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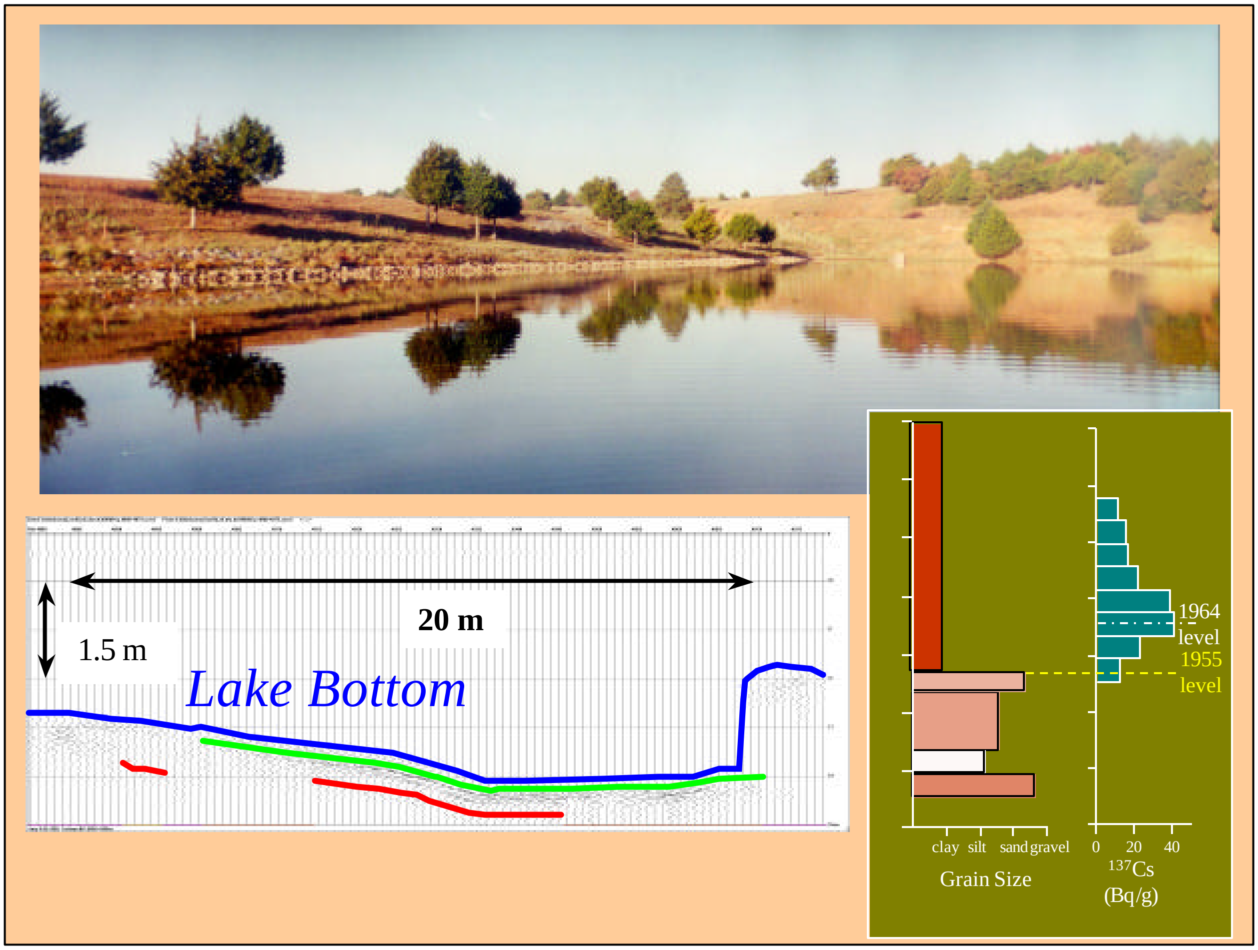
National Sedimentation Laboratory
Oxford, Mississippi 38655

Characterizing the Sediment Impounded by USDA-NRCS Flood Control Dams, Oklahoma



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A final report prepared for the USDA-NRCS, Stillwater, OK

Executive Summary

Since 1948, the USDA-NRCS has constructed over 10,000 upstream flood control dams in 2000 watersheds in 47 states, over two-thirds of these dams have a design life of 50 years. Because of population growth, land use changes, and time, sediment pools are filling, some structural components have deteriorated, safety regulations are stricter, and the hazard classification has changed for some dams. Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment. This report represents the completion of a demonstration project designed to evaluate technologies, methodologies, and protocols for the cost-effective characterization of this sediment.

Three field sites were chosen for this project. Sugar Creek #12 and Sugar Creek #14 are located near Hinton, OK, and historic land use of cultivated fields of cotton and peanuts at Sugar Creek #12 suggests that agrichemicals may be present in the lake sediments. Sergeant Major #4 is located near Cheyenne, OK, and it has become the sole water supply for the town of Cheyenne. Thus, preserving water quality is a major concern.

Seismic profiles were successfully obtained in each of the three reservoirs in Oklahoma. However, the very shallow water depths at Sugar Creek #12 and Sugar Creek #14 caused unwanted noise in the seismic signal, and the processed data are virtually impossible to interpret. The seismic profiles at Sergeant Major #4 show a number of distinct interpreted seismic reflectors in the subsurface, and select seismographs show some correlation to the stratigraphic boundaries observed in the sediment cores.

Ten continuous, undisturbed cores of lake sediment were successfully obtained at Sugar Creek #12. These cores are composed of sand, silt, and clay, but most of the deposited sediment is silt and clay in nearly equal proportions. Four continuous, undisturbed cores of lake sediment were successfully obtained at Sergeant Major #4. These cores are composed of poorly sorted gravel, sand, silt, and clay.

The analysis of sediment quality included 50 different pesticides, herbicides, PCBs, heavy metals, elements, and other contaminants. A total of 57 sediment samples obtained from these reservoirs were analyzed. Results from testing these sediments show very good overall sediment quality. Residual breakdown products of DDT and methyl parathion are found in low concentrations in all three reservoirs but such concentrations pose no health concern.

By using radioactive Cesium emission as a dating technique, relatively high rates of sedimentation are deduced at Sugar Creek #12, presumably related to a basin-wide historic conversion of forested areas to cropland and knickpoint erosion and channel degradation above the reservoir. The historic conversion of cropland to native seed grasses within the watershed of Sergeant Major #4 has resulted in relatively low rates of sedimentation.

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Acknowledgments

This project would not have been possible without the direction and cooperation of L. Caldwell and G. Miller, USDA-NCRS, Stillwater, OK. B. Elder, USDA-NRCS, Hinton, OK provided logistical assistance at the Sugar Creek sites. G. Allen and J. Swartwood, USDA-NRCS, provided logistical assistance at Sergeant Major #4 and provided land use, conservation practice, and herbicide/pesticide data for the watershed. During Phase I, we thank S. Testa and T. Welch for collecting and processing the sediment samples and R. Wells, D. Wren, and G. Nabors for assisting in the seismic surveys. We acknowledge the participation of P. Simpkin, IKB-Technologies, LTD., who conducted the seismic surveys, and the expertise and assistance of T. McGee and C. Lutkin, Mississippi Mineral Resource Institute, University of Mississippi, who processed the seismic data. During Phase II, we thank R. Wells and D. Wren for assisting in all sediment coring activities, F. Rhoton, V. Campbell, and D. McChesney for processing the sediment samples, and J. Ritchie for the Cesium analysis.

1. Introduction

1.1 Federal Program for Flood Control

In response to devastating floods of the 1930's and 1940's, Congress enacted legislation for the construction of flood control dams on small tributary streams. The Flood Control Act of 1944 (PL-534) authorized 11 projects in the United States. Since 1948, more than 3,400 flood control dams have been constructed in the 320 subwatershed projects covering more than 35 million acres in 12 states (Caldwell, 1999).

In 1954, Congress enacted the Watershed Protection and Flood Preventaion Act (PL-566), commonly referred to as the Small Watershed Program (Caldwell, 1999). Since that time, more than 6,300 flood control dams have been constructed in every state as well as Puerto Rico and the Pacific Rim, covering over 109 million acres.

The Pilot Watershed Program provided the transition between PL-534 and PL-566 (Caldwell, 1999). More than 400 flood control dams were constructed in 62 projects in 33 states, covering almost 3 million acres. In addition, the RC&D Program has provided technical and financial assistance to local sponsors for the planning, designing, and construction of more than 200 flood control dams since the 1960's.

In total, the U.S. Department of Agriculture, Natural Resources Conservation Service (USDA-NRCS) and its cooperators have constructed over 10,450 flood control dams in 47 states. More than $8.5 billion (1997 dollars) of federal funds and over $6.0 billion of local funds have been invested in these projects since 1948. This $14.5 billion infrastructure provides over $1 billion in benefits annually.

The primary purposes for these structures were to prevent flooding and to protect watersheds. Other dams were built or have evolved into structures for water management, municipal and industrial water supply, recreation, and the improvement of fish and wildlife, water quality, and water conservation. Local sponsors were to provide leadership in the program and secure land rights and easements for construction. The USDA-NRCS was to provide technical assistance and cost-sharing for the construction of these dams.

Flood control dams typically consist of an earthen embankment 6 to 20-m high with a principal spillway made of concrete pipe 0.3 to 1.8-m wide (Caldwell, 1999). Because the dams were built on small streams in the upper reaches of watersheds, upstream drainage areas range from 1.6 to 16 km^2. The majority of these dams were planned and designed for a 50-year service life. The inlet pipe of the principal spillway is placed at an elevation that would provide water retention for the design storm and storage for sediment accumulation. Each reservoir also has an emergency or auxiliary spillway for safe conveyance of water around the embankment when runoff rates exceed storage capacity.

1.2 Current Status of Small Watershed Program

At present, more than half of the dams constructed are older than 34 years and more than 1,800 will reach their 50-year design life within the next 10 years (Caldwell, 2000). A rapid survey conducted in April 1999 revealed more than 2,200 dams in need of immediate rehabilitation at an estimated cost of more than $540 million. The primary issues of dam rehabilitation are: replacement of deteriorating components, change in hazard classification, reservoir sedimentation, failure to meet dam safety regulations, failure to meet resource needs of the watershed, inadequate land and water rights, inadequate community benefits, and the potential transfer of responsibility. Common approaches to address rehabilitation typically involve dredging the reservoir to remove accumulated sediment, raising the dam to increase storage capacity, and removing or decommissioning the dam.

Rehabilitation of aging watershed flood control dams is critical to Oklahoma. Since 1948 more than 2,100 watershed flood control dams have been constructed including 1,140 in the Washita River Basin, which was one of the original 11 watershed projects authorized by PL-534. Many of these dams are in critical need of rehabilitation (Caldwell, 2000).

1.3 Problem Statement

Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment.

In response to a verbal requests by Larry Caldwell, State Conservation Engineer, USDA-NRCS, OK, and Glen Miller, Geologist, USDA-NRCS, the USDA-ARS National Sedimentation Laboratory and its partners at the University of Mississippi established a task force in September 1998 to address the immediate research needs of the USDA-NRCS. Members of this task force met with USDA-NRCS representatives in November 1998 and visited two reservoirs: Sugar Creek #12 near Hinton, OK, and Sergeant Major #4 near Cheyenne, OK. These two sites are of interest to the NRCS because (1) excessive sedimentation has occurred at Sugar Creek #12 and historic land use of cultivated fields of cotton and peanuts suggests that agrichemicals may be present in the lake sediments, and (2) the reservoir at Sergeant Major #4 has become the sole municipal source of water for neighboring communities, and water quality is a major concern.

For a given lake within an embankment flood control structure, the USDA-NRCS needs to determine (1) the volume of sediment deposited, (2) the rates of sedimentation, (3) the quality of sediment with respect to agrichemicals (related to agricultural practices) and petrochemicals (related to hydrocarbon extraction, drilling, and well development), and (4) the spatial distribution of the sediment quality. To this end, a demonstration project was designed to evaluate technologies, methodologies, and protocols for the cost-effective characterization of sediment.

1.4 Statement of Work

Three field sites were selected for this demonstration project. These are Sugar Creek #12, Sugar Creek #14 (also located near Hinton, OK), and Sergeant Major #4. The work as described below represents the recommendations of the task force and subsequent discussions with the USDA-NRCS, and the project was to be completed in two phases. Phase I entailed seismic surveying and sediment quality analysis of select samples at all three locations. Phase II entailed vibracoring and detailed sediment analysis based on results from Phase I. This report represents the completion of both Phase I and Phase II.

Below is a description of the techniques to be used in the demonstration project, and the products to be delivered.

1. Seismic Surveying: High-resolution seismic technology relies on the detection of reflected seismic waves from subsurface horizons. A horizon might include any sediment deposit that displays variations in composition (such as mineralogy), texture (such as sediment grain size or porosity), or structure (such as bedding planes). These variations can occur both with depth and spatially. All geophysical equipment will be mounted to a boat, and seismic profiles will be recorded along selected lines at boat speeds of several knots in water as shallow as 0.6 m deep. Upon completion of these soundings, the digitally recorded seismic lines will be post-processed, and reflected horizons identified and verified.

2. Vibracoring of Sediment: Undisturbed sediment cores will be extracted in water depths from 0.6 to 15 m using a vibracorer. An aluminum irrigation pipe, either 3 or 4 inches in diameter, will be connected to a high frequency vibration unit via a core driver and flange. The corer will be suspended from a tripod on a pontoon boat, and stabilizing buoys will ensure the core remains in a vertical position as it descends into the water. A check-valve within the core tube flange creates the suction necessary to retain the sediment during extraction. Once extracted, each core will be cut open, photographed, and logged, and samples of the sediment will be secured.

3. Sediment Analysis: First, the sediment in the cores will be subsampled at 0.1-m intervals and at the bounds of distinct horizons. Depending on the physical characteristics of the cores, these samples will be further analyzed for color, grain size distribution, and magnetic susceptibility. Magnetic susceptibility provides a stratigraphic signature that is related to the type and amount of iron-bearing minerals present and can be used for stratigraphic correlation. Second, based on the information provided by the USDA-NRCS on land use within each watershed, the following suites of chemical analyses are recommended, and these are grouped in Table 1-1. Each sample is depth-integrated except for Group 6. The sediment quality analyses recommended for Phase I and Phase II of the project are listed in Table 1-2. The number of samples and the types of compounds to be analyzed in Phase II will depend heavily on the results of Phase I as well as the distribution, stratigraphy, and thickness of sediment, and the results of a land use inventory for the watershed (to be provided to the USDA-ARS by the USDA-NRCS). The Appendix provides some

background information on toxicity levels for the chemicals and compounds examined herein.

Table 1-1. List of chemical groupings.

Group	Title	Elements/Compounds
(1)	U.S. Environmental Protection Agency Priority Pollutant Pesticide/PCB of potentially dangerous compounds	Pesticides: Aldrin, BHC-alpha, BHC-beta, BHC-delta, BHC-gamma, Chlordane, Toxaphene, DDD 4,4', DDE 4,4', DDT 4,4', Dieldrin, Endrin, Endrin aldehyde, Endosulfan I, Endosulfan II, Endosulfan sulfate, Heptachlor, Heptachlor epoxide PCBs: Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, and Aroclor 1260
(2)	U.S. Environmental Protection Agency Oil Field Contaminants	pH, Electrical Conductivity, Sodium Absorption Ratio, Cation Exchange Capacity, Exchangeable Sodium Percentage, Sodium, Potassium, Calcium, Magnesium, Oil & Grease, Arsenic, Barium, Cadmium, Chromium, Lead, Mercury, Selenium, Silver, Zinc
(3)	Herbicides and Insecticides	Command and Cotoran, Methyl Parathion, Lasso, Danitol and Thimet, Prowl, Dual, Karate, Lorsban
(4)	Rangeland	Nitrates, DDT, and metabolites (breakdown products from compounds such as DDT)
(5)	Sedimentation Rates	Cesium at 10 cm sampling; analyzing for Cesium may date specific horizons, hence sedimentation rates, based on known occurrences of nuclear testing (U.S., Russia, and China) and nuclear accidents (Chernobyl)

Table 1-2. Recommended sediment quality analysis for each field site for Phase I and Phase II of the demonstration project.

Site	Treatment	Phase	Groups
Sugar Creek #12	Cotton and peanuts	I	1 & 2
		II	3 & 5
Sugar Creek #14	Cotton and peanuts (minor amount)	I	1 & 2
Sergeant Major #4	Rangeland (with no herbicide application) and oil production	I	1 & 2
		II	4 & 5

1.5 Global Positioning Systems

In order to construct maps depicting all activities, two global positioning systems (GPS) were employed. A commercially-available, hand-held global positioning receiver was used to demarcate the outline of the reservoir, the location of the embankment, the dam marker, the principal spillway drain, and any other pertinent geographic indicators. Data were collected by (1) setting the receiver to record positions at one-second intervals, (2) walking the desired geographic feature, and (3) logging the data to a file. Once completed, the operator would cease recording data. Files for each geographic feature were temporarily stored in the receiver and later downloaded to a personal computer. All positioning data were differentially corrected (DGPS) using base station data from Vici, OK and Purcell, OK using commercially-available software. These base stations are part of the National Continuously Operating Reference Station network operated by the National Geodetic Survey, a division of the National Oceanic and Atmospheric Administration, and the corrections can be accessed through the following web-site: www.ngs.noaa.gov/Cors. Under optimum conditions, sub-meter accuracy of DGPS is possible.

A second hand-held global positioning receiver was used to demarcate the location of the seismic lines on the lake. These data were collected with a military-grade receiver that was placed on the vessel and exported time, latitude, and longitude to a dedicated laptop computer and to the DAT tape recorder used in the seismic surveys (see below). These data required no differential corrections, were accurate to less than 4 meters, and were converted into Universal Transverse Mercator (UTM) coordinates for consistency with the commercial receiver.

2. Field Sites

2.1 Sugar Creek #12

Sugar Creek #12 is located near Hinton, OK, and it is a relatively small lake (19 acres) with a mud bottom and fairly shallow water depths (0.6 to 2 m; Figures 2-1, 2-2, and 2-3). Dam construction was completed on April 6, 1964. This structure has an upstream drainage area of 2,016 acres. The main stream supplying the lake is considered unstable due to the presence of actively migrating knickpoints, and excessive sedimentation rates have significantly decreased storage capacity. No boat ramp is available, and access for small vessels is difficult but tolerable.

