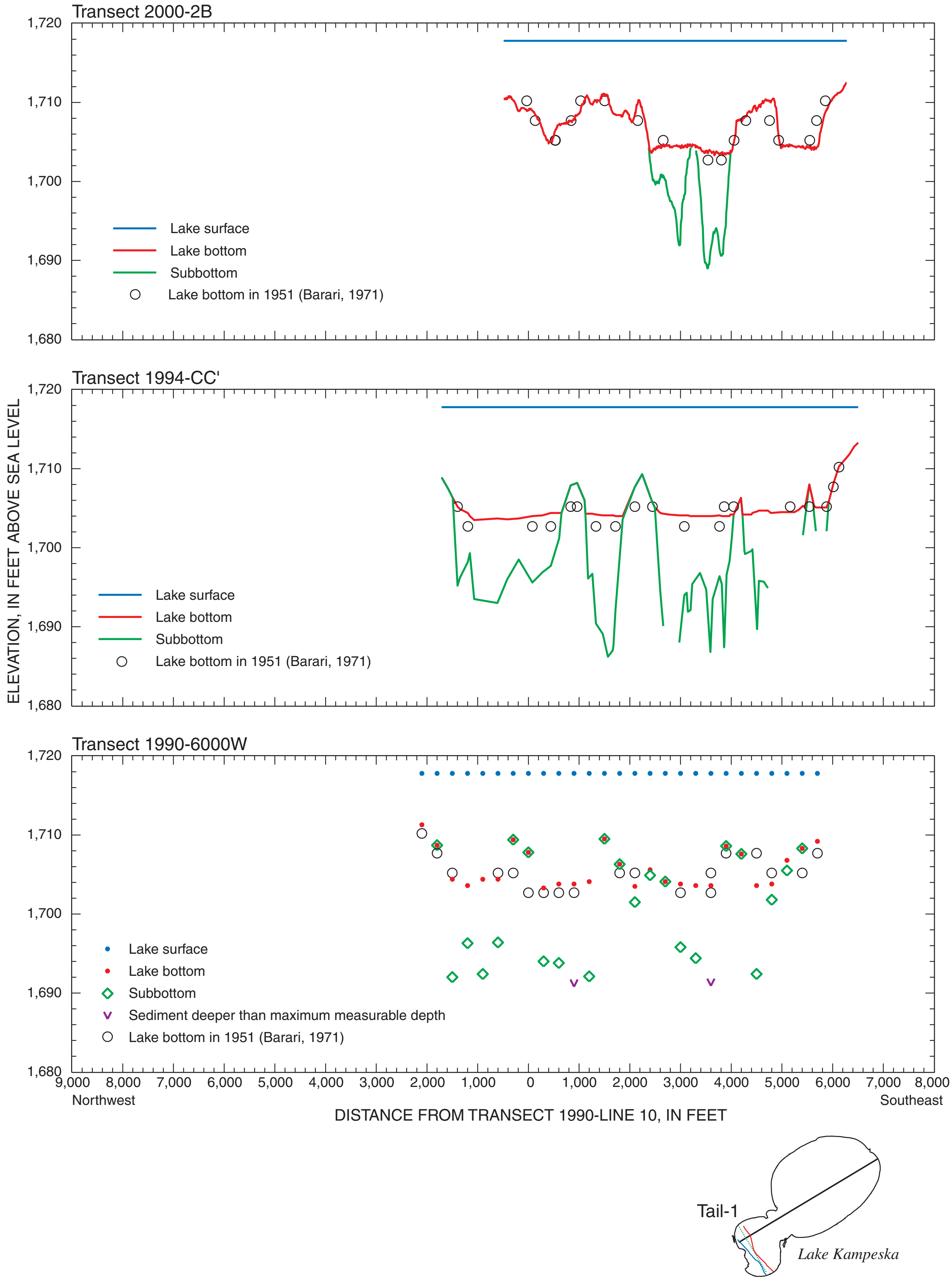


**Figure 10.** Cross sections for tail-1 transects across Lake Kampeska.

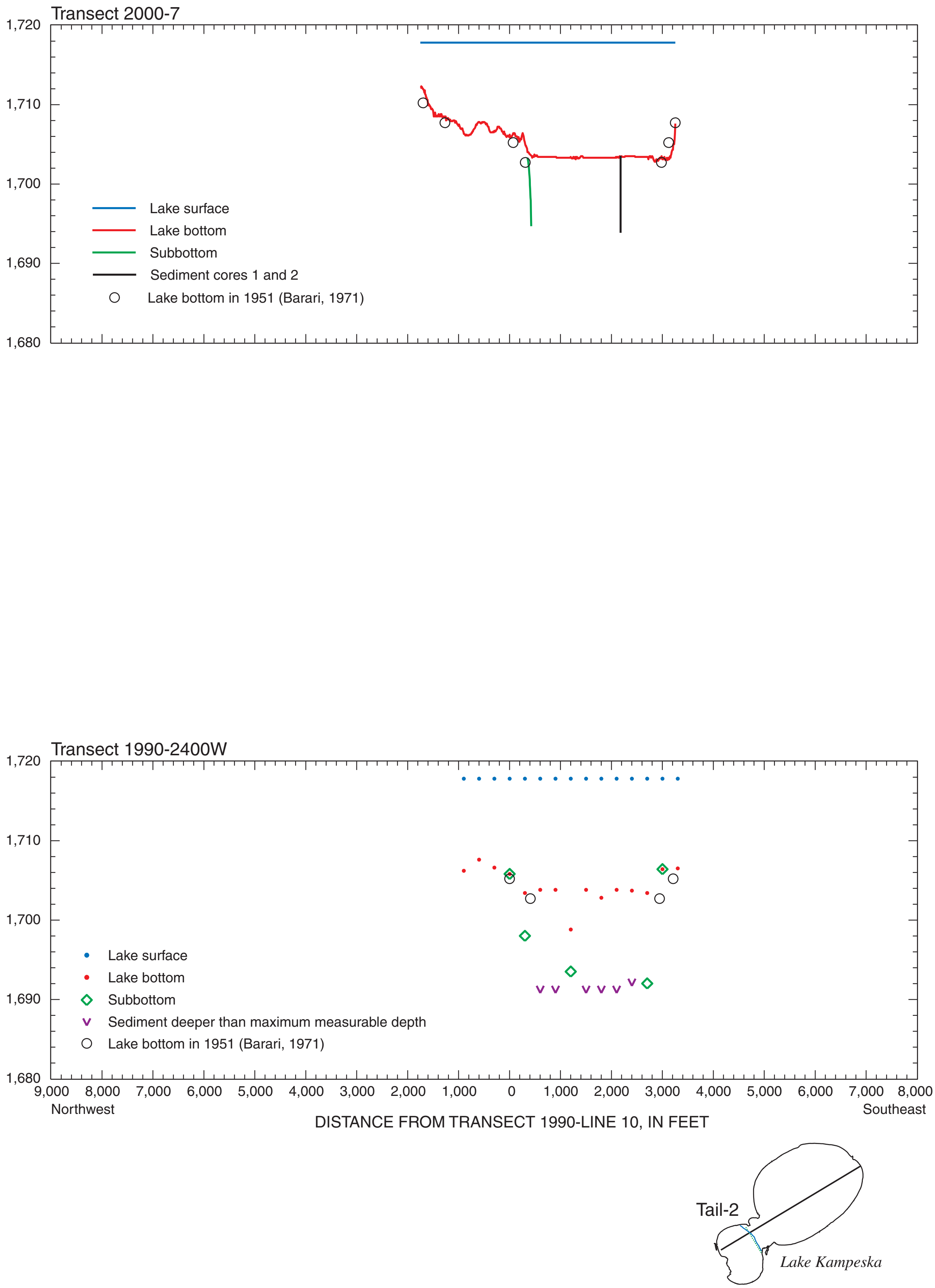


**Figure 11.** Cross sections for tail-2 transects across Lake Kampeska.

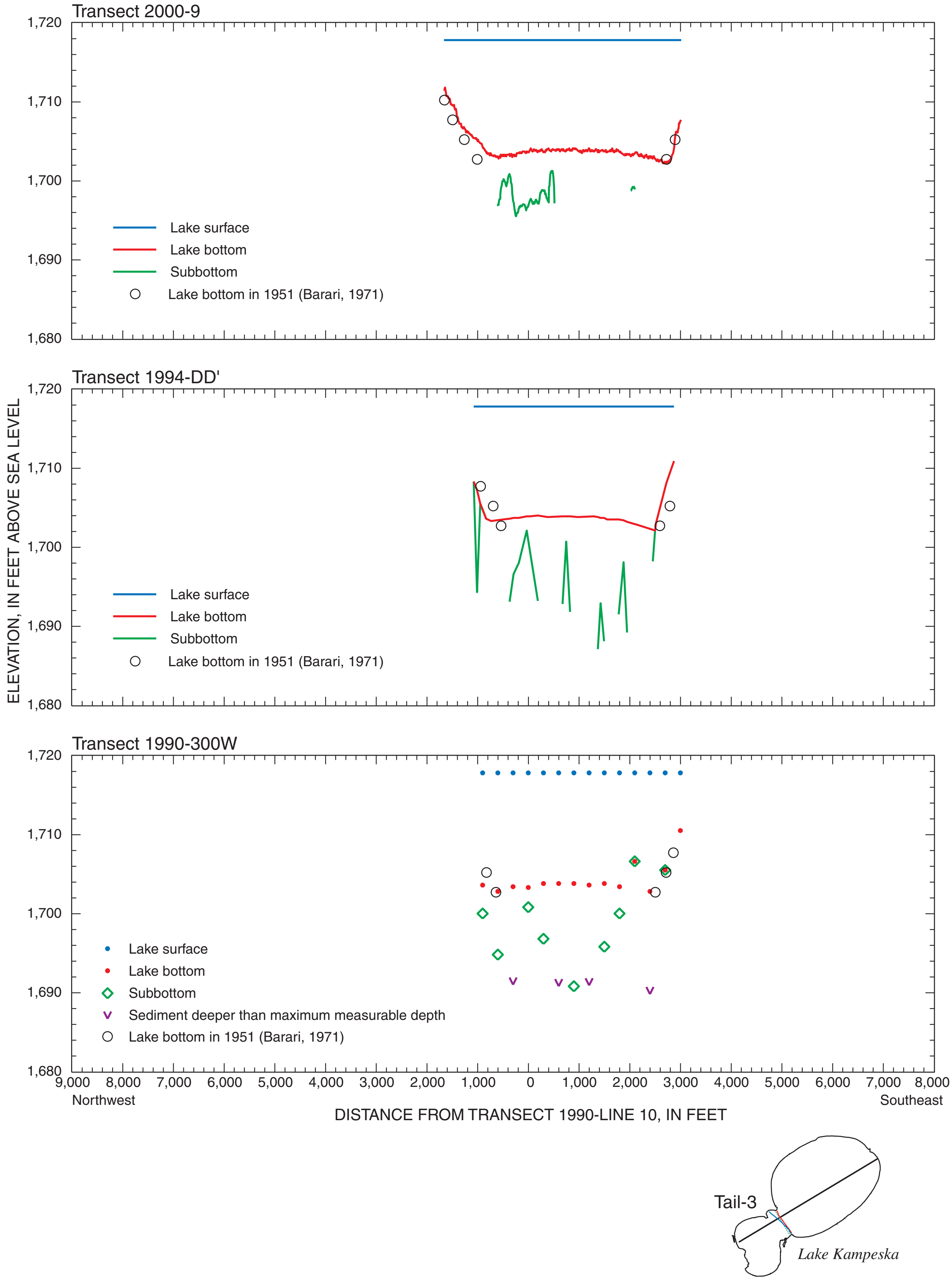


**Figure 12.** Cross sections for tail-3 transects across Lake Kampeska.

The transects of tail-2 (2000-7, 1990-2400W) and tail-3 (2000-9, 1994-DD′, 1990-300W) are fairly close to the other transects within the respective subgroup, especially on the southeast side of 1990-line 10 (fig. 9). The transects of tail-2 and tail-3 match the 1951 lake-bottom elevations fairly well (figs. 11 and 12) although there are no elevation contours along the central parts of the transects for comparison. Both subgroups show the relatively abrupt change from no sediment to thick sediment at the transition from side to flat-bottom interior, tail-2 along the northwestern side of the lake and tail-3 along the southeastern side of the lake. Sediment cores 1 and 2 were collected about 20 feet southwest from transect 2000-7, and the gravity corer penetrated 9.7 feet of sediment at that site. At 1,200 feet southeast of 1990-line 10, transect 1990-2400W (fig. 11) shows a relatively abrupt decrease in lake-bottom and subbottom elevation. This is an accurate depiction of the values in the field notes; however, the existence of such a trough feature is unlikely because the nearby portion of transect 2000-7 does not show any evidence of such a feature, and the soft sediment seen in the cores probably would not retain such a shape for any extended period of time. This apparent lake-bottom trough and subsurface peak may be the result of a measurement, communication, or transcription error.