Historic land use data for the environs of Sugar Creek #12 are not very extensive. In the mid-1960's near the time of dam construction, the watershed was primarily covered with trees and pastureland (Table 2-1; Figure 2-4; data provided by the USDA-ARS field office in Hinton, OK). Between the mid-1960's and the mid-1980's, apparently all forested areas were converted to cropland that included peanuts, cotton, and small grains. Since the mid-1980's, approximately 40% of the cultivated land has been converted to pastureland with no change in the amount of grassland and tree-lined drains. Cultivated fields of cotton and peanuts suggests that agrichemicals may be present in the lake sediments.

Table 2-1. Changes in land use within the watershed of Sugar Creek #12 (percentages based on 2,016 acres; values are estimates). Information provided by the USDA-NRCS field office in Hinton, OK.

	Time Interval		
Land Use	mid-1960's	mid-1980's	Present
Trees	55	0	0
Improved Pastureland: Bermuda, Plains Bluestem, and Lovegrass	10	27	50
Cropland: Peanuts, Cotton, and Small grains	25	65	41
Native Grasses and Tree-Lined Drains	10	8	9

Figure 2-1. Photograph of Sugar Creek #12 looking directly south showing earthen embankment on left, spillway channel in far distance, and reservoir (November 1999).

Figure 2-2. Photograph of Sugar Creek #12 looking toward the southwest showing the reservoir and the main tributary on right (November 1999).

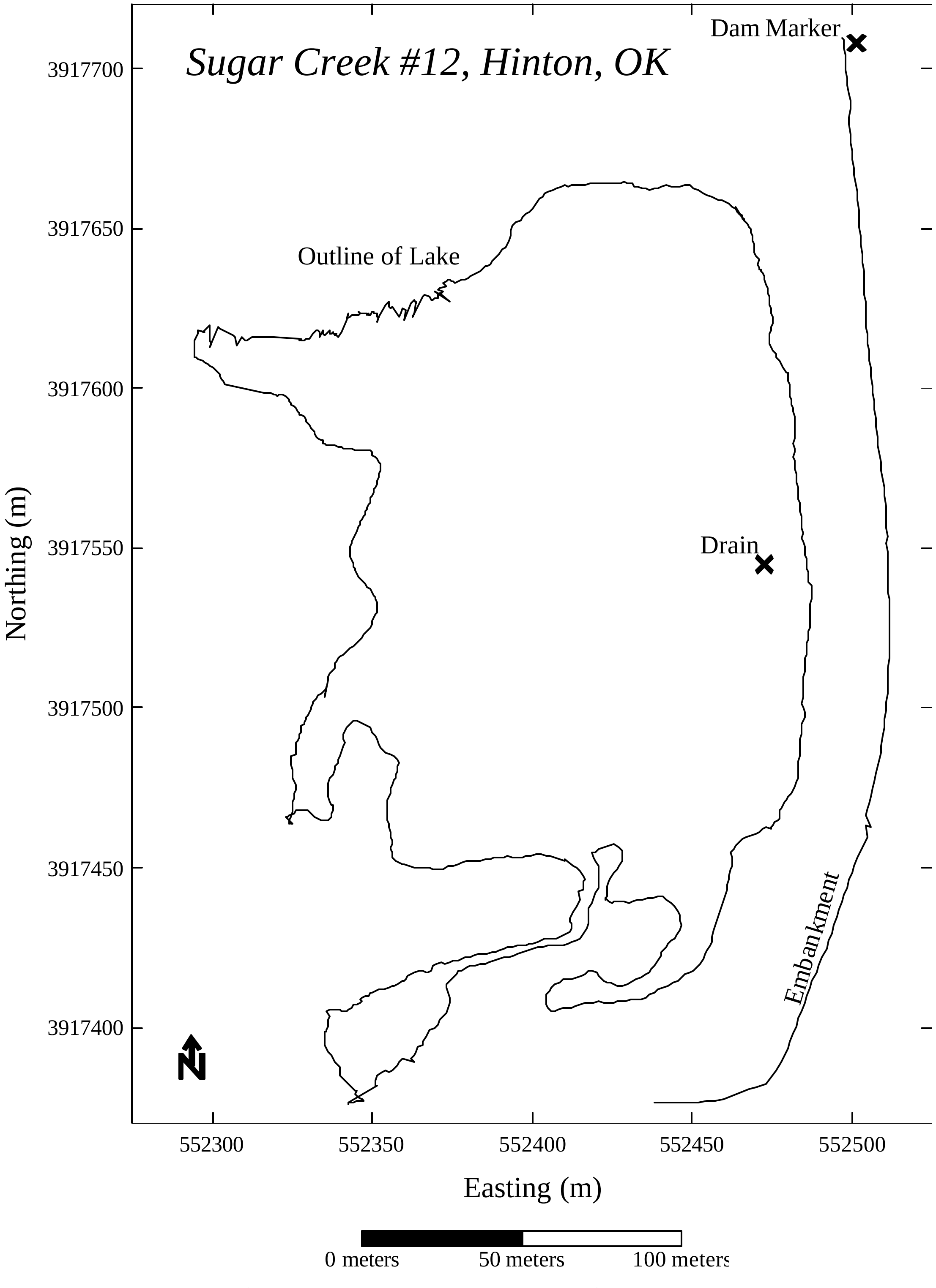

Figure 2-3. Base map of Sugar Creek #12 constructed from a hand-held global positioning system receiver with differential corrections applied. Shown are the outline of the lake, the centerline of the earthen embankment, the primary spillway drain, and the cement dam marker. All positions are in UTM coordinates.

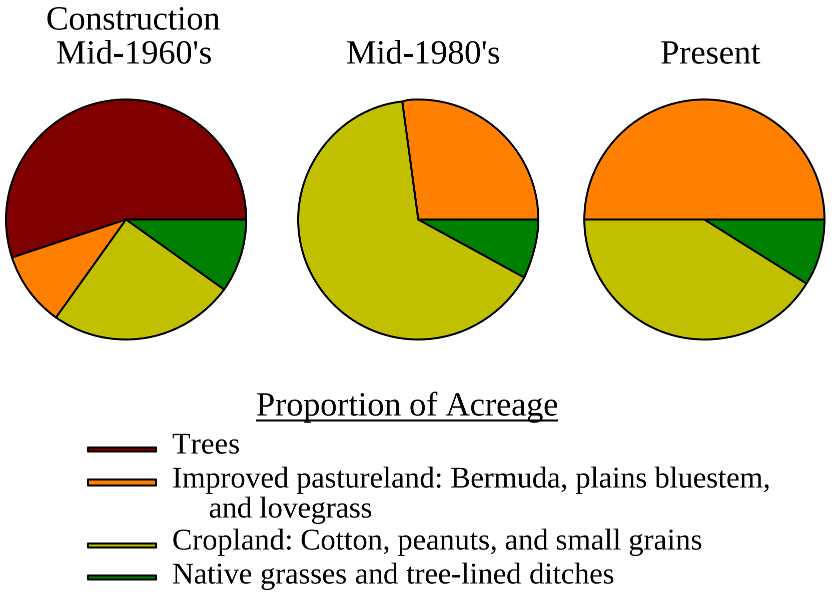

Figure 2-4. Temporal variation in the land use within the watershed of Sugar Creek #12.

2.2 Sugar Creek #14

Sugar Creek #14 is also located near Hinton, OK, and it is a relatively small lake with a mud bottom and fairly shallow water depths (about 1 to 3 m; Figures 2-5, 2-6, and 2-7). Dam construction was completed in 1962. This structure has an upstream drainage area of 1,252 acres and a lake surface area of 18 acres. Historic land use does include cultivation of cotton and peanuts, but this is small component of the watershed. Preliminary surveys indicate that sedimentation rates here were not as high as they were at Sugar Creek #12. A simple boat ramp enabled easy access to the site.

Figure 2-5. Photograph of Sugar Creek #14 looking northeast from the embankment showing reservoir, primary spillway drain on left, and main tributary source in far distance (November 1999).

Figure 2-6. Photograph of Sugar Creek #14 looking directly west showing reservoir, earthen embankment of left, and primary spillway drain in far distance (November 1999).

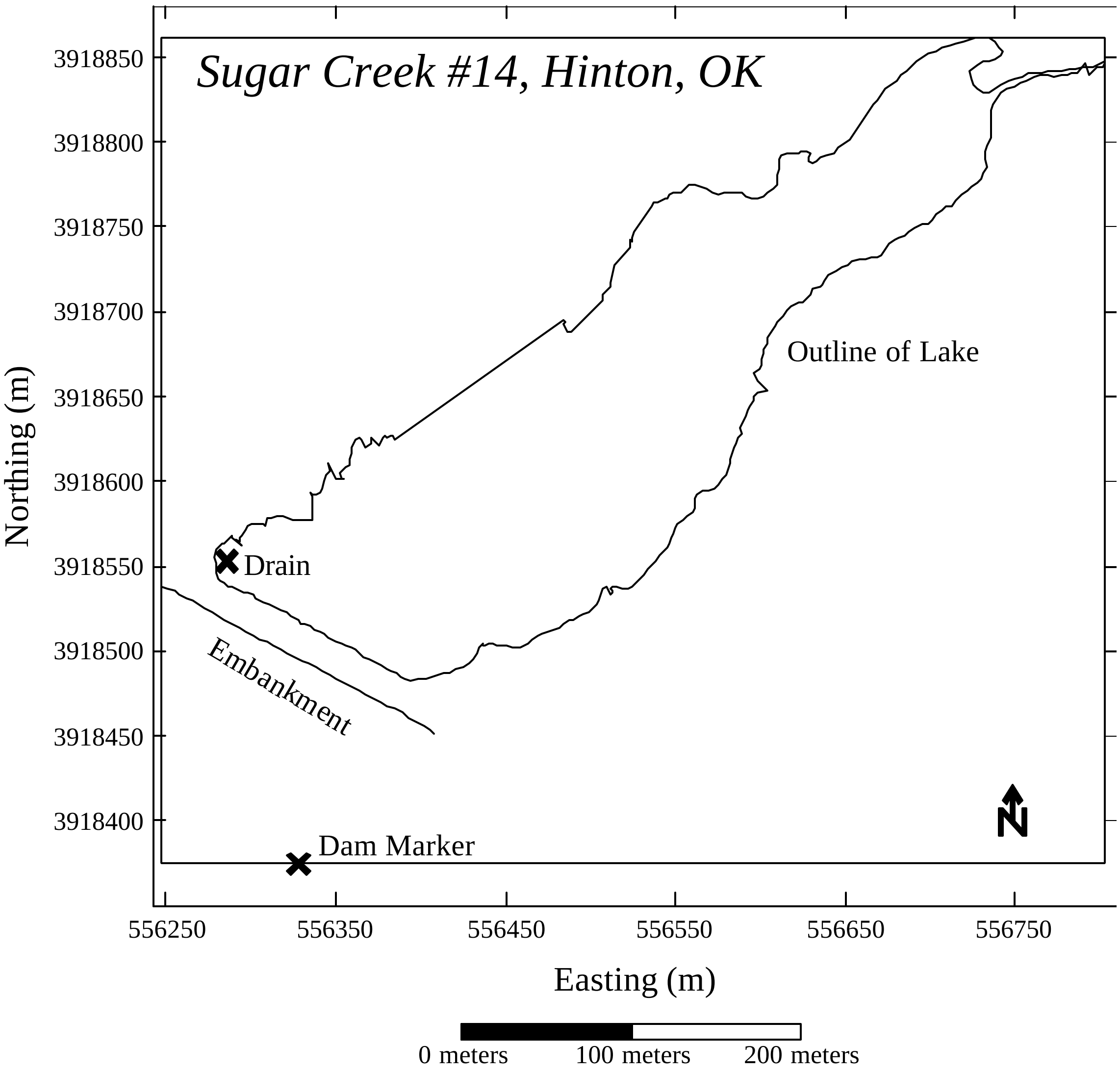

Figure 2-7. Base map of Sugar Creek #14 constructed from a hand-held global positioning system receiver with differential corrections applied. Shown are the outline of the lake, the centerline of the earthen embankment, the primary spillway drain, and the cement dam marker. All positions are in UTM coordinates.

2.3 Sergeant Major #4

Sergeant Major #4 is located near Cheyenne, OK and was constructed in 1955. It is a moderately sized structure, with a lake surface area of about 35 acres (Figures 2-8, 2-9, and 2-10), and has an upstream drainage area of 3,735 acres. This site was chosen for investigation because it has become the sole municipal source of water for the town of Cheyenne and preserving water quality is a major concern. At least three surface water sources as well as some underground springs feed the lake. Water depth ranges from 2 to 10 m, and near-vertical banks of terrigenous siliclastic rocks characterize the lake boundary. Some exposed salt deposits (primarily gypsum) also occur within the watershed. Access to the site for small vessels is good.

In 1940, land use within the watershed of Sergeant Major #4 was predominantly native rangeland and cropland, which included cotton and row crops with a rotation of small grains (Table 2-2; Figure 2-11; data from the USDA-NRCS field office in Cheyenne, OK). In 1960, the amount of cropland decreased by nearly 50% and these areas were replaced with seeded native grass mix. The acreage of native rangeland remained unchanged. By 1980, the amount of cropland decreased by nearly 30%, replaced almost entirely by seeded native mix. By 2000, the amount of cropland decreased by nearly 65%, seeded native mix increased by 32%, and the amount of pastureland increased by 265%. The amount of native rangeland remained the same. In summary, the watershed of Sergeant Major #4 has evolved from a rangeland and cultivated watershed to a predominantly rangeland and grassland watershed with minor amounts of cropland and pastureland.

Table 2-2. Changes in land use within the watershed of Sergeant Major #4 (percentages based on 3,735 acres). Information provided by the USDA-NRCS field office in Cheyenne, OK.

	Year			
Land Use	1940 (%)	1960 (%)	1980 (%)	2000 (%)
Cropland	42.9	24.2	17.6	6.3
Pastureland	0	0	1.7	6.2
Seeded Native Mix	0	17.9	23.1	30.5
Native Rangeland	54.7	54.7	55.2	53.8
Roads	1.9	1.9	1.9	1.9
Oil/Gas Sites	0	0	0	0.4
Homesteads and Farmsteads	0.4	0.4	0.4	0.9
Flood Control Dams	0	0.9	0.9	0.9

Figure 2-8. Photograph of Sergeant Major #4 looking almost directly south from the embankment showing reservoir, primary spillway drain in foreground, and the vessel used during seismic surveying in the distance (November 1999).

Figure 2-9. Photograph of Sergeant Major #4 looking southeast from access road showing the reservoir and the vessel used during seismic surveying in the distance (November 1999).

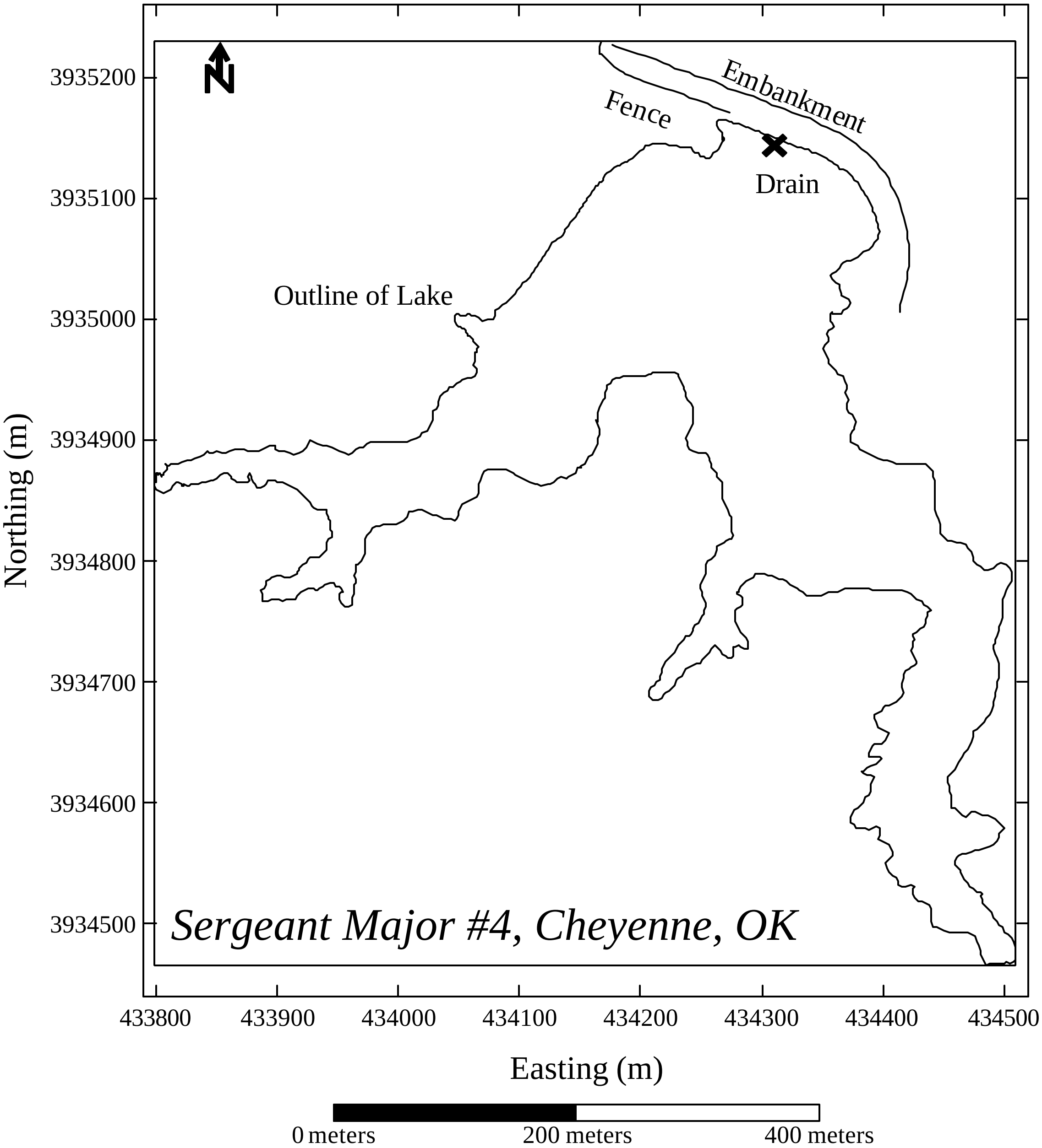

Figure 2-10. Base map of Sergeant Major #4 constructed from a hand-held global positioning system receiver with differential corrections applied. Shown are the outline of the lake, the centerline of the earthen embankment, the primary spillway drain, and the fence line near the embankment. All positions are in UTM coordinates.