### Body

Four subgroups of selected transects are used to examine the body part of the lake (fig. 9). They show the similar general form of a relatively steep-sided lake with a relatively flat, featureless lake bottom (figs. 13-16) as seen in the tail. Sediment cores 3, 4, and 5 were collected about 100 feet northeast of transect 2000-17B of subgroup body-2 (fig. 14). The analysis of the cesium-137 profiles for those cores indicates that the total sediment accumulation in the collection area from 1952 to 2000 probably is less than 1 foot. The lake bottoms defined by the 1990-91, 1994, and 2000 studies match the 1951 lake-bottom elevations with the 2.5-foot contour interval fairly well. The limited comparisons in the interior of the lake indicate that water depths may have decreased by about 1 foot since 1951, but considering the many factors affecting the accuracy of the data sets, the conclusion that this difference was caused by sediment accumulation can not be made with confidence.

The cross sections for all four subgroups (figs. 13-16) also show the relatively abrupt change from no sediment to thick sediment at the transition from side to flat-bottom interior. Some scattered subbottom features were detected along the middle parts of the transects, but the sediment thicknesses of 10 feet or more in much of the interior of the lake limited the effectiveness of the seismic surveys and prevented the probes used during the Izaak Walton League study from reaching the subbottom.

Transect 2000-24 (fig. 16) generally is a little farther to the northeast than the other two transects of body-4 (fig. 9). The small increase in lake-bottom elevation at about 1,300 feet northwest of 1990-line 10 appears to be associated with deposits of coarser grained sediment, such as sand and gravel, from the Big Sioux River.