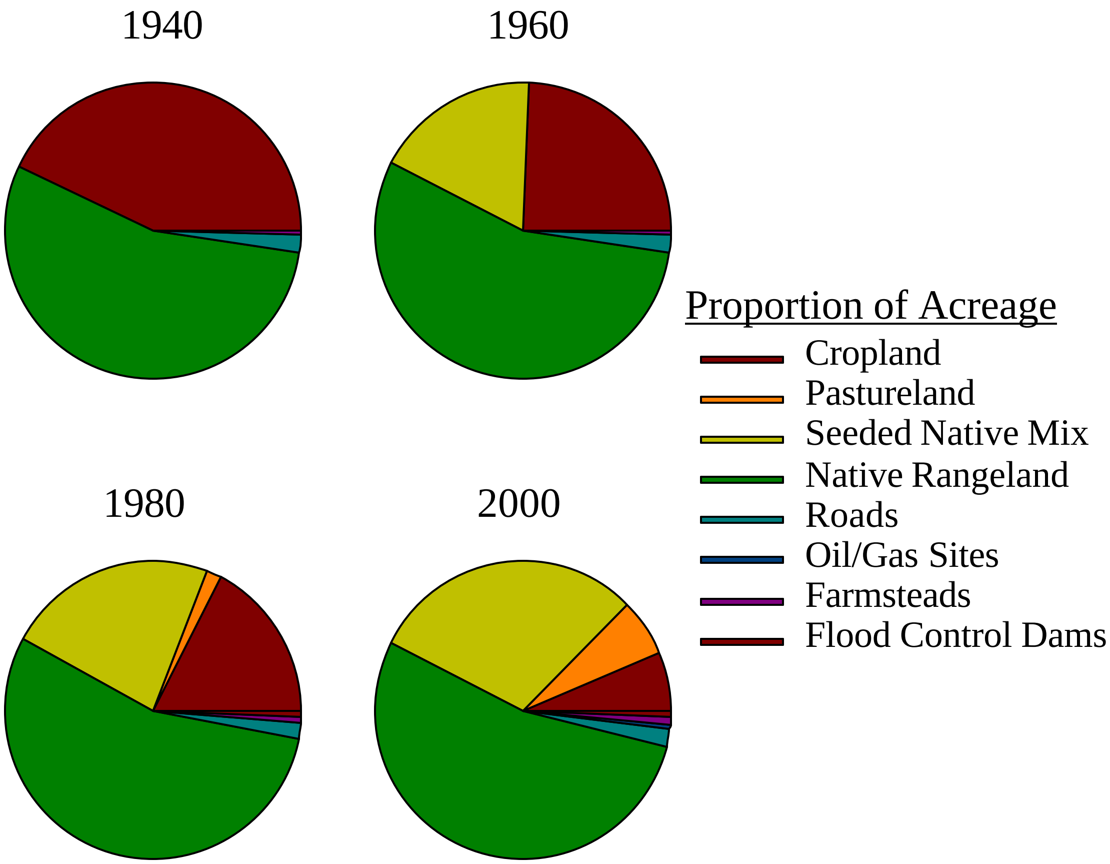

Figure 2-11. Temporal variation in the land use within the watershed of Sergeant Major #4.

The USDA-NRCS, Stillwater, OK provided the following information on the water quality of Sergeant Major #4. The town of Cheyenne monitors the levels of alkalinity, pH, hardness, and turbidity in the raw water. According to the water treatment plant operator, alkalinity is high, usually between 260 to 340 mg/l, pH generally ranges from 7.7 to 8.2, hardness usually ranges from 153 to 205 mg/l, and turbidity ranges from 2.0 to 20.0 NTU after a hard rain. Water samples obtained on October 7, 1998 showed key organic and inorganic indictors were in compliance with the Oklahoma Water Quality Standards for all classes of livestock and poultry and the water was deemed suitable for irrigation. The total dissolved solids measured (409 mg/l) were below the recommended limit for drinking water (500 mg/l).

3. Seismic Surveying

During the period from November 4 to November 6, 1999, each lake was surveyed using high-resolution geophysical equipment. The details of the equipment used, seismic lines run, and examples of the processed data are described below.

3.1 Seismic Equipment Used

The physical characteristics of the lakes and sediments necessitated the use of geophysical techniques that could be employed in shallow water (as little as 0.6 m) with thin sediment (no greater than 5 m). Most geophysical equipment commonly used cannot be applied in shallow water environments. IKB Technologies, LTD., Bedford, Nova Scotia, Canada, owned and operated by Dr. Peter Simpkin, has developed a seismic profiler for use in such environments.

The IKB-SEISTEC^{TM} profiling system comprises a catamaran, boomer, source receiver, and signal processor (Simpkin and Davis, 1993). The catamaran is 2.6-m long, 0.8-m wide, and its drained weight is approximately 100 kg (Figures 3-1 and 3-2). In this configuration, a boomer sound source is mounted directly in front of the hydrophone fairing. The catamaran can be operated at 0 to 4 knots, and cable distance from the vessel to the catamaran was approximately 7 m.

The seismic source incorporated into the catamaran is a reliable, wide-band electrodynamic boomer that produces a single positive pressure pulse with very high repeatability (Simpkin and Davis, 1993; see also www.seistec.com). The energy expended by the boomer ranges from 100 to 300 Joules per shot with the majority of the energy concentrated within a ±30° cone. The pulse width is 100 to 180 µm. The boomer has a circular footprint, a diameter of 0.46 m, an overall thickness of 0.05 m, and it weighs 15 kg. For the present application, the frequency of the boomer's pulse was set at four pulses per second.

The fairing houses the seismic receiver or hydrophone. The seismic receiver is based on the line-in-cone concept where the cone has an aperture of 0.61 m, a circular array of seven element acceleration canceling stick hydrophones, and a variable gain preamplifier (Simpkin and Davis, 1993; see also www.seistec.com). It has a near-field distance of less than 1 m, it is fully enclosed, and it is placed as close as physically possible to the source (about 0.7 m).

An SPA-3 analog signal conditioner and processor were used, which are suitable for a wide range of single channel seismic profiling systems. This processor provides input signal level matching, separate high and low pass filters, and raw and conditioned signal outputs. During operation, the processor was connected to (1) an oscilloscope to monitor and optimize the incoming seismic signal, (2) a gray-scale line recorder for real-time display of the seismic profile, and (3) a DAT tape recorder for data storage (Figure 3-3).

All equipment was placed onto a 16-ft aluminum boat (Figure 3-4). This included signal processor, oscilloscope, gray scale recorder, DAT tape recorder, and boomer power unit. In addition, a laptop computer was used to log positioning data from a military-grade GPS receiver. A 5.8 kW generator supplied 220 V power to the boomer, and a 2.8 kW generator supplied a clean power source to all other electronic equipment. Three people typically were on the vessel: one to operate the boat and to monitor the position of the catamaran, one to operate the positioning system, and one to operate the seismic equipment.

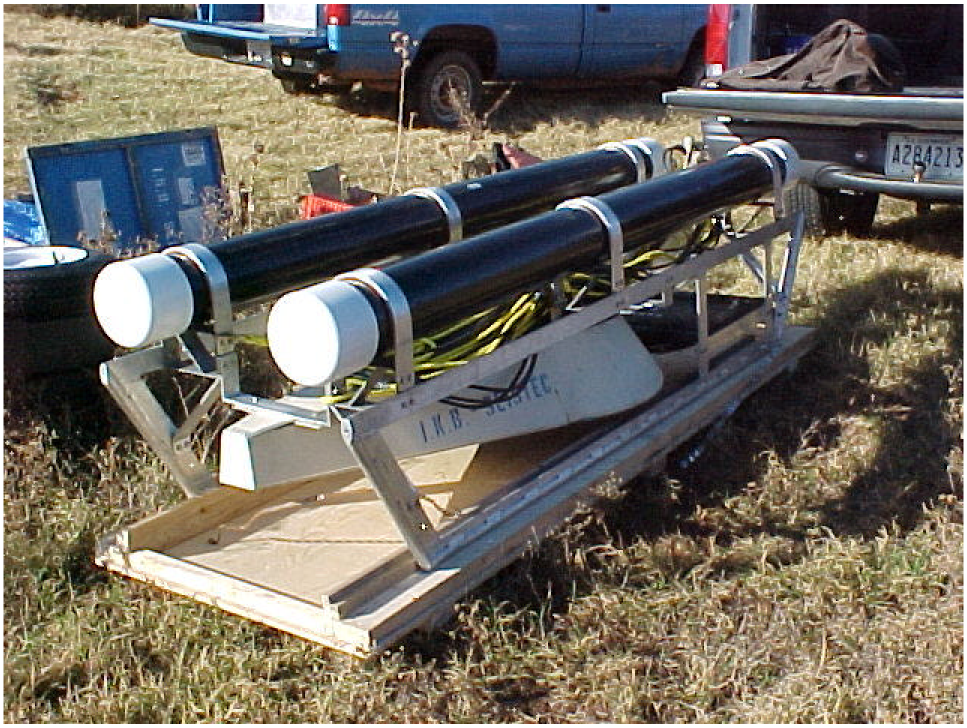

Figure 3-1. Photograph of the catamaran. The black PVC pipes provided floatation, the aluminum frame is resting on the wooden box the catamaran was shipped in, and the front of the catamaran is on the right (November 1999).

Figure 3-2. Photograph of the catamaran being towed by the vessel. The catamaran is about 7 meters from the vessel, and it is moving toward the left (taken at Sugar Creek #12, November 1999).

Figure 3-3. Photograph of the oscilloscope on left and gray-scale printer (foreground on right), DAT tape recorder (background top), and signal processor (background bottom; November 1999).

Figure 3-4. Photograph of general operating procedure for the seismic surveying and the number of personnel required (taken at Sugar Creek #14, November 1999).

3.2 Post-processing of Seismic Data

Geophysicists from the Mississippi Mineral Resources Institute, located at the University of Mississippi, conducted the post-processing of the seismic data. All data recorded to tape were played back in real-time and digitally recorded to a personal computer. During digitization, individual seismic lines were correlated to the GPS data so that all seismic data could be resolved in both time and space.

Once all data were digitized, specific segments of the seismic lines were identified for further processing. Post-processing entailed three steps. First, all data were digitally filtered in order to remove any low frequency oscillation in the seismic signal, and this process is called detrending. Second, all data were digitally processed in order to enhance the low-amplitude (low-magnitude) seismic data at depth, and this numerical technique is called spherical divergence. Third, all data were digitally filtered in order to reduce the number of reverberations (echos or multiples) or distortions in the seismic signal, and this process is called predictive deconvolution. These three steps employed both user-defined and commercially-available software packages.

After each seismic segment was detrended and both spherical divergence and predictive deconvolution were applied, the seismic lines were printed. The operator still can alter the magnitude or the gain of the seismic signal, thereby enhancing or suppressing reflectors prior to printing. In general, two copies of each line were generated, at low and high gain, and this enabled the identification of specific seismic reflectors. For clarity, only the low-gain seismograms are presented herein.

In addition, all seismograms were printed as a function of time. For the vertical scale, time in milliseconds can be converted to distance by assuming a velocity for the propagation of seismic waves through the water and the saturated, unconsolidated sediments and then back to the receiver. Herein this velocity is assumed to be 1500 m/s. Please note that this value depends greatly on water salinity and temperature, and the material's grain size, composition, degree of consolidation or lithification, and the presence of gas. For the horizontal scale, the GPS data were used to calculate the total distance of each line, assuming that the boat was moving at a constant velocity between measured points.

3.3 Results

3.3.1 Seismograms for Sugar Creek #12

Figure 3-5 shows the seismic lines obtained for Sugar Creek #12 and the location of the three segments chosen for presentation here. Figures 3-6, 3-7, and 3-8 show the seismograms for sections A-A', B-B', and C-C', respectively.

At the time these seismic data were collected, water depth was quite low, no greater than 1 m. This caused the seismic source (boomer) and receiver to be in very close proximity to the sediment bottom. In fact, the catamaran frequently ran aground. Thus the areal coverage within the lake was restricted to water depths of at least 0.6 m. Moreover, this close proximity caused a great deal of reverberation and distortion of the seismic signal and many multiple reflectors from the same source were recorded. The numerical algorithms presented above were unable to filter the seismic signals completely.

In general, the following observations can be made. The sediment near the water-sediment interface is quite soft, and it is represented by weak or low-amplitude reflectors (Figure 3-6, 3-7, and 3-8). The thickness of this reflector is about 0.15 to 0.2 m and it does not vary in thickness across the basin. However, this reflector does appear to thicken towards the southern part of the lake (towards B'; see Figure 3-7). At a depth of approximately 0.4 m, a very strong seismic reflector is observed, and this reflector is ubiquitous in all the seismic records. This strong seismic reflector caused most of the seismic reverberations due to its strong seismic properties and its close proximity to the water surface and seismic receiver. Again, this seismic reflector is observed basin wide, and may represent a change in sediment composition such as a sand or gravel layer, a change in sediment density such as variation in mineralogy or relative compaction, have a biological origin, or represent some kind of hard-pan. Because this reflector has such strong seismic characteristics, it is virtually impossible to observe and verify any deep horizons.

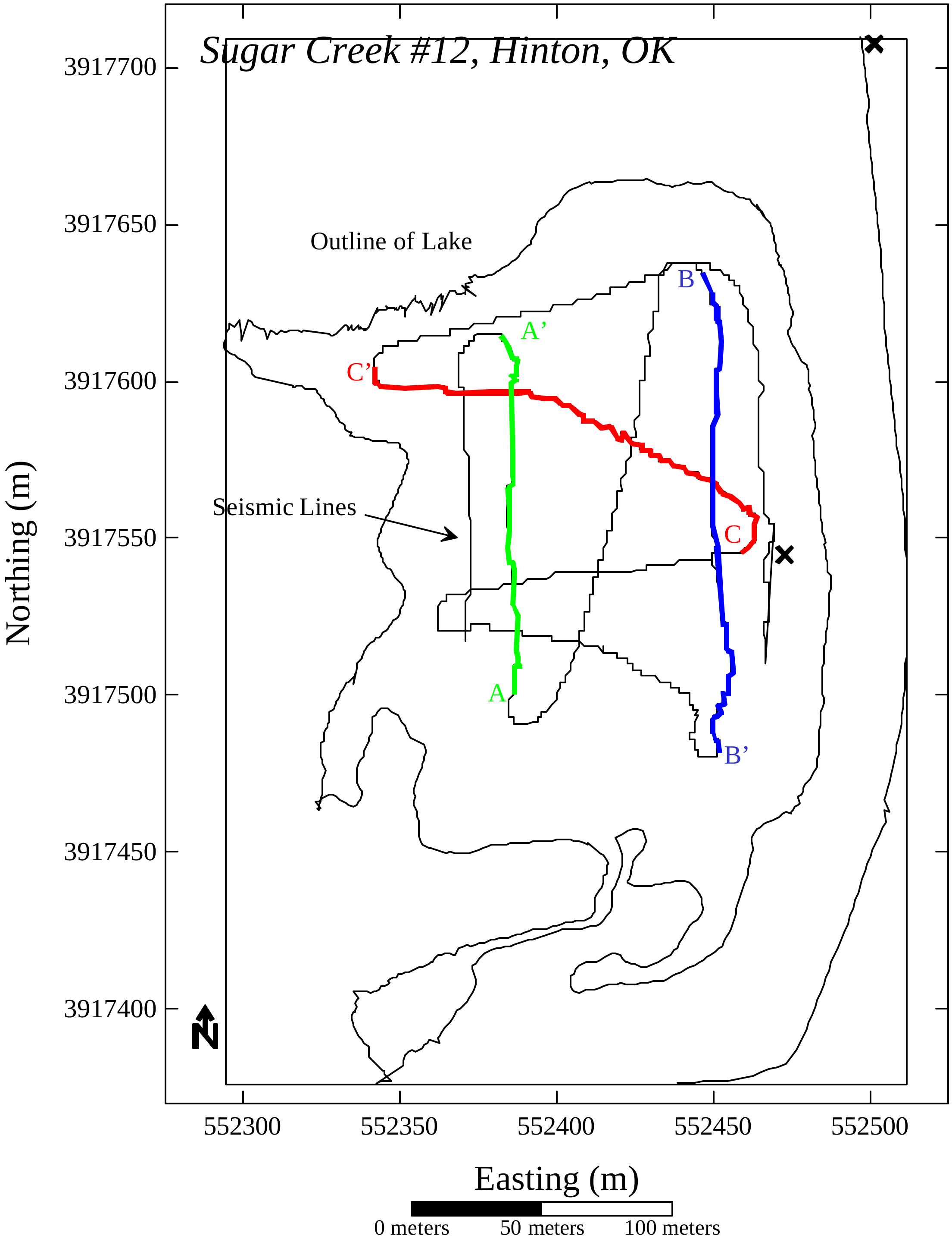

Figure 3-5. Base map of Sugar Creek #12 showing traces for all seismic lines. Three segments, labeled A-A', B-B', and C-C', are discussed in text. All positions are in UTM coordinates.

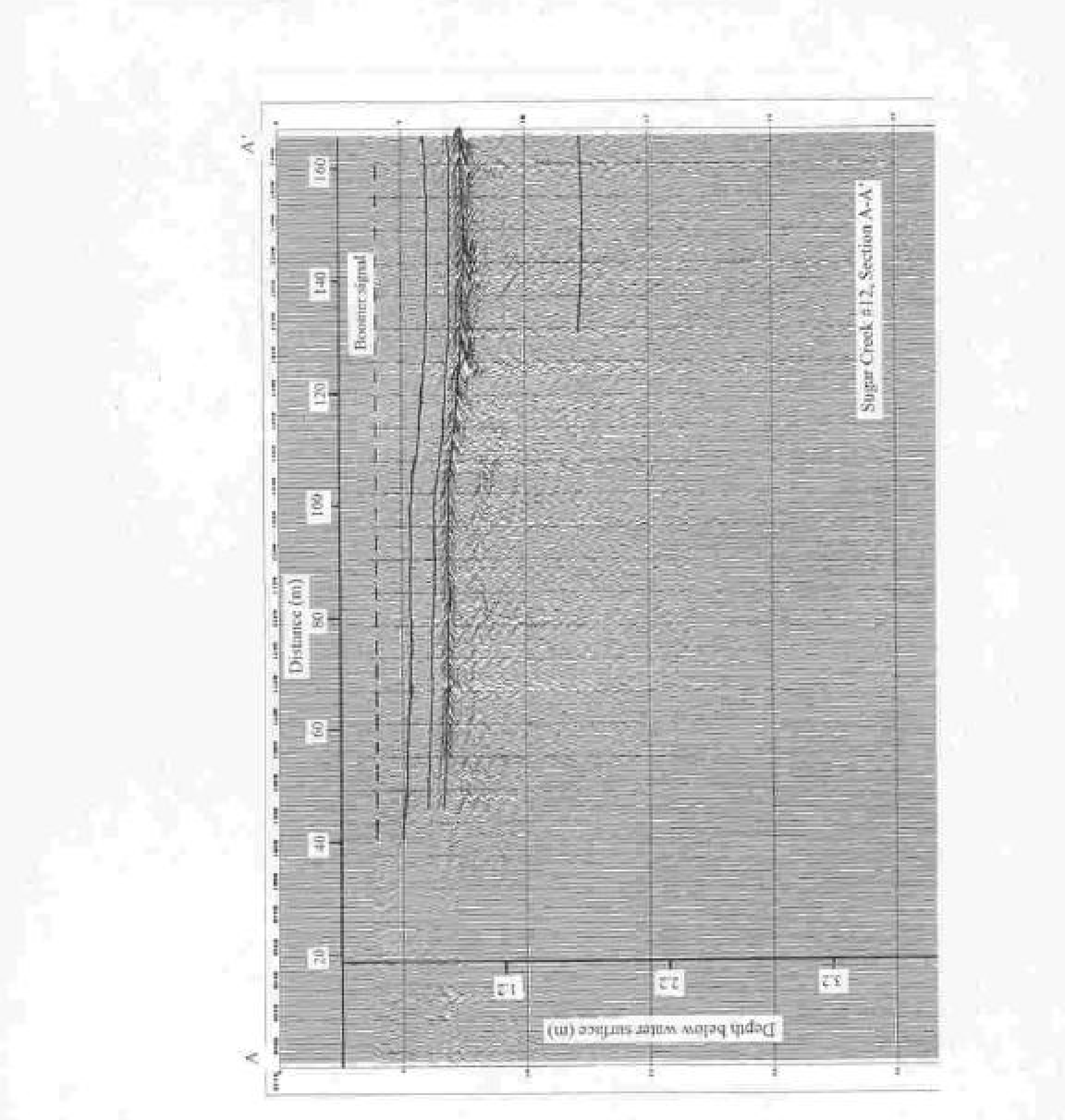

Figure 3-6. Seismogram of section A-A' from Sugar Creek #12 (next page; refer to Figure 3-5). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 162 m.

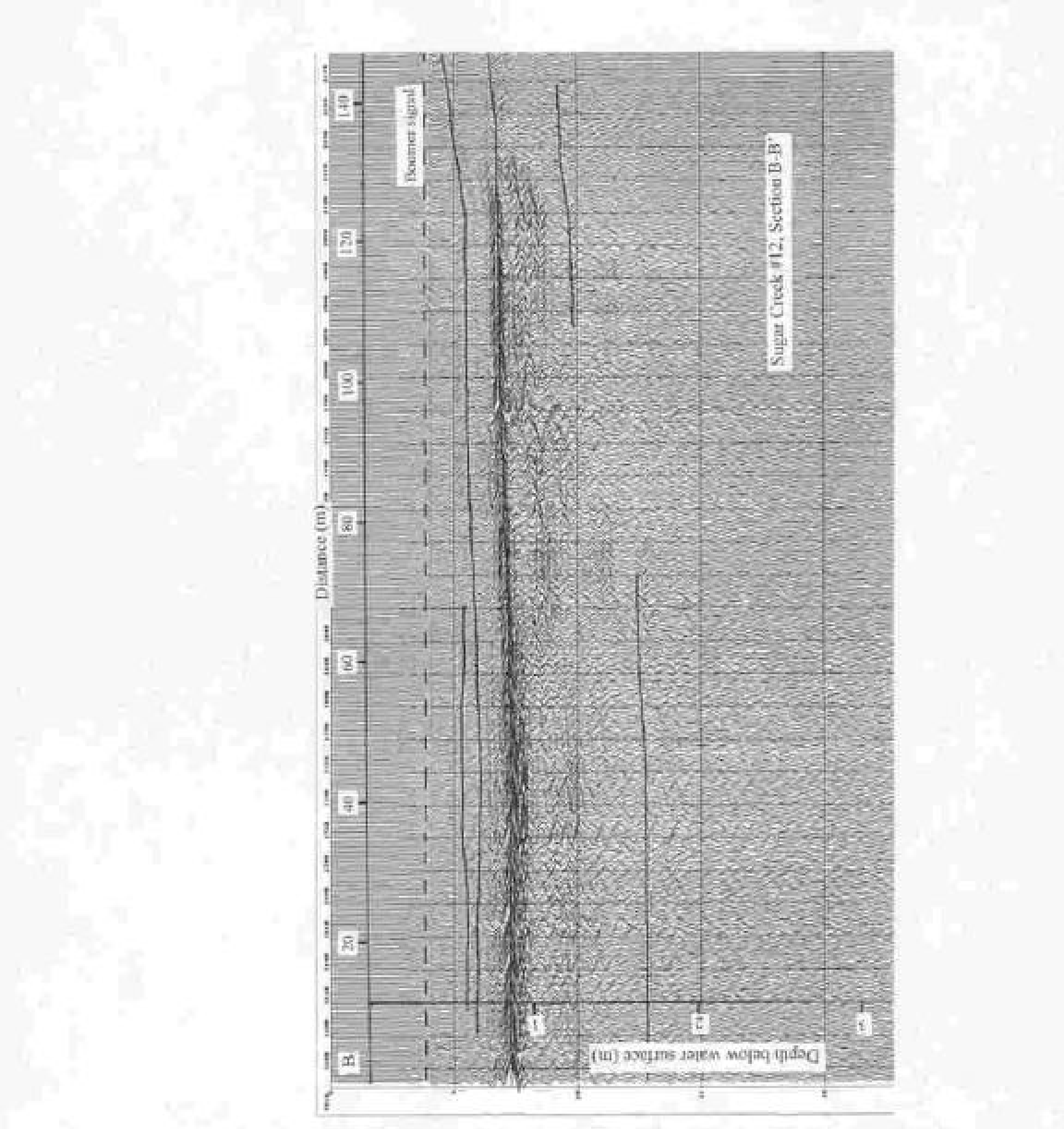

Figure 3-7. Seismogram of section B-B' from Sugar Creek #12 (next page; refer to Figure 3-5). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 158 m.

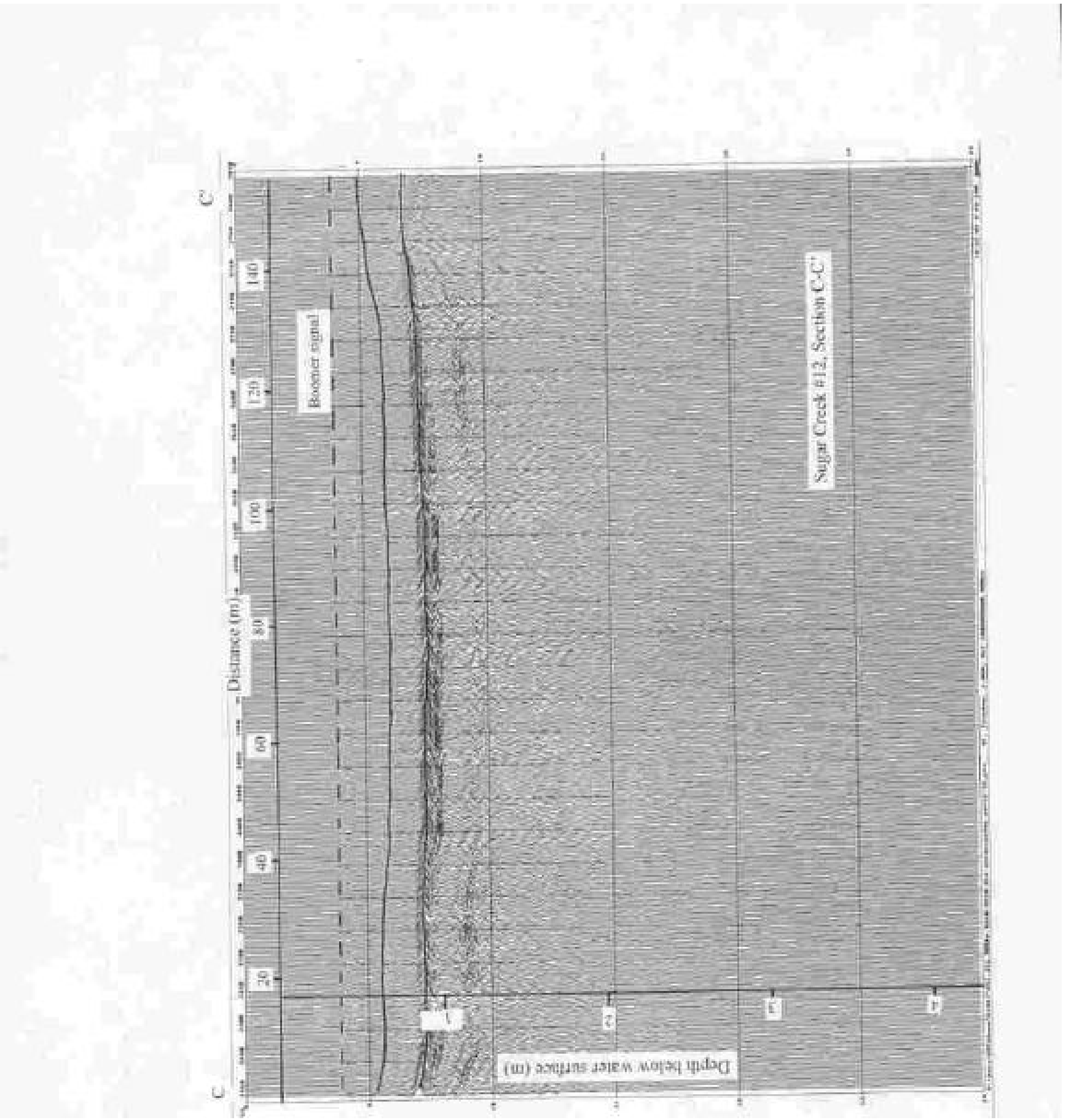

Figure 3-8. Seismogram of section C-C' from Sugar Creek #12 (next page; refer to Figure 3-5). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 156 m.

3.3.2 Seismograms for Sugar Creek #14

Figure 3-9 shows the seismic lines obtained for Sugar Creek #14 and the location of the three segments chosen for presentation here. Figures 3-10, 3-11, and 3-12 show the seismograms for sections A-A', B-B', and C-C', respectively. At the time these seismic data were collected, water depth was on the order of 1 to 3 m. As such, the post-processing algorithms were more successful in removing multiples here than at Sugar Creek #12.

In general, the following observations can be made. The sediment near the water-sediment interface is quite soft, and it is represented by weak or low-amplitude reflectors, similar to Sugar Creek #12 (Figures 3-10, 3-11, and 3-12). This near-surface reflector is about 0.2 m thick, and it displays little variation in thickness across the basin. Some thinning of this unit occurs toward the principal spillway (towards A'; Figure 3-10). At a depth of approximately 0.2 m, a very strong seismic reflector is observed, and this reflector is ubiquitous in all the seismic records. This strong seismic reflector is similar in depth and character to the reflector observed at Sugar Creek #12, and the reason for its presence is still unknown. Because of this strong, shallow seismic reflector, no deep reflectors can be identified and verified with confidence.

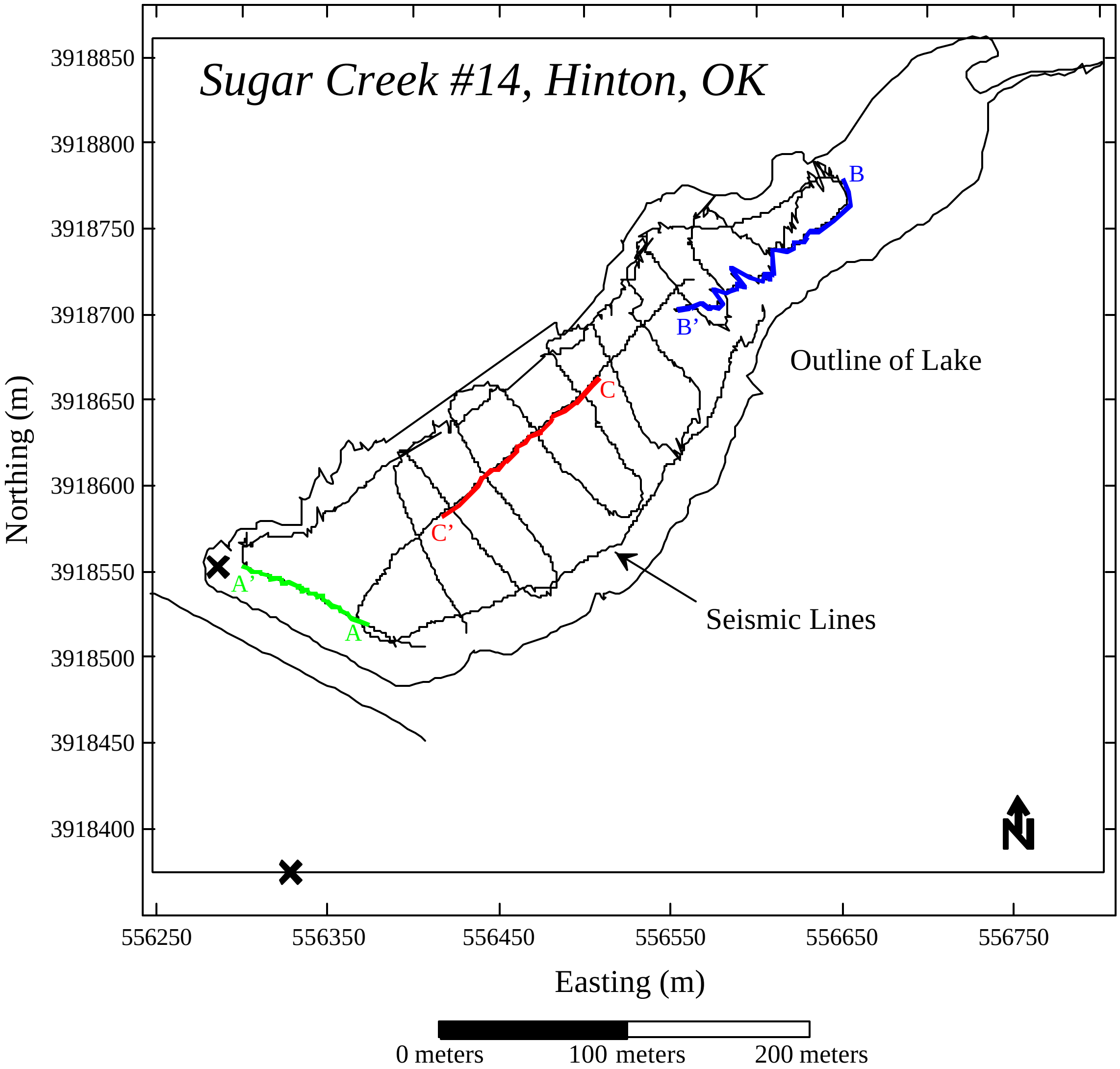

Figure 3-9. Base map of Sugar Creek #14 showing traces for all seismic lines. Three segments, labeled A-A', B-B', and C-C', are discussed in text. All positions are in UTM coordinates.

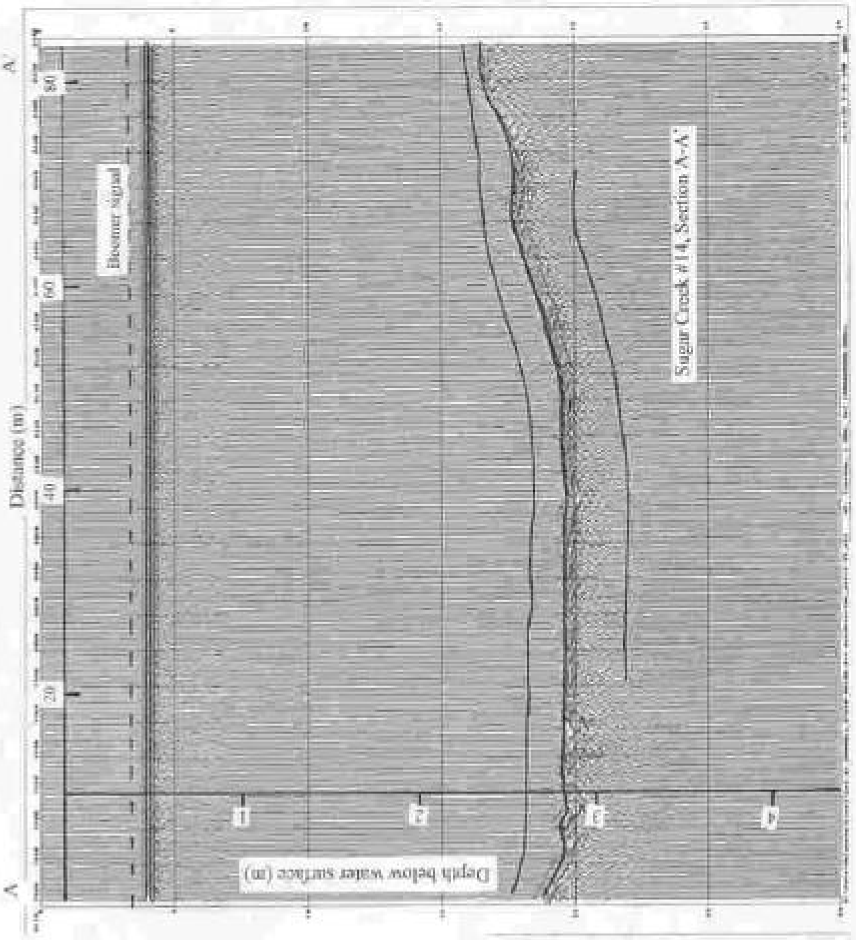

Figure 3-10. Seismogram of section A-A' from Sugar Creek #14 (next page; refer to Figure 3-9). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 84 m.