### Mouth

The transects of mouth-1 (2000-27, 1990-15600W) cross the northeast end of the lake (fig. 9) near the surface-water connection to the Big Sioux River. They cover an area where the lake bottom has more variability than much of the rest of the lake; this makes comparisons between the two surveys more difficult. Transect 2000-27 shows the steep sides of the lake, but rather than the flat interior seen in much of the rest of the lake, in this area, the lake-bottom elevation increases to a peak at about 1,600 feet northwest of transect 1990-line 10 (fig. 17). This lake-bottom high is in an area where the bottom material has been identified as “gravel” (fig. 5) by Blackwell (2001) and “sand” (fig. 4) by the Izaak Walton League study. These coarser grained sediments are assumed to have been brought into the lake by the Big Sioux River, and the nearly 4-foot increase in lake-bottom elevation between 1951 and 2000 may have been deposited during several high-velocity events (floods) rather than gradually over time. This may be the only area of the lake where significant deposition has occurred during this interval.

Along transect 1990-15600W, the sediment was several feet thick in the area near 1990-line 10, but to the northwest and southeast, sediment thickness was zero. Between 1991 and 2000, events such as the record flood of 1997 (Teller and Burr, 1998) may have brought in enough sand in the area so that the seismic signal was reflected, and this may explain why the sediment was not observed along the transect 2000-27 cross section.