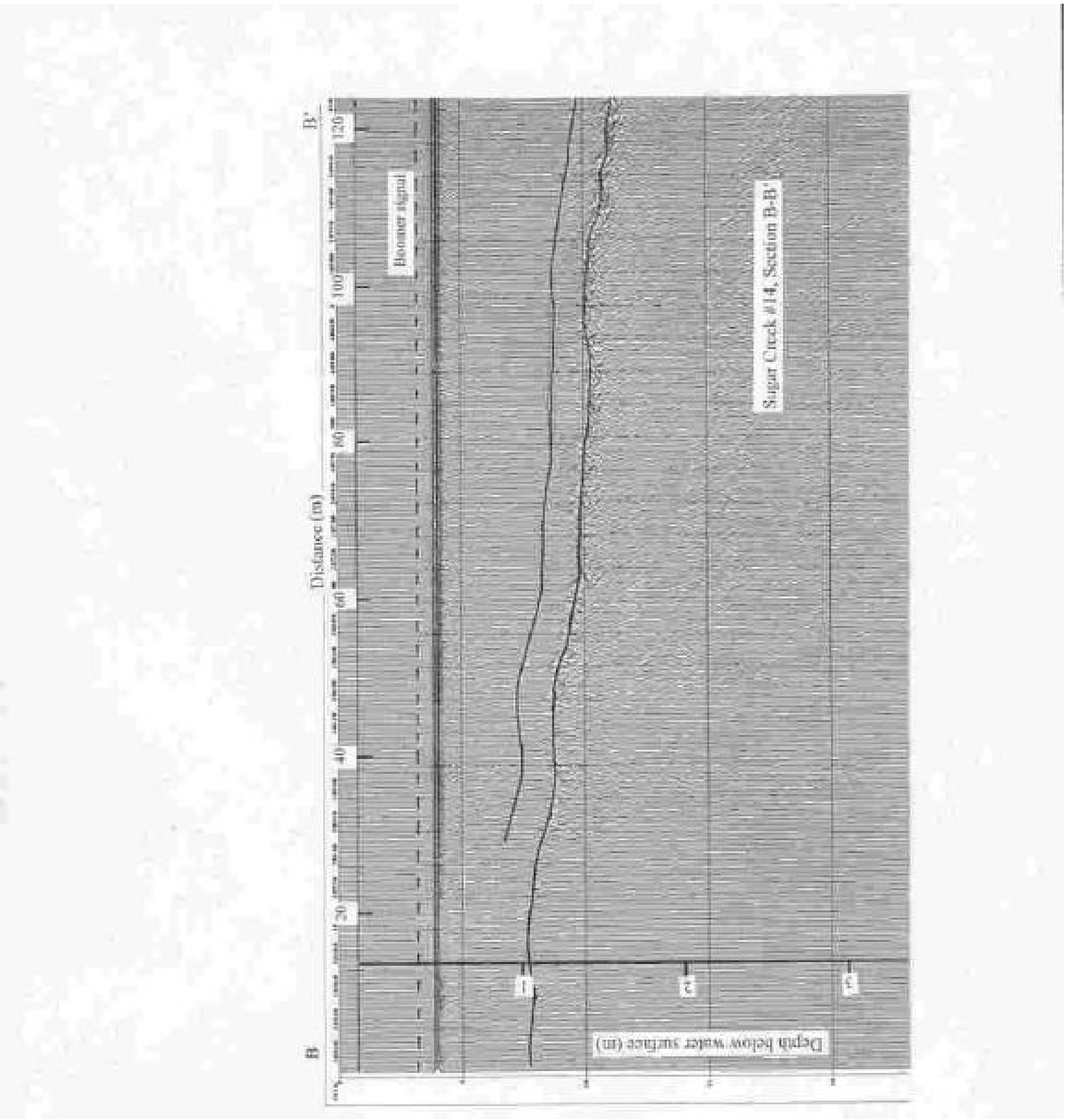

Figure 3-11. Seismogram of section B-B' from Sugar Creek #14 (next page; refer to Figure 3-9). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 134 m.

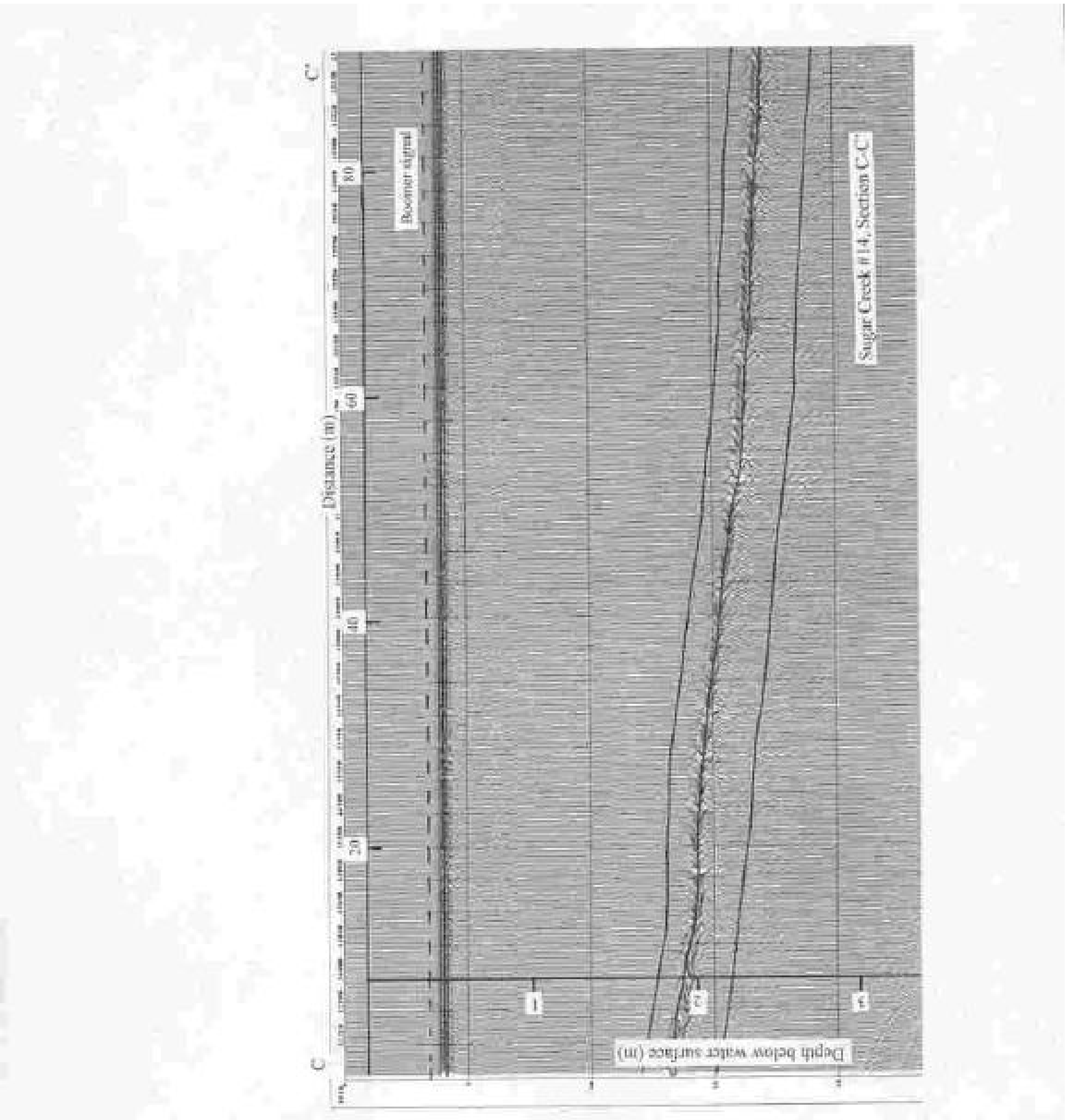

Figure 3-12. Seismogram of section C-C' from Sugar Creek #14 (next page; refer to Figure 3-9). Dashed line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 116 m.

3.3.3 Seismograms for Sergeant Major #4

Figure 3-13 shows the seismic lines obtained for Sergeant Major #4 and the location of the three segments chosen for presentation here. Figures 3-14, 3-15, 3-16, 3-17, and 3-18 show the seismograms for sections A-A', B-B', C-C', D-D', and E-E', respectively. At the time these seismic data were collected, water depth ranged from about 1 m in the tributary arms to about 10 m near the center of the lake. Post-processing algorithms successfully removed the majority of multiples and distortions of the seismic signal.

In general, the following observations can be made. The seismic profiles show a number of interpreted but unverified reflectors in the subsurface. Along the northwestern tributary arm, (section A-A'; Figure 3-14), reflectors range in thickness from 0.1 to 0.5 m, they occur at depths up to 1 m, they have variable inclinations, and they are observed to thin toward the deeper part of the reservoir. In this deeper region, the reflectors become horizontal and much thinner, less than 0.2 m thick. The deeper region also displays greater seismic reflectivity, suggesting a change in substrate grain size and composition.

Similar interpreted but unverified reflectors are observed along the central tributary arm (section B-B'; Figure 3-15). But these reflectors are quite thin, about 0.2 m, they are restricted in depth to about 0.3 m, and they display little variation in thickness towards the deeper basin. Reflectors in the topographically low regions assume horizontal attitudes.

Along the southern tributary arm, (section C-C'; Figure 3-16), interpreted but unverified reflectors are more numerous in the topographically low regions, they range in thickness from 0.1 to 0.3 m, and they are restricted in depth to about 0.3 to 0.7 m. Many of these reflectors pinch-out toward the sides of the topographic depressions.

The seismic line parallel to the embankment (section D-D'; Figure 3-17) shows several interpreted but unverified reflectors that parallel the subsurface topography. These reflectors range in thickness from 0.1 to 0.2 m and are observed to depths of about 1.5 m. Several of these reflectors are continuous for up to 80 m across the basin, while others show very short lateral extents.

The seismic line through the central part of the reservoir (section E-E'; Figure 3-18) also displays numerous interpreted but unverified reflectors ranging in thickness from 0.1 to 0.5 m. These reflectors drape the existing reservoir bathymetry and are restricted in depth to about 1 m. The reflectors appear to thicken towards the southeast (towards E'), away from the center of the basin.

The reservoir bathymetry is relatively rugged as compared to the Sugar Creek sites with several topographic highs and lows. The deepest part of the reservoir occurs near the center of the lake, and maximum bathymetric relief is about 4 m. The presumable cause of this topography is the rock outcrops observable above the water line.

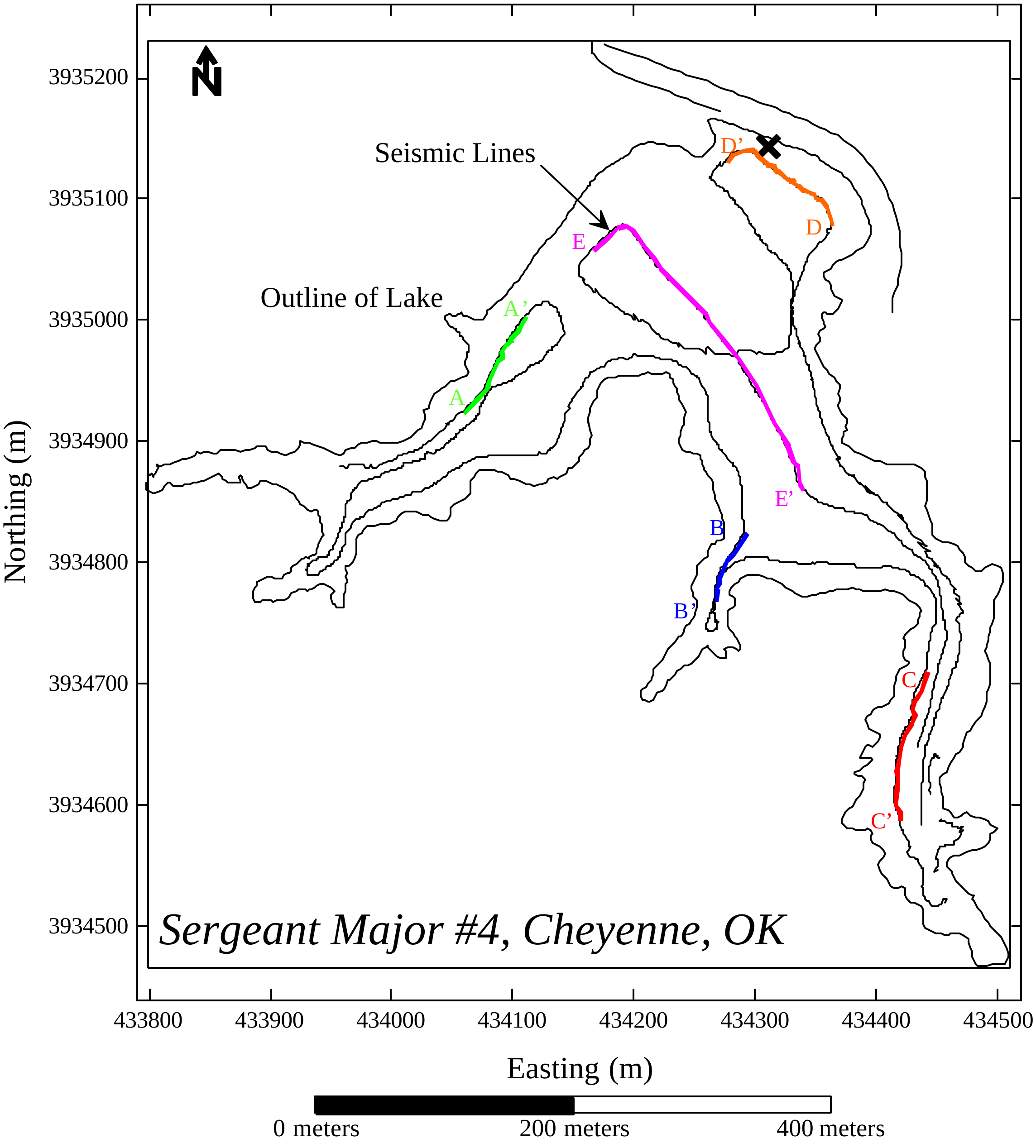

Figure 3-13. Base map of Sergeant Major #4 showing traces for all seismic lines. Five segments, labeled A-A', B-B', C-C', D-D', and E-E' are discussed in text. All positions are in UTM coordinates.

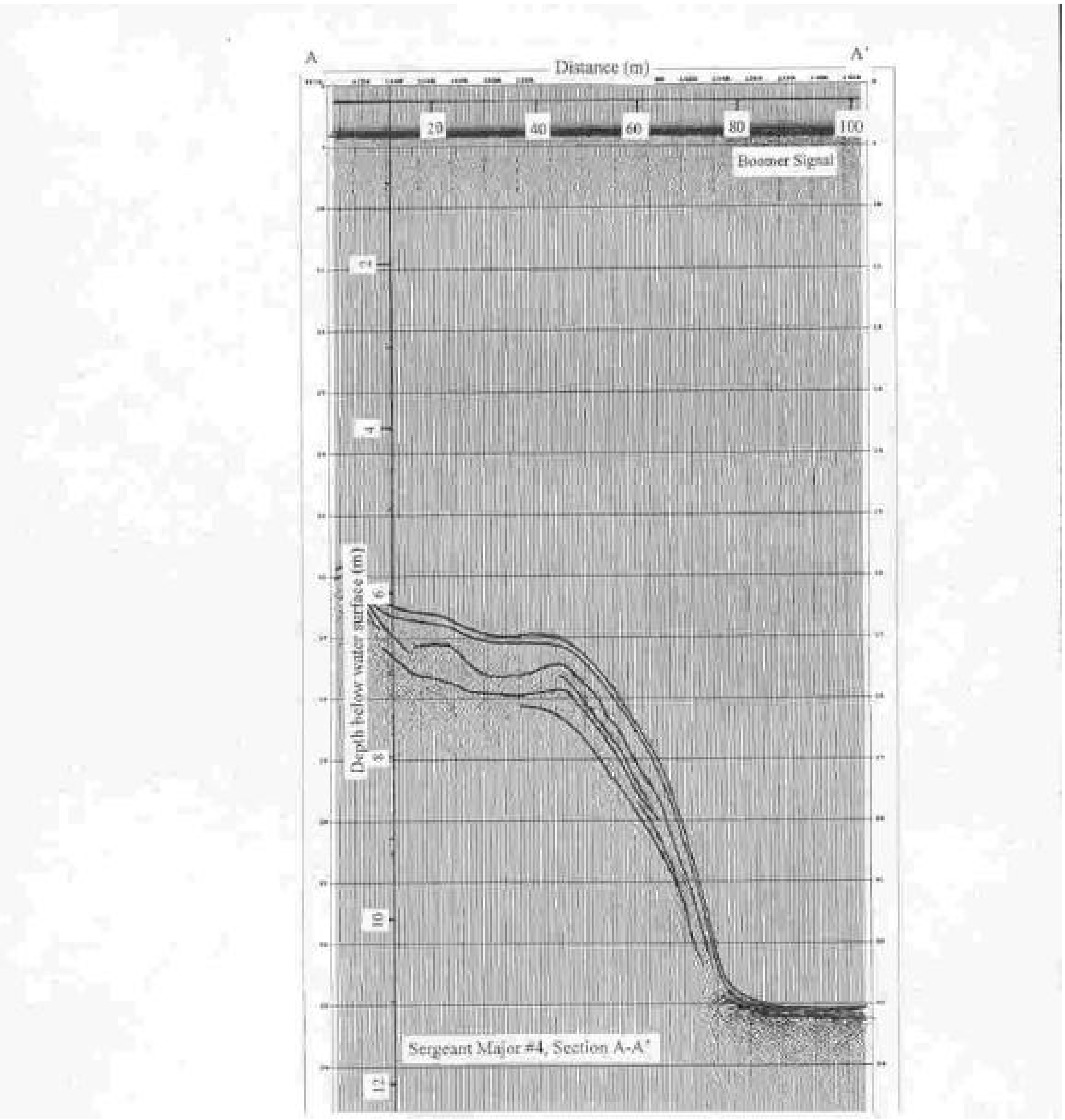

Figure 3-14. Seismogram of section A-A' from Sergeant Major #4 (next page; refer to Figure 3-13). Thick solid line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 105 m.