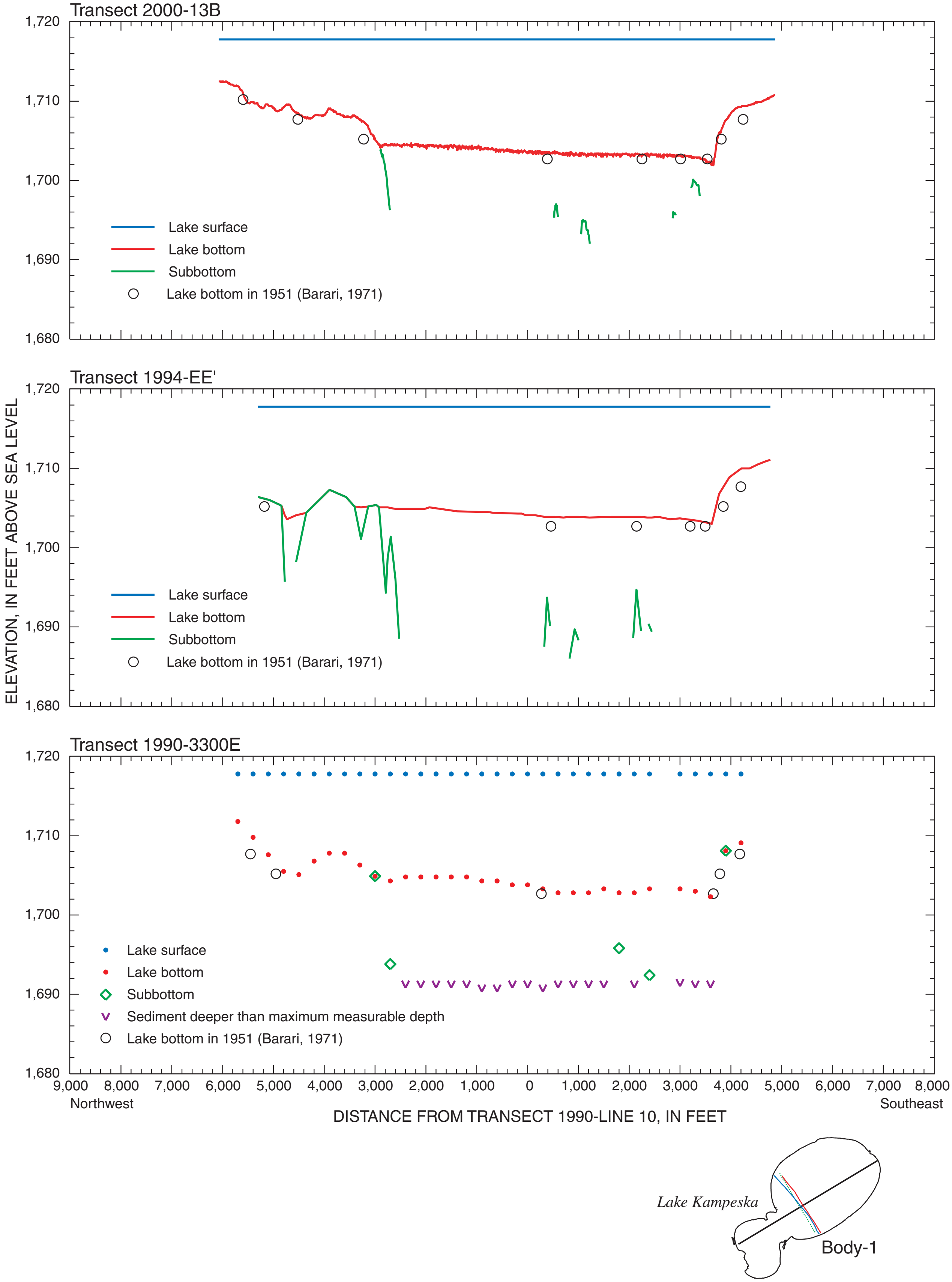


**Figure 13.** Cross sections for body-1 transects across Lake Kampeska.

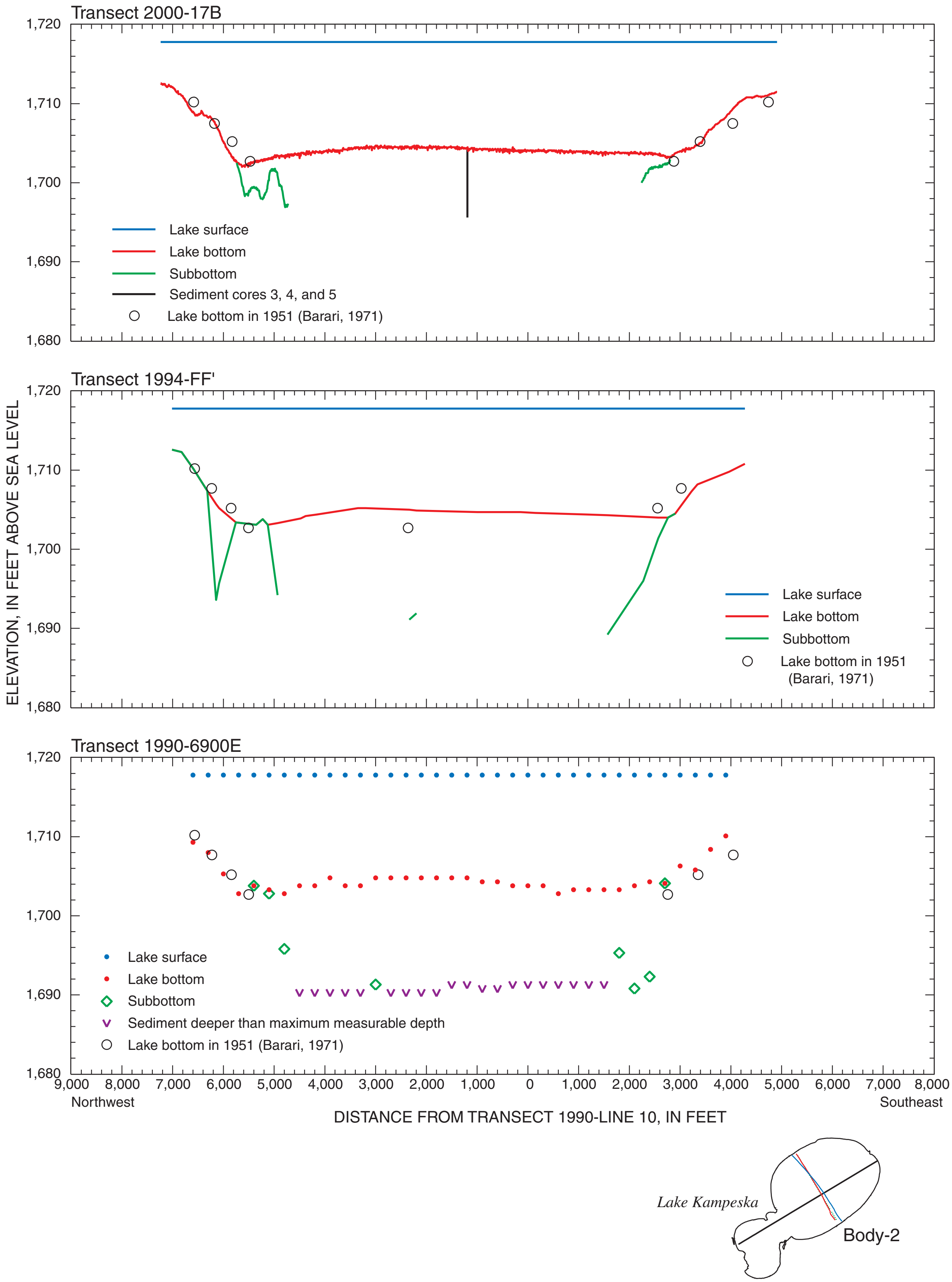


**Figure 14.** Cross sections for body-2 transects across Lake Kampeska.

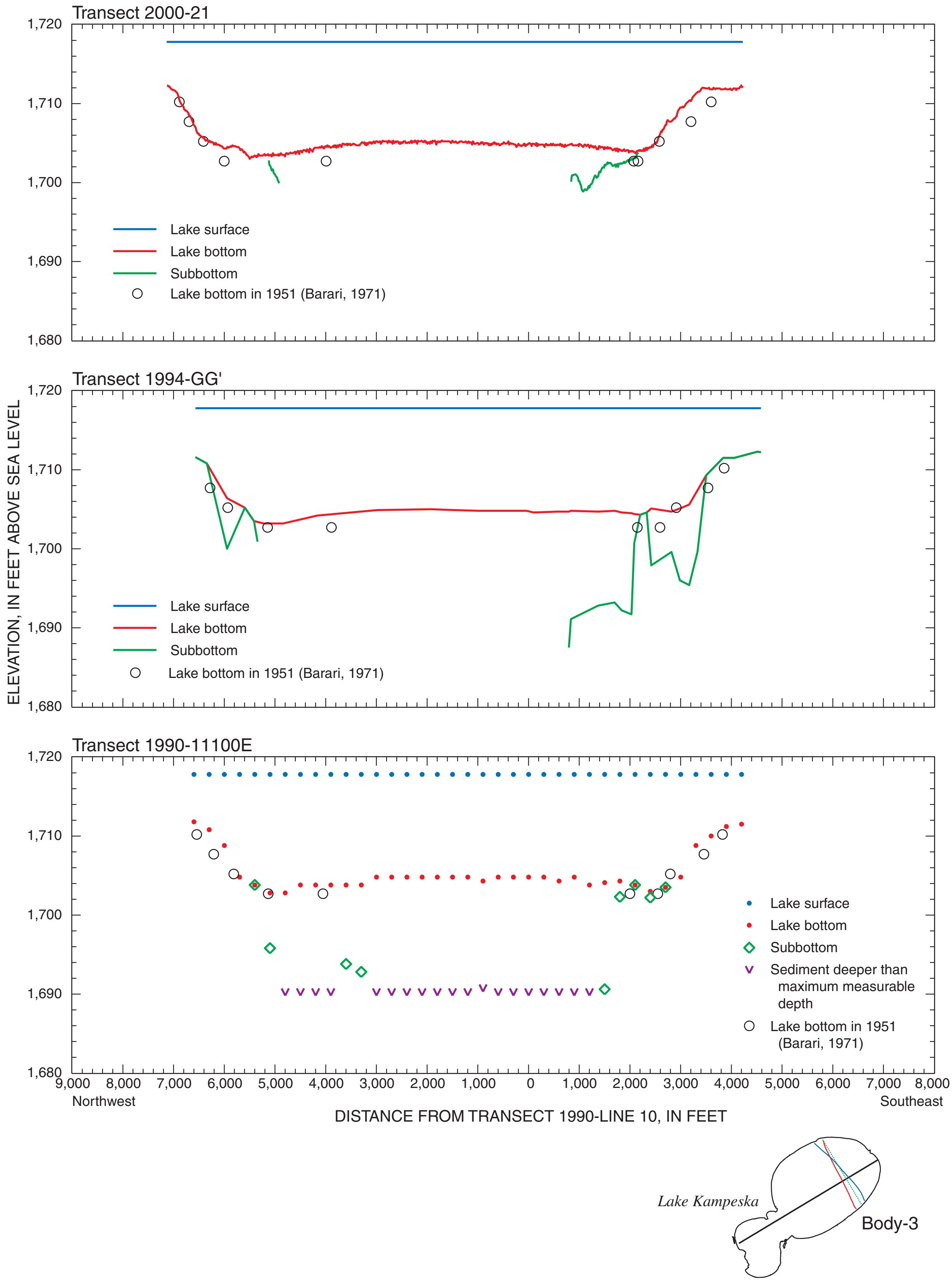


**Figure 15.** Cross sections for body-3 transects across Lake Kampeska.

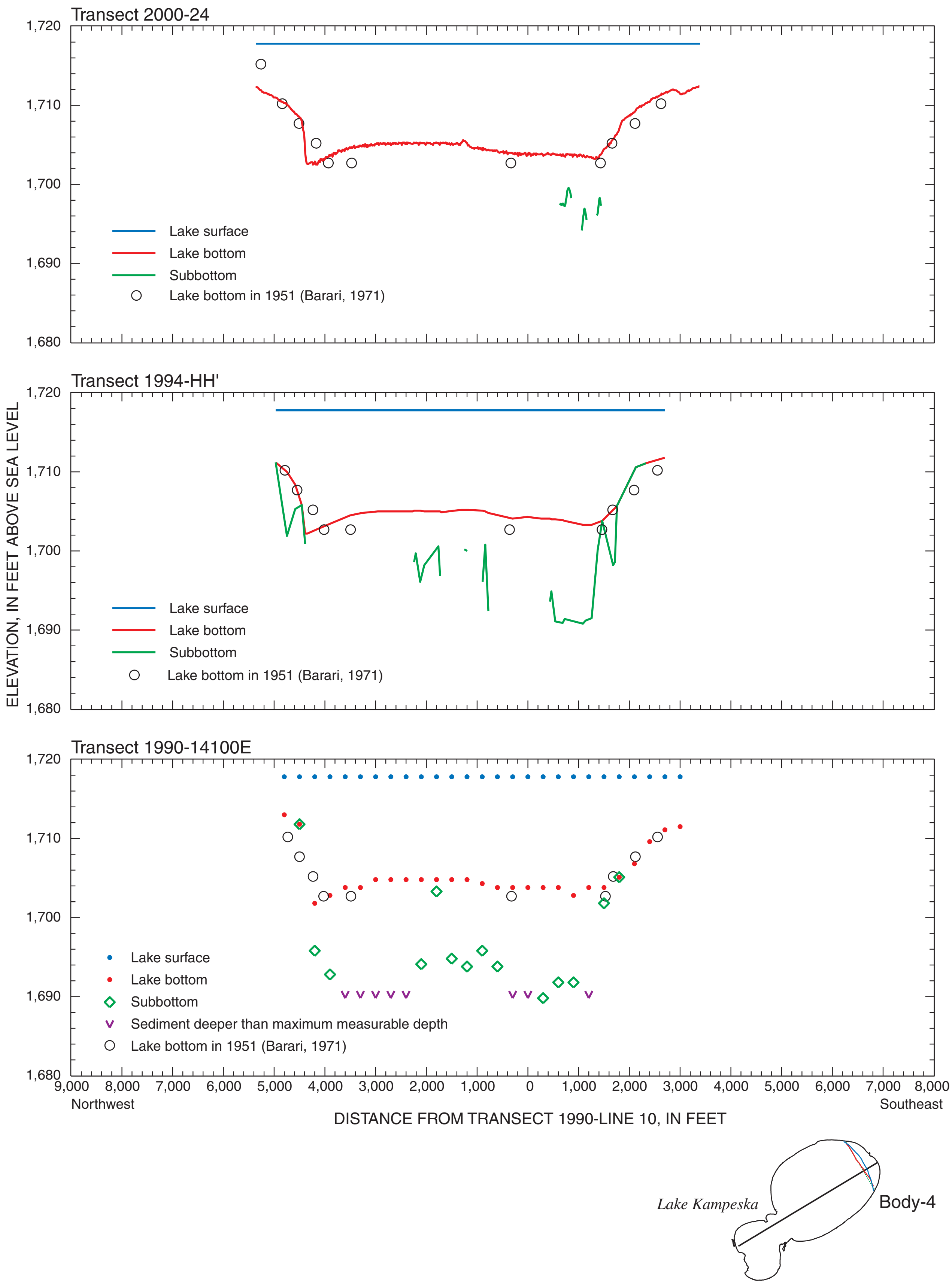


**Figure 16.** Cross sections for body-4 transects across Lake Kampeska.

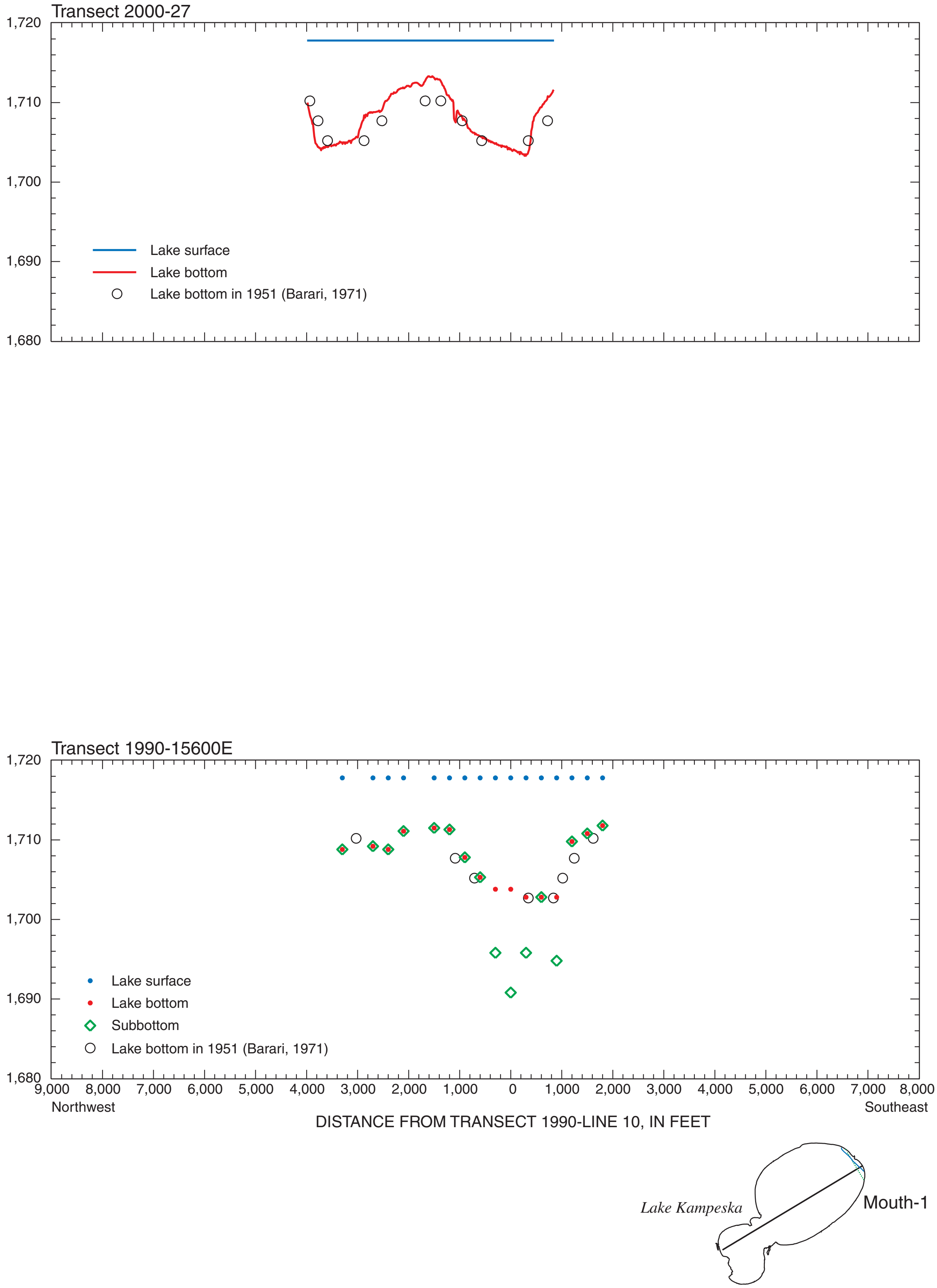


**Figure 17.** Cross sections for mouth-1 transects across Lake Kampeska.

## SUMMARY

The sediment in Lake Kampeska has been a concern for many years because of the value of the lake as a water source and recreational