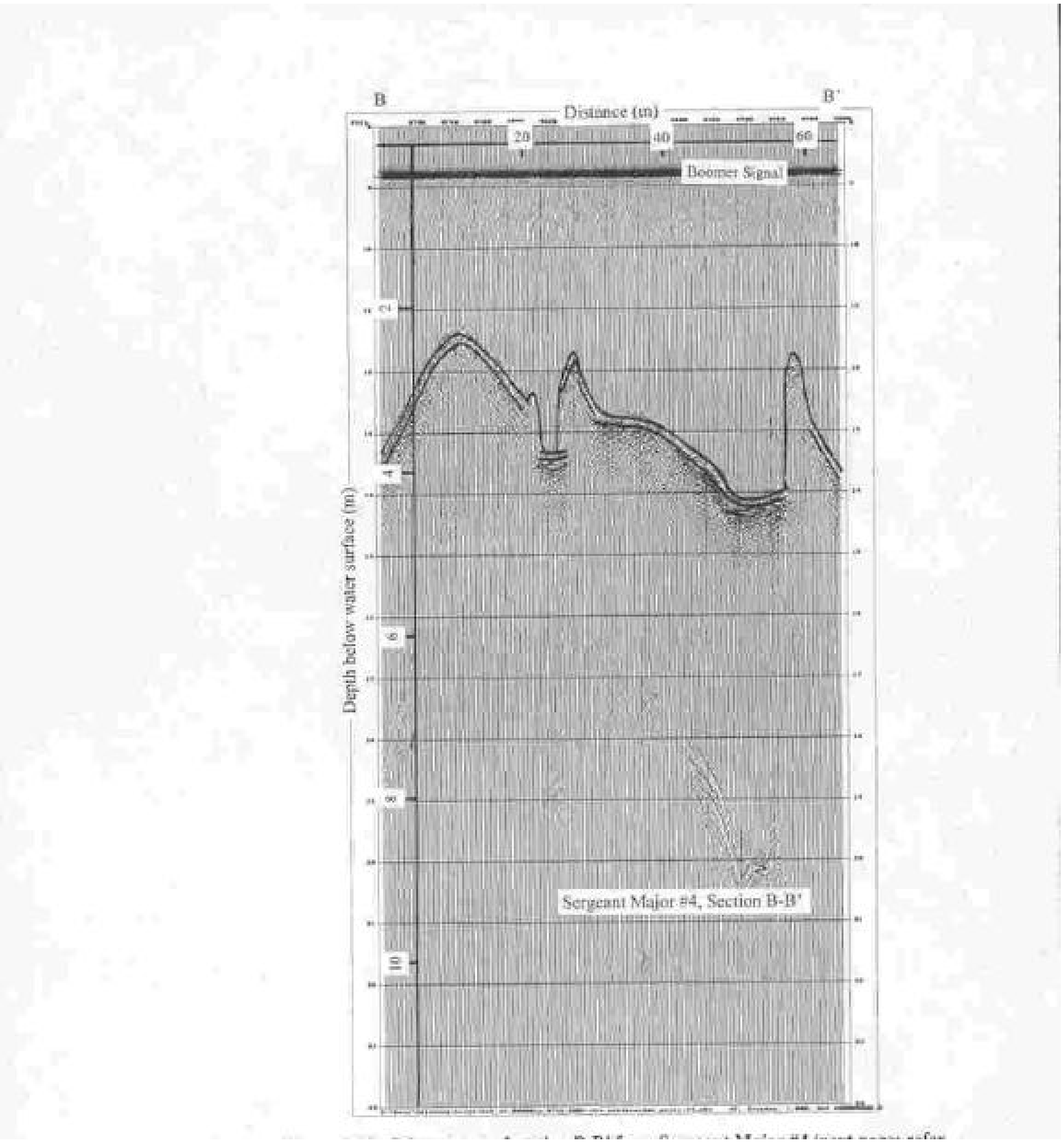

Figure 3-15. Seismogram of section B-B' from Sergeant Major #4 (next page; refer to Figure 3-13). Thick solid line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 66 m.

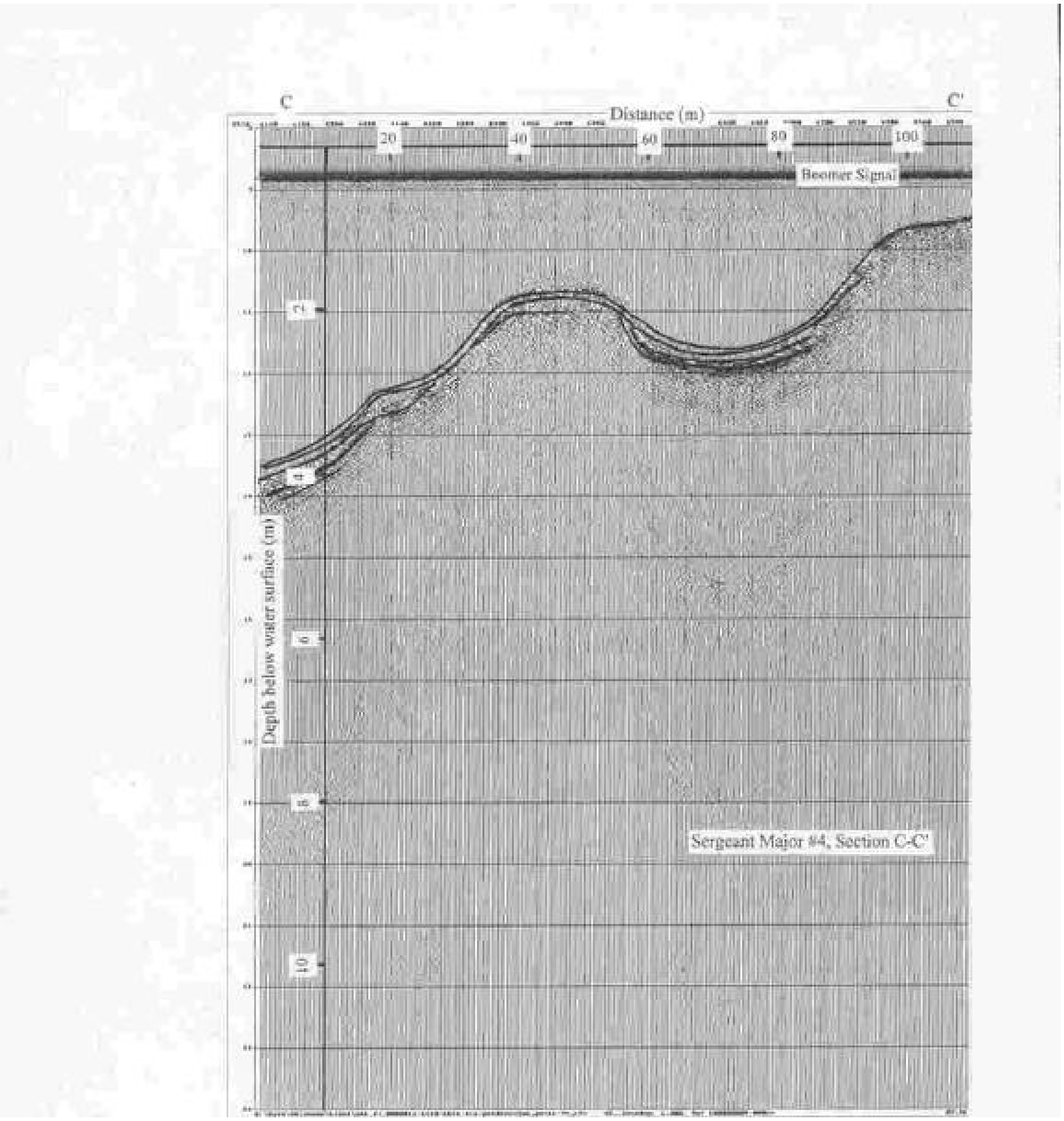

Figure 3-16. Seismogram of section C-C' from Sergeant Major #4 (next page; refer to Figure 3-13). Thick solid line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 120 m.

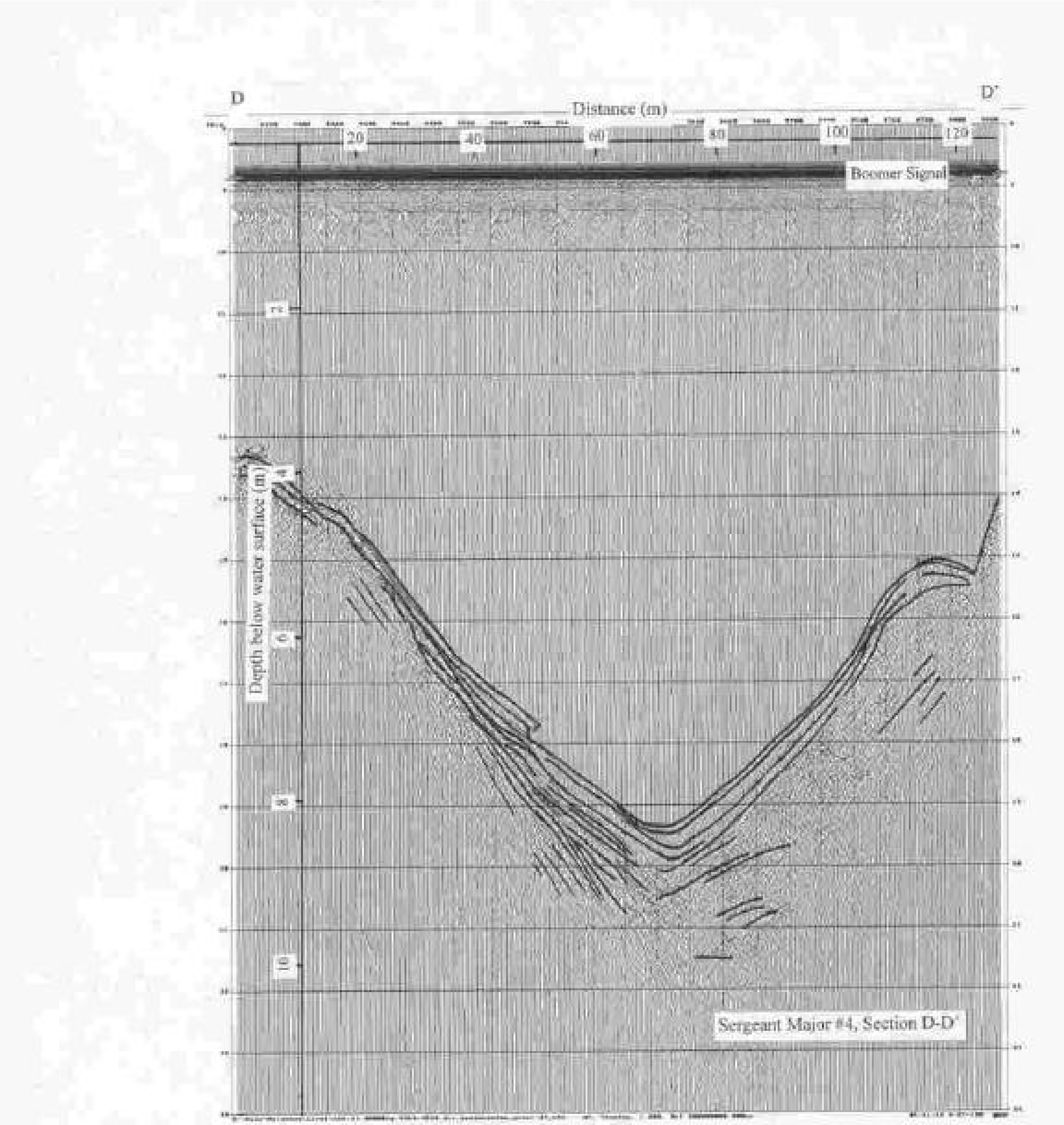

Figure 3-17. Seismogram of section D-D' from Sergeant Major #4 (next page; refer to Figure 3-13). Thick solid line is location of boomer (approximately 0.5 m below the water surface), the first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 127 m.

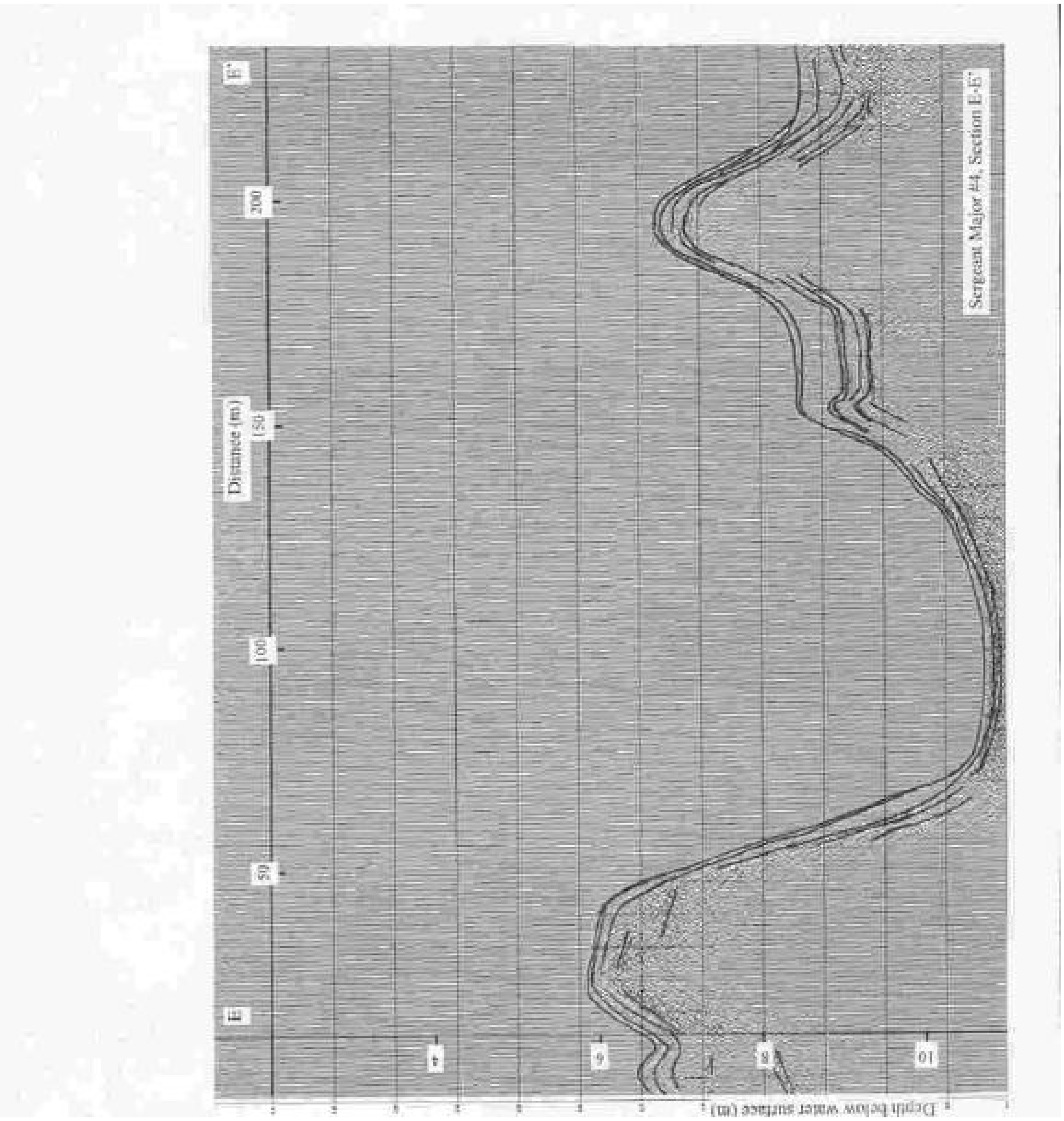

Figure 3-18. Seismogram of section E-E' from Sergeant Major #4 (next page; refer to Figure 3-13). The first solid line represents the water-sediment interface, and the solid lines at depth are interpreted seismic reflectors identified but not verified. Depth and length scales are shown, and total length of seismic record is 293 m. Due to space limitations, the location of the boomer was omitted.

3.4 Discussion

Seismic profiles were successfully obtained in each of the three reservoirs in Oklahoma. However, the very shallow water depths at Sugar Creek #12 and Sugar Creek #14 caused unwanted noise in the seismic signal, and the processed data are virtually impossible to interpret. The seismic profiles obtained at Sergeant Major #4 required less processing, and hence these show better performance of the seismic system. Some individual seismic reflectors were interpreted but could not be verified. These were less than 0.1 m in thickness and were recognizable at distances of 10 m below the water surface and at depths of up to 1.5 m below the sediment bed.

The seismic profiles obtained at Sugar Creek #12 and #14 show that very soft sediment occurs near the sediment-water interface, and this sediment is approximately 0.1 to 0.2 m thick. This horizon can be traced across each reservoir, but its thickness does not vary appreciably. In both lakes, a very strong seismic reflector is observed at a subsurface depth of approximately 0.2 m. This reflector caused a significant amount of unwanted noise in the seismic signal, thus requiring a great deal of meticulous numerical processing with little success. No deep reflectors are observed in these seismic profiles due to this unwanted noise. The cause for this reflector and its characteristics are still unknown.

The seismic profiles at Sergeant Major #4 show a number of distinct interpreted seismic reflectors in the subsurface. These reflectors range in thickness from 0.1 to 0.5 m and occur at depths of up to 1.5 m below the sediment bed. Several reflectors can be traced up to 80 m across the lake, while others appear to be restricted to the topographically low regions. Reflector thickness appears to be greatest along the northwestern tributary arm, while the thinnest reflectors occur along the small central tributary arm. Nonetheless, reflectors were ubiquitous in all regions of the lake. These reflectors, however, are unverified. More rigorous interpretations of seismic profiles are presented and discussed in §5.

Seismic data alone is not enough to characterize the subsurface stratigraphy within these reservoirs. The acquisition of deep sediment cores at key locations would provide invaluable information because such data will constrain the location and physical characteristics of the observed seismic horizons. More importantly, the core data would provide the opportunity to reanalyze the seismic profiles with *a priori* knowledge of the subsurface stratigraphy.

4. Sediment Coring

Vibracoring is a common approach for obtaining undisturbed cores of unconsolidated sediment in saturated or nearly saturated conditions (Lanesky et al., 1979; Smith, 1984). Vibracoring works on the principle of transferring a high-frequency vibration to a thin-walled core pipe held in a vertical position on the sediment bed. The vibrating pipe causes the liquefaction or fluidization of sediment only at the core-sediment interface, thereby allowing the pipe to penetrate the sediment with little resistance and without disrupting sediment stratification.

A commercially available vibracoring system was used in this study (Figures 4-1, 4-2, and 4-3). This system uses a 1-HP motor that drives a pair of weights (masses) eccentrically mounted on two shafts and housed within a water-tight aluminum chamber (Figure 4-3). When in operation, the masses rotate in opposite directions causing the chamber to vibrate at frequencies ranging from 6000 to 8000 RPM depending upon the sediment substrate. The chamber (driver) is connected to the top of an aluminum irrigation pipe 1.5-mm thick, 76-mm wide, and over 3-m long and cabled to a 4.2-m high aluminum tripod fitted with a battery-operated winch (Figures 4-1, 4-2, and 4-3). Since the driver is sealed, the entire system can be immersed in water. A simple check valve placed into the flange connecting the core pipe to the driver induces internal suction during core extraction. The tripod is mounted to a raft that can be easily carried and assembled on site, towed with a small boat, and anchored into position (Figure 4-2).

Once the core was driven into the sediment, the vibrating motion was stopped and the winch lifted the core to the water surface (Figure 4-3). When successful, the core typically had a hard sediment bottom that acted as a seal. If excessive sand or gravel was present at the bottom of the core, the entire contents of the pipe would be lost during lifting. The position of the raft was recorded with a hand-held GPS receiver whose data were differentially corrected using available base station information. The core was transferred to the boat and transported to shore. Each core was opened on site by cutting the aluminum pipe length-wise on both sides with a circular saw, and the top half of the pipe was carefully lifted from the sediment (Figure 4-4). Typical photographs of the sediment within a core are shown in Figure 4-5.

After the core was opened, sediment samples were secured for laboratory analysis. For the physical characterization of the sediment, approximately 200 g of sediment was secured from each major stratigraphic horizon and placed into a sterilized bag. From 2 to 4 sediment samples would be taken from each core. For agrichemical analysis, approximately 1 to 2 kg of sediment was secured and placed into a bottle previously washed with acetone. These samples were integrated over the entire core or over the lower-half and upper-half. All agrichemical samples would be placed into chests, covered in ice during transport, and placed into a cooler on site until the analyses were performed. If a core were to be analyzed for Cesium, the remaining contents were subdivided into intervals, 0.15 m at Sugar Creek #12 and 0.1 m at Sergeant Major #4, and all sediment was placed into plastic bags. Once completed, any sediment remaining was disposed on site.

4.1 Sediment Cores Obtained at Sugar Creek #12

Ten continuous, undisturbed cores were obtained at Sugar Creek #12 and their positions are shown in Figure 4-6. These cores ranged in length from 1.3 to 3.1 m and were extracted from water depths ranging from 0.5 to 3 m. The positions of the cores were chosen to coincide precisely with the seismic profiles collected previously (see Figure 3-5).

Stratigraphic columns for each core are shown in Figures 4-7, 4-8, 4-9, 4-10, and 4-11. The stratigraphic logs show the schematic textural and color characteristics of each core, the location of the sediment samples secured (e.g., GS 1, GS 2, etc.), and the location of agrichemical and Cesium samples obtained.

In general, the cores at Sugar Creek #12 are composed of sand, silt, and clay. In places, alternating layers of black and brown silt and clay are present (see Core 7, Figure 4-10). These layers are interpreted as varves, which represent seasonal variations in water stratification due to temperature and its effect on silt and clay deposition (Leeder, 1982). In the classic interpretation for varve formation, warmer, sediment-laden river water flows over and within the colder lake water during the summer, producing a constant rain of particles larger than clay. The clay particles are held in suspension until the incoming water temperature drops below the lake water temperature in autumn, which causes a wholesale overturn of the water, and the remaining sediment is deposited forming a light-colored winter blanket. Very thick accumulations, up to 2.4 m, of silt and clay are common (see Cores 1 and 2, Figure 4-7; Core 7, Figure 4-10; and Core 10, Figure 4-11). Many of these thick silt and clay units have thin-bedded sand units (ca. 5 to 20 mm) within them (see Core 4, Figure 4-8; and Cores 9 and 10, Figure 4-11). Layers rich in organic material such as vegetation are also common (see Core 5, Figure 4-9; and Core 9, Figure 4-11). Virtually no gravel is observed.

Figure 4-1. Photograph of floating vibracore system showing the tripod and portable rafts. A core pipe is being connected to the vibracore head.

Figure 4-2. Photograph of floating vibracore system showing the tripod and portable rafts. The pipe is being positioned to obtain a core (June 1999).

Figure 4-3. Photograph of vibracore system showing the tripod, vibracore head, and winch and cable assembly.

Figure 4-4. Photograph of extracted core being cut open on-site (June 1999).

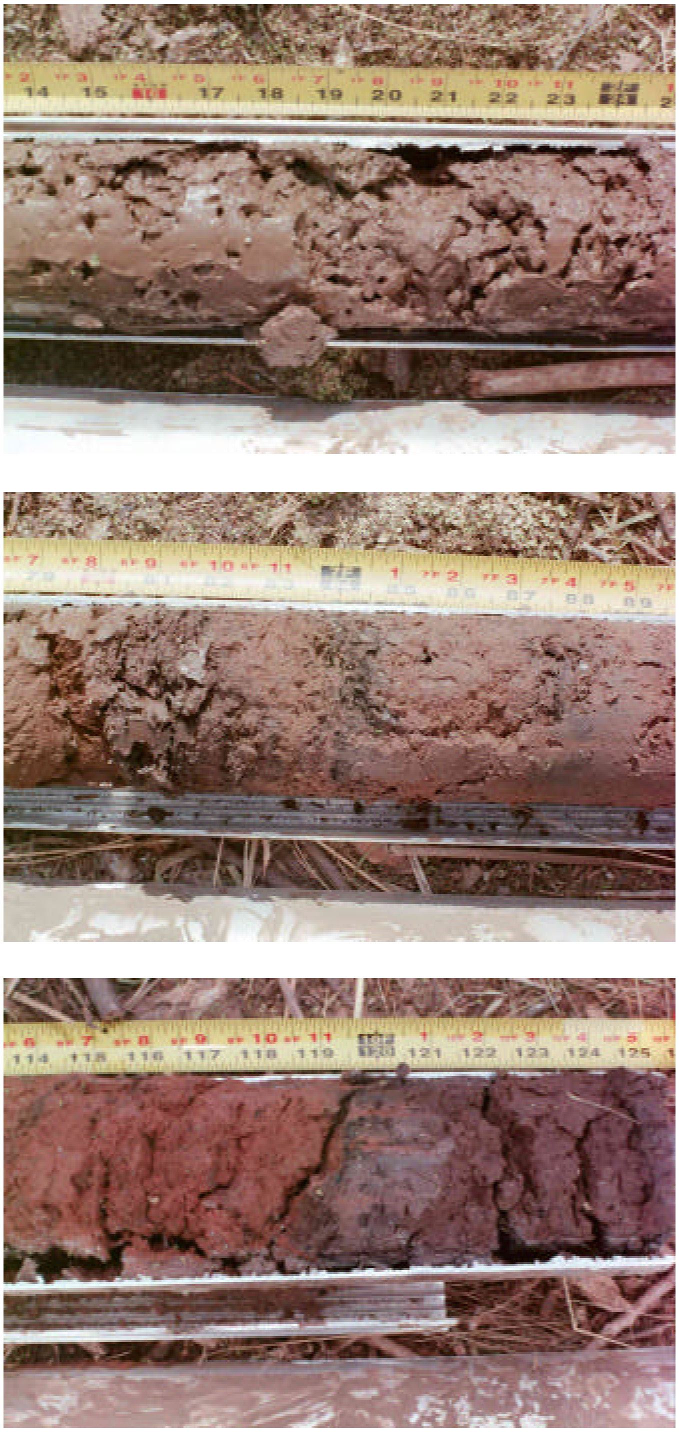

Figure 4-5. Typical photographs of sediment within the extracted cores (June 1999).

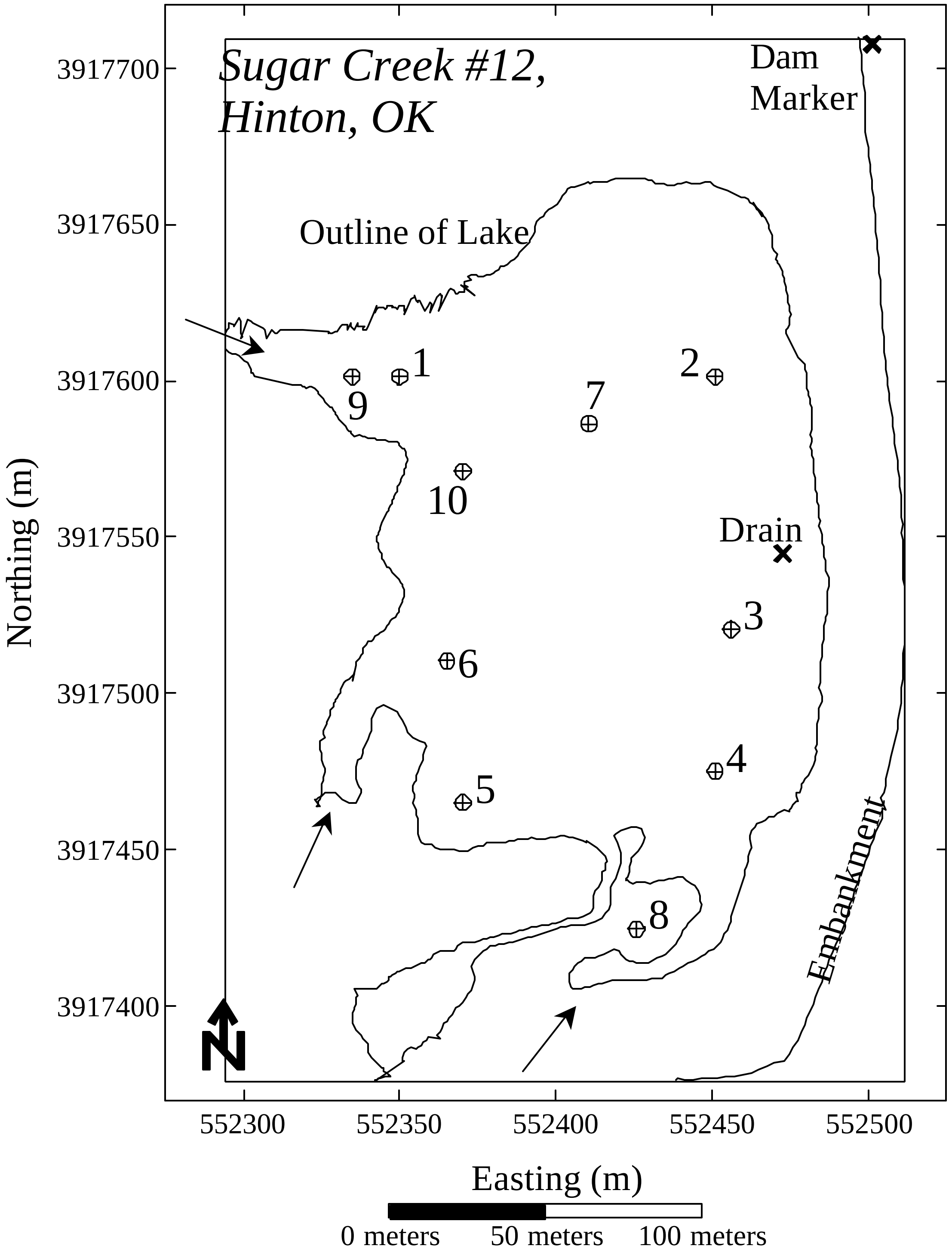

Figure 4-6. Base map of Sugar Creek #12 showing locations of all cores (numbered 1-10). Arrows show flow direction of major tributaries entering the reservoir. All positions are in UTM coordinates.

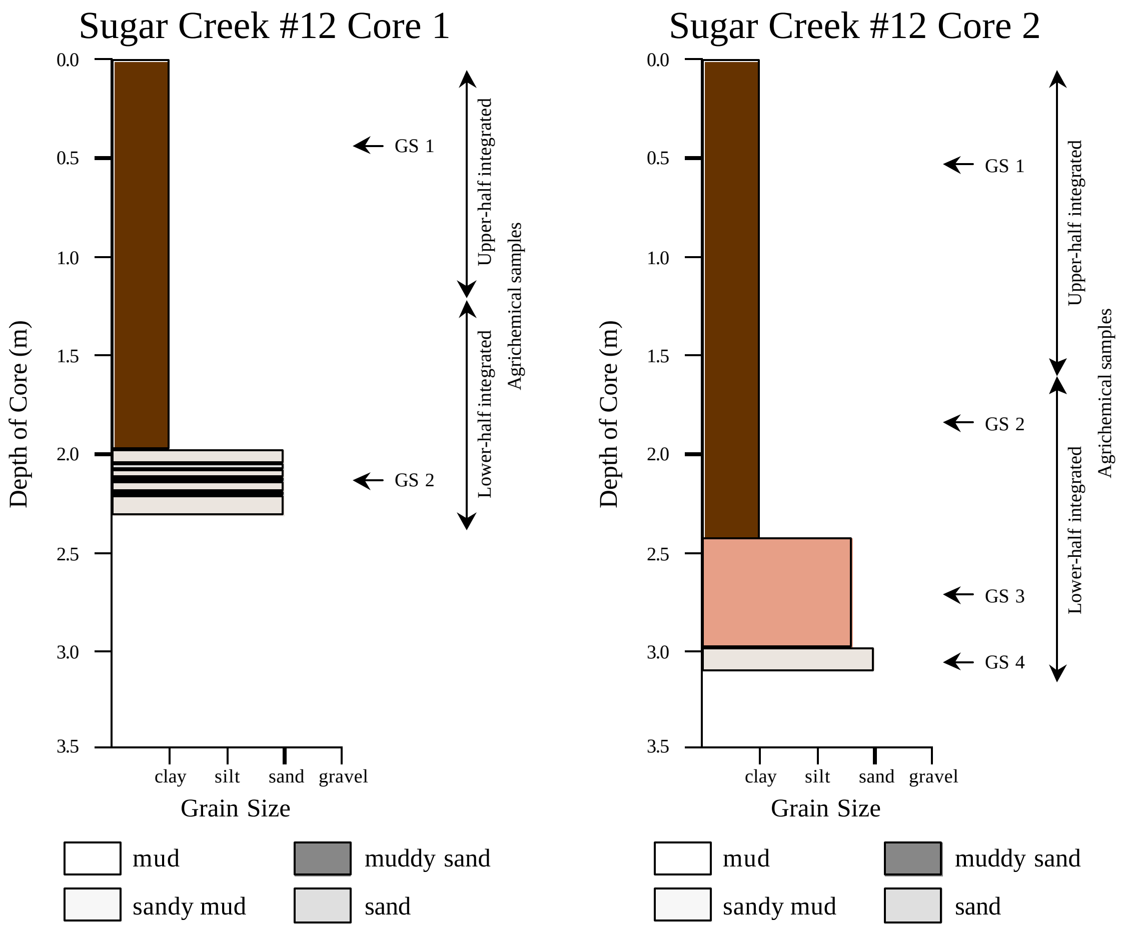

Figure 4-7. Stratigraphic logs of Core 1 (left) and Core 2 (right) obtained at Sugar Creek #12 (see Figure 4-6 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment and agrichemical analysis.

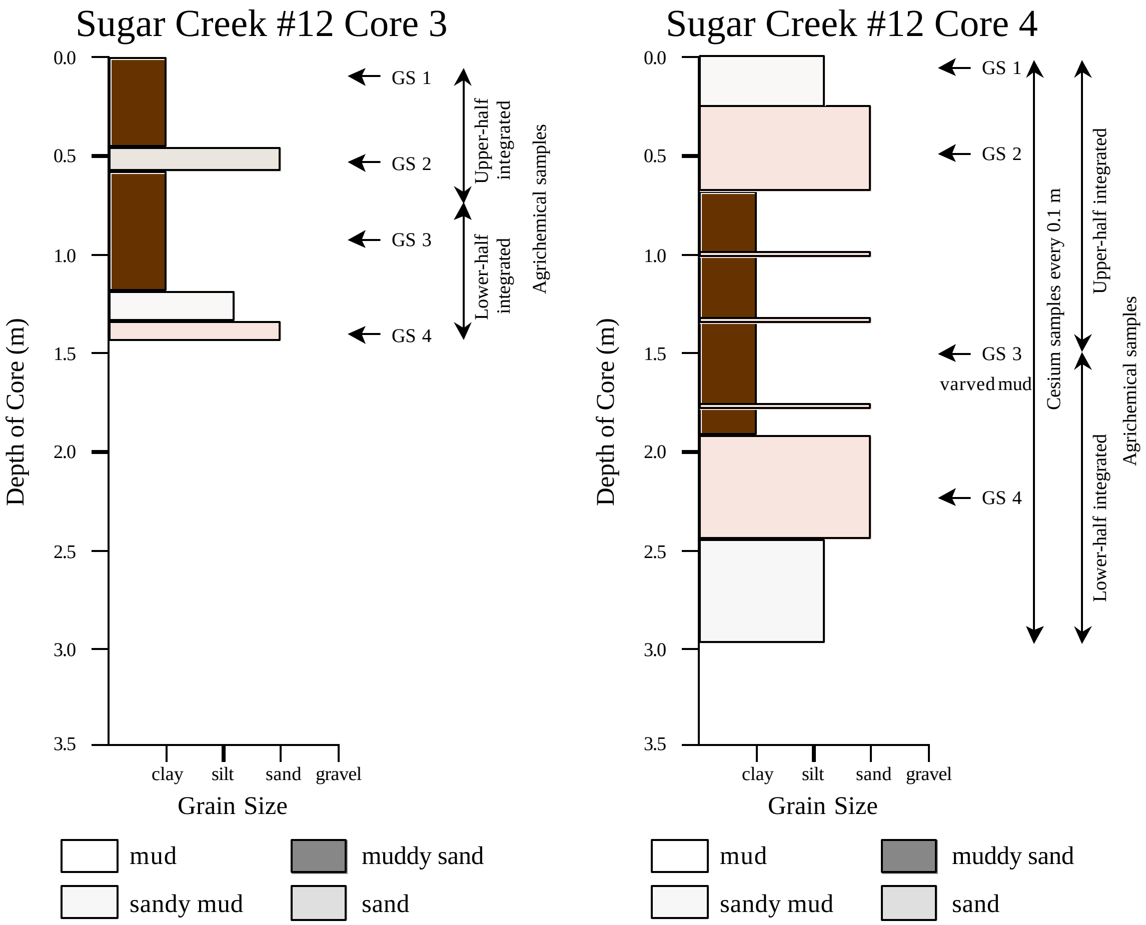

Figure 4-8. Stratigraphic logs of Core 3 (left) and Core 4 (right) obtained at Sugar Creek #12 (see Figure 4-6 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment, ^{137}Cs, and agrichemical analysis.