area. Several studies have been conducted to learn more about the sediment, including its rate of accumulation and distribution. Previous studies have provided information regarding water depth, sediment thickness, lake-bottom material, and the lake boundary.

The sediment cores for this study were collected in the deep-water areas in the southwestern and central parts of the lake. At each site, the maximum cesium-137 concentrations were from the samples nearest the top of the cores, and background levels of cesium-137 associated with pre-1952 deposition (prior to worldwide nuclear testing) were encountered at about 0.7 foot or less from the top of the cores. The lack of a distinct peak associated with 1964 when the amount of cesium-137 released into the atmosphere decreased as aboveground nuclear testing decreased may have been caused by resuspension and redeposition of the sediment. The true sediment depth associated with 1952 would be affected by the depth of mixing and the compression of the sediment during the collection of the cores. Based on analysis of cesium-137 concentrations and changes in lake-bottom elevation over time, the sediment accumulation rate is on the order of 0.01 foot per year or less.

During the nearly 50-year interval between the data collection for a water-depth map during 1951 and the collection of water depth for this study in 2000, any additional deposition appears to be less than the margin of error in the water-depth measurements except possibly in the area of the lake near the connection to the Big Sioux River. Farther into the lake, direct physical measurements and marine seismic surveys indicate that the flat bottom is associated with a relatively irregular subbottom. During 1990-91, measurements made on a 300-by-300-foot grid as part of a probing survey found that much of the lake had more than 10 feet of sediment. Marine seismic surveys conducted in 1994 and 2000 confirmed the results of the 1990-91 survey and provided additional evidence that sediment thickness in the flat-bottom interior part of the lake may be quite variable and the subbottom has much more relief than the modern lake bottom.

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# SUPPLEMENTAL INFORMATION

This study was not conducted for the purpose of creating an updated water-depth map for Lake Kampeska, but it was assumed that such a map would be created as part of the lake-wide analysis. The proposal for the study was based on the assumption that the lead-210 analysis of the sediment core had provided a minimum estimate of the sediment-accumulation rate, and that about 2.5 feet or more of sediment had been deposited throughout much of the lake during 1951-2000. The plan was to create a 3-dimensional surface of the lake bottom for the individual water-depth data sets of 1951, 1990-91, and 2000. These surfaces could have been compared using the GIS, and maps of changes in lake-bottom elevation, sediment thickness, and other variables, could have been generated. In fact, before the October 2000 field work was started, this approach was used to get an idea of what techniques worked the best for representing the hand-drawn lines of equal water depth from 1951 and the dense point data from 1990-91 as 3-dimensional surfaces, and to get an idea of the differences that these data sets and methods could be used to demonstrate. These early tests indicated that there was very little overall difference between the two data sets. Localized differences were associated, in part, with the density of the basic information, the choice of cell size, and other factors associated with the representation of the lake bottom, rather than in any changes in the lake bottom itself between 1951 and 1990-91. There was some possibility that the large flood in 1997 had deposited considerable amounts of sediment in the lake, and that changes between 1990-91 and 2000 could be mapped using this method.

Comparisons of water-depth information along transects across the lake indicated that there was very little evidence for any significant deposition except near the connection with the Big Sioux River. The cesium-137 results indicated that, at least at two sites in the deeper part of the lake, sediment accumulation was less than 1 foot during the nearly 50-year interval, and that this rate of change was much too small to be mapped using these methods and this time interval.

Data collected during 1990-2000 were used to create a modern water-depth map of the lake relative to 1,717.8 feet calculated (fig. 18). The 2000 water-depth data were considered to be the most accurate, and a thinned-down version of the data along the transects was used to provide the primary data for the new lines of equal water depth. Information collected by the Kampeska Chapter of the Izaak Walton League was used for those areas with limited data from the 2000 survey. The boundary of the lake (water depth = 0) is from Blackwell (2001).

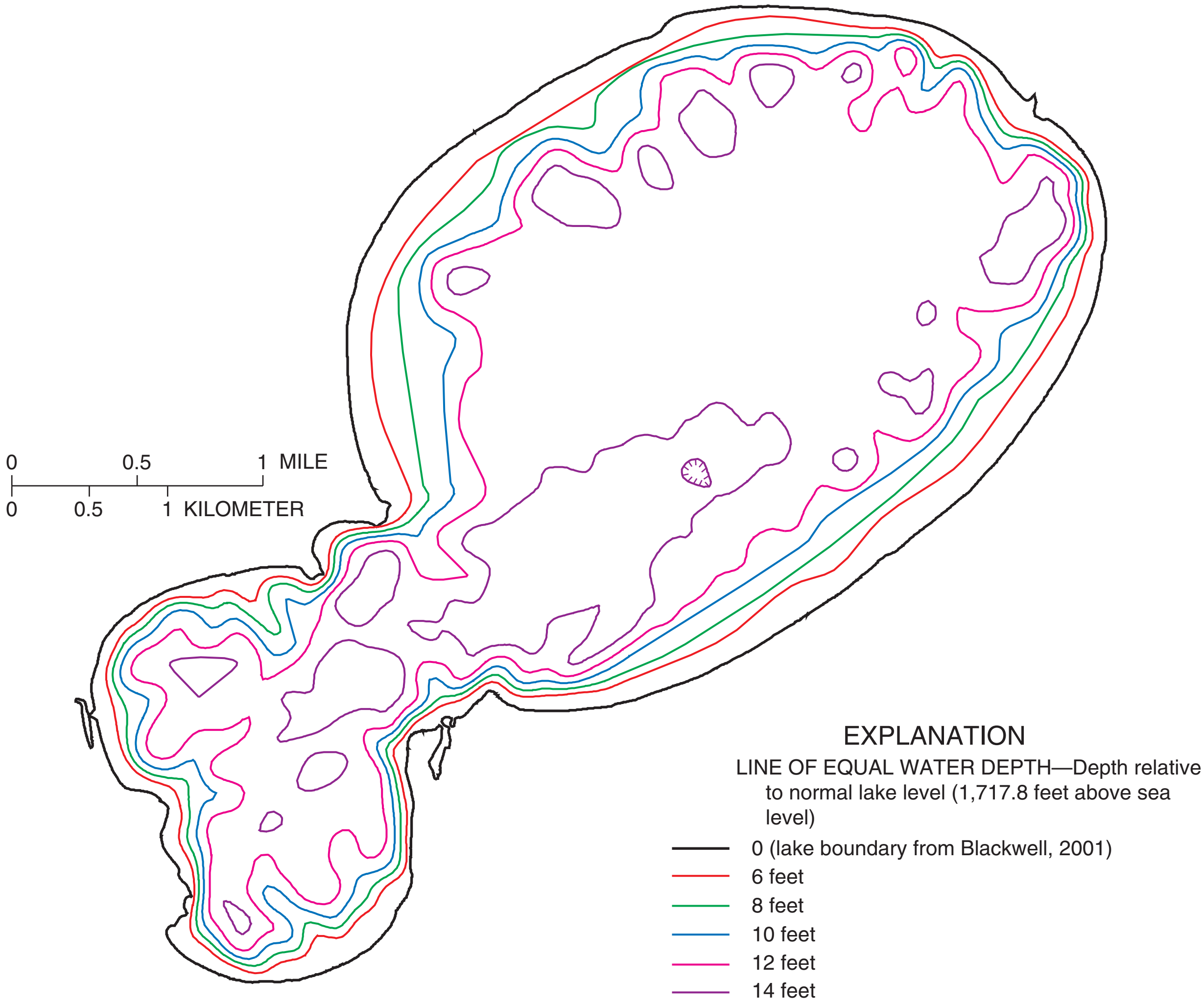


**Figure 18**. Water depth in Lake Kampeska based on 1990-2000 data.