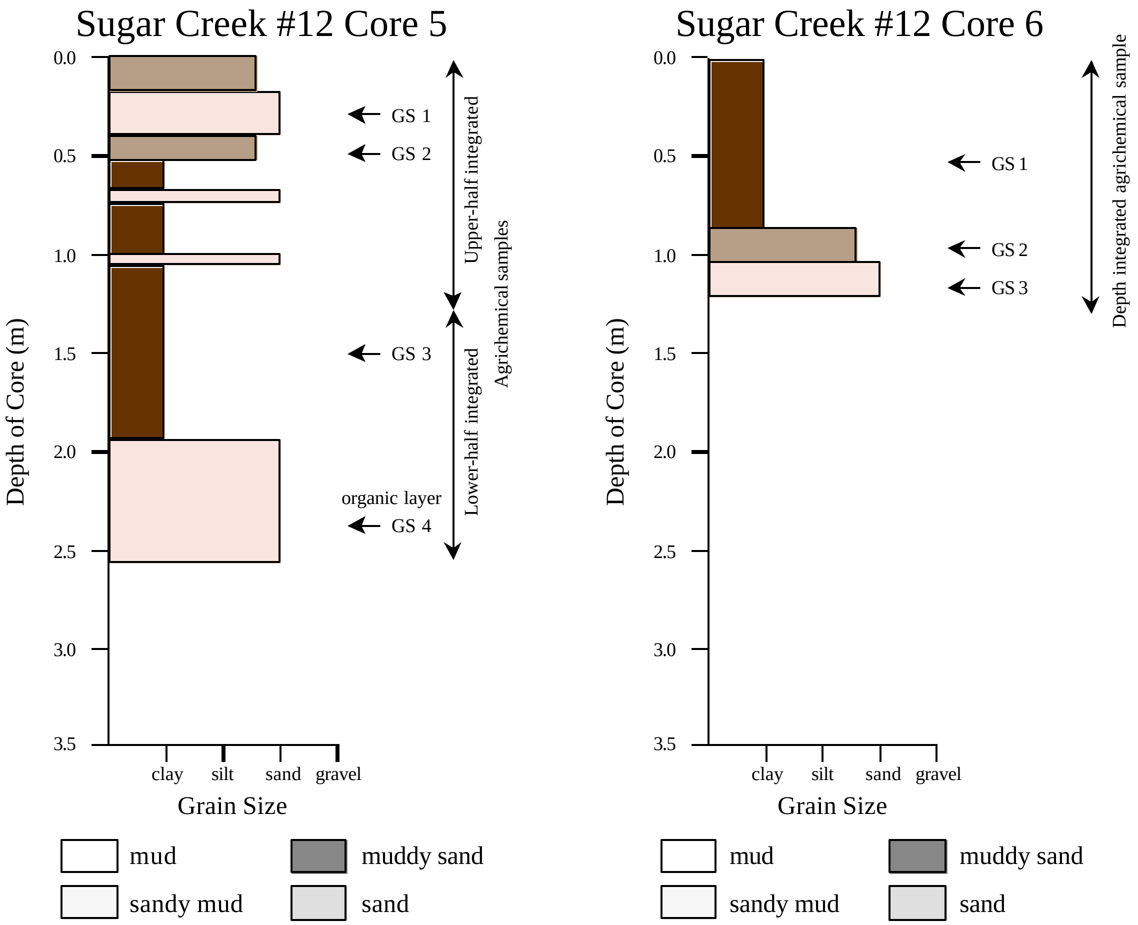

Figure 4-9. Stratigraphic logs of Core 5 (left) and Core 6 (right) obtained at Sugar Creek #12 (see Figure 4-6 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment and agrichemical analysis.

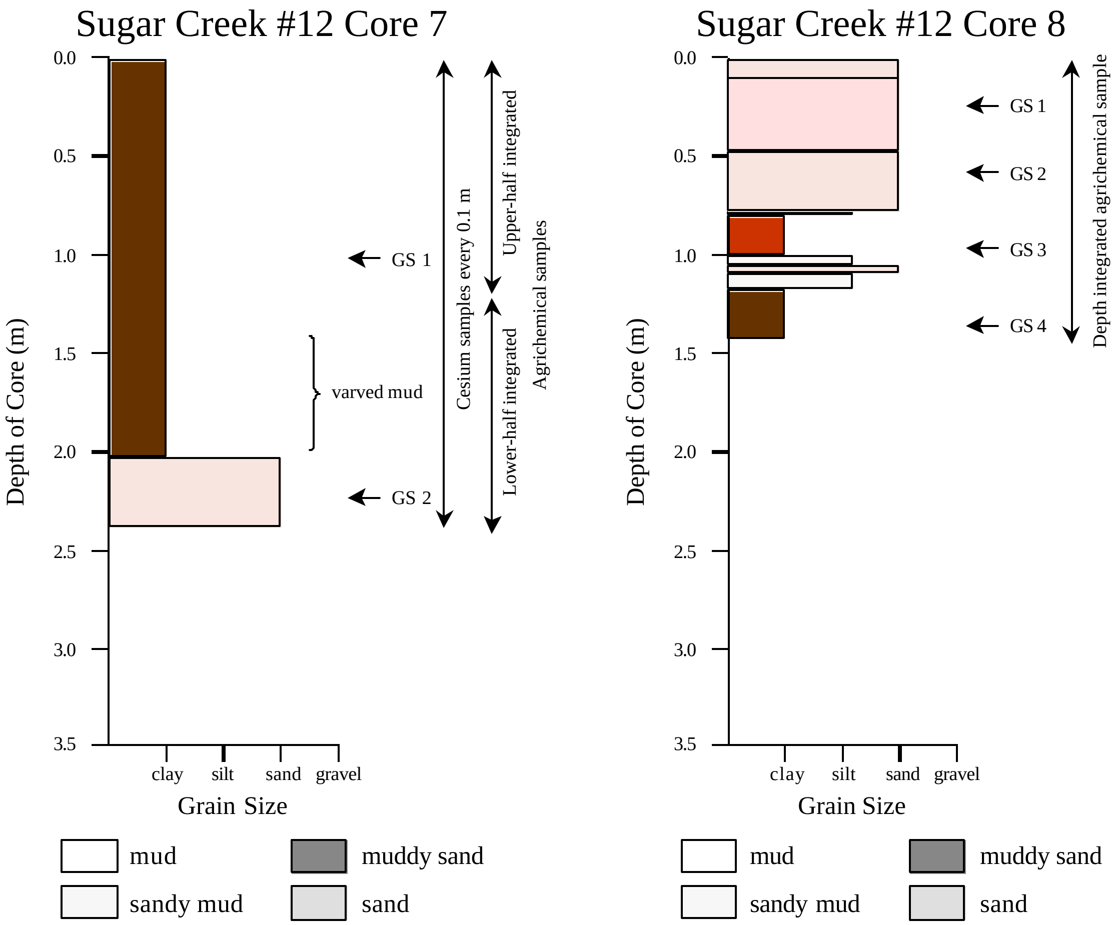

Figure 4-10. Stratigraphic logs of Core 7 (left) and Core 8 (right) obtained at Sugar Creek #12 (see Figure 4-6 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment, ^{137}Cs, and agrichemical analysis.

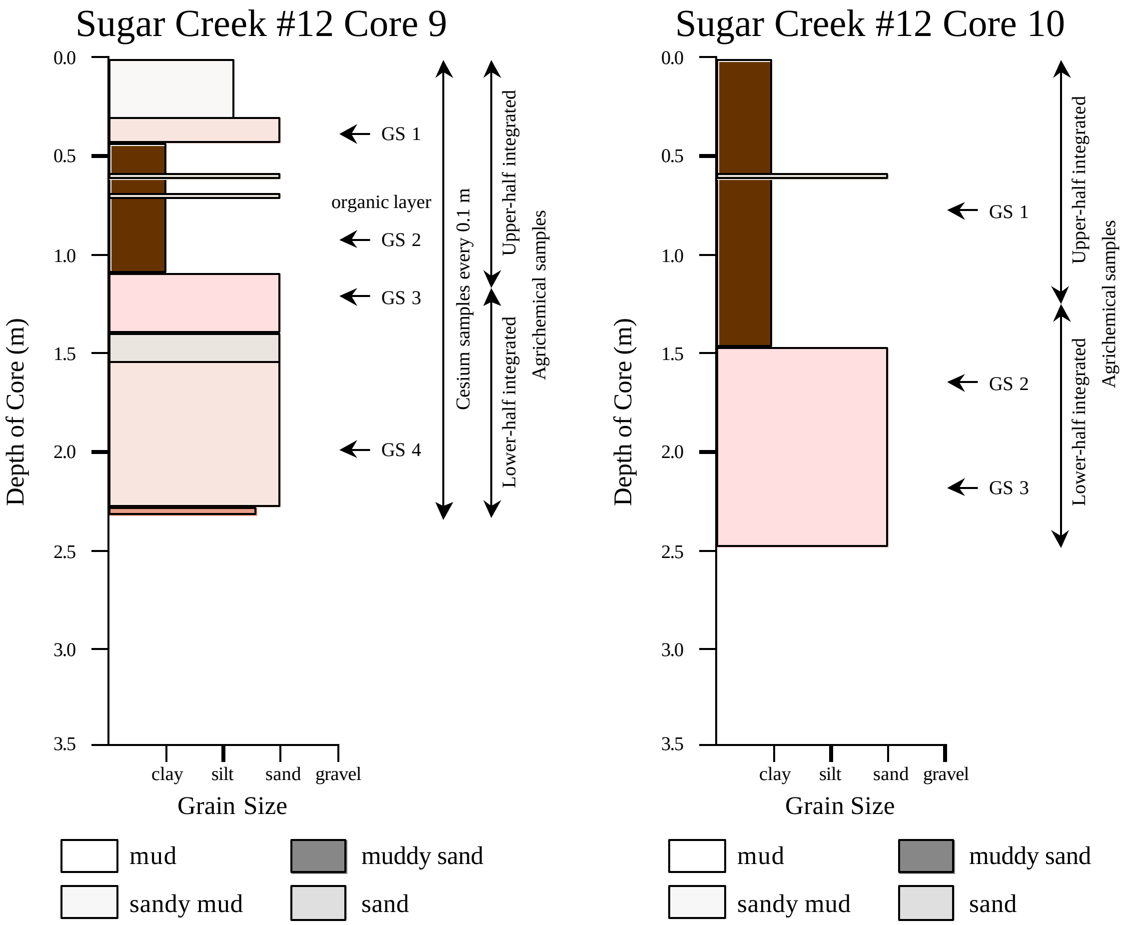

Figure 4-11. Stratigraphic logs of Core 9 (left) and Core 10 (right) obtained at Sugar Creek #12 (see Figure 4-6 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment, ^{137}Cs, and agrichemical analysis.

4.2 Sediment Cores Obtained at Sergeant Major #4

Four continuous, undisturbed cores were obtained at Sergeant Major #4 and their positions are shown in Figure 4-12. These cores ranged in length from 1.3 to 1.6 m and were extracted from water depths ranging from 1 to 12 m. The positions of the cores were chosen to coincide precisely with the seismic profiles collected previously (see Figure 3-13). Equipment failure prohibited the collection of additional cores.

Stratigraphic columns for each core are shown in Figures 4-13 and 4-14. The stratigraphic logs show the schematic textural and color characteristics of each core, the location of the sediment samples secured (e.g., GS 1, GS 2, etc.), and the location of agrichemical and Cesium samples obtained.

In general, the cores at Sergeant Major #4 are composed of gravel, sand, silt, and clay. In places, alternating layers of black and red-brown silt and clay (varves) are present (see Core 1, Figure 4-13; and Core 4, Figure 4-14). Very thick accumulations, up to 1.1 m, of silt and clay are common (see Core 1, Figure 4-13; and Core 4, Figure 4-14), but also common are large sand accumulations of up to 1 m (see Core 2, Figure 4-13; and Core 4, Figure 4-14). The thick silt and clay unit in Core 1 has a very thin (ca. 5 mm) sand unit (Figure 4-13). Gravel is observed near the base of Core 1 (Figure 4-13) and Core 4 (Figure 4-14), and rock fragments are present near the base of Core 2 (Figure 4-13). Roots are observed near the base of Cores 3 and 4 and a layer rich in organic material is present within the silt and clay layer of Core 3 (Figure 4-14).

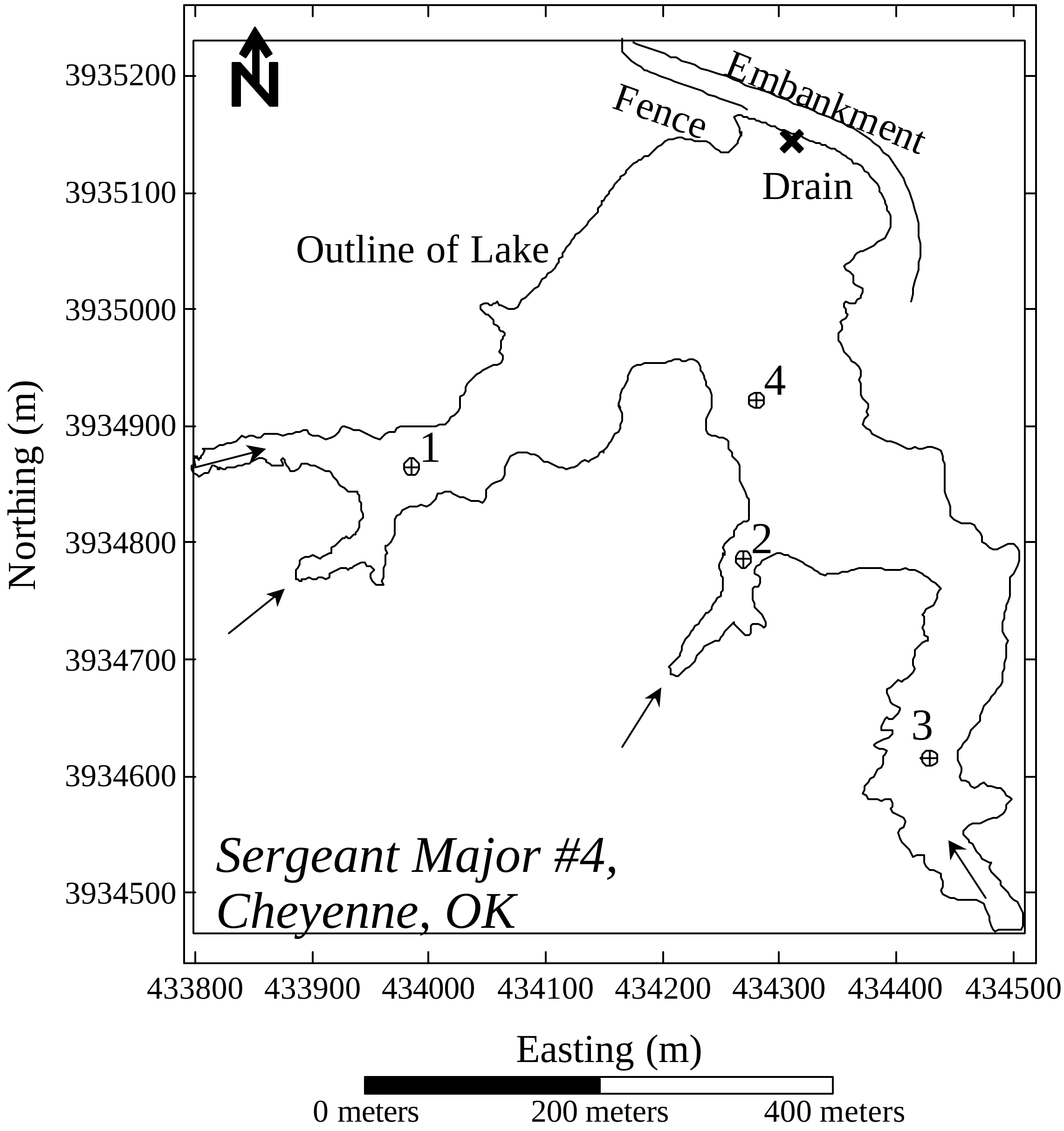

Figure 4-12. Base map of Sergeant Major #4 showing locations of all cores (numbered 1-4). Arrows show flow direction of major tributaries entering the reservoir. All positions are in UTM coordinates.

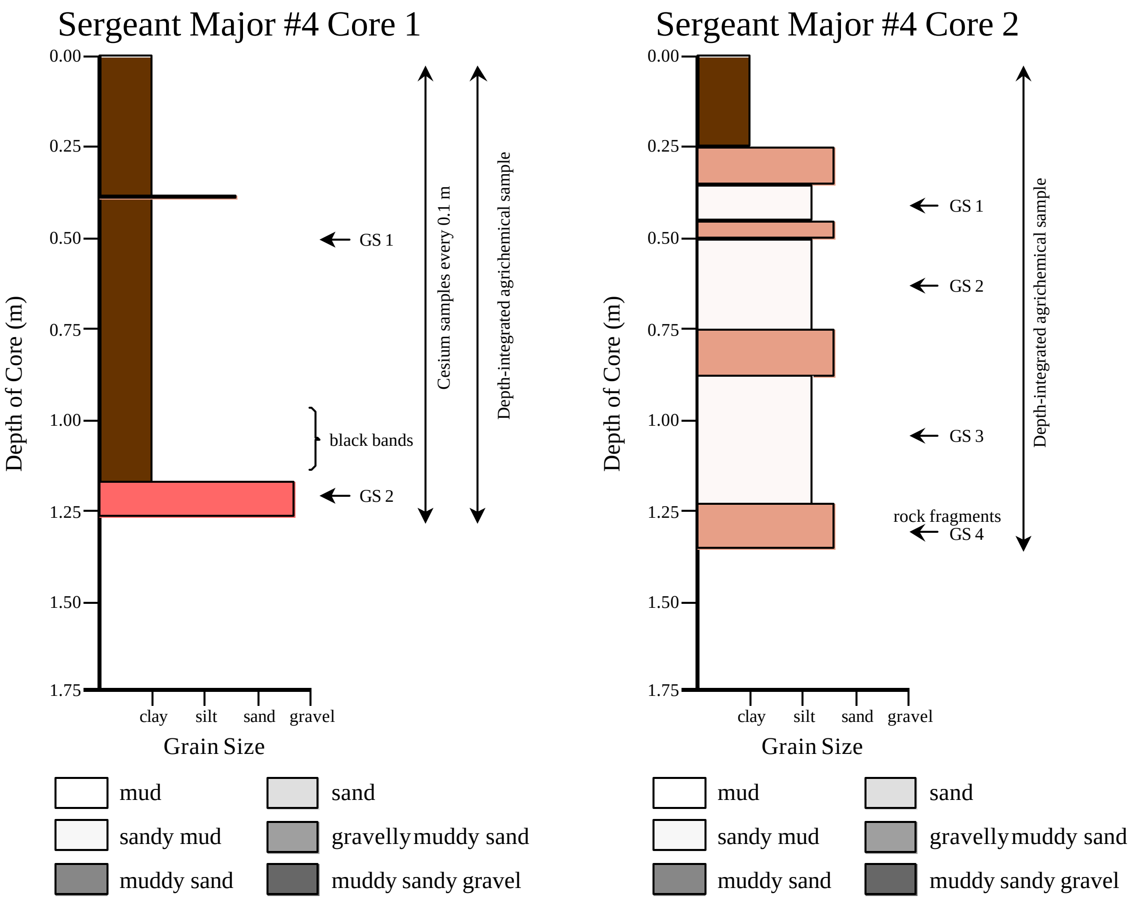

Figure 4-13. Stratigraphic logs of Core 1 (left) and Core 2 (right) obtained at Sergeant Major #4 (see Figure 4-12 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment, ^{137}Cs, and agrichemical analysis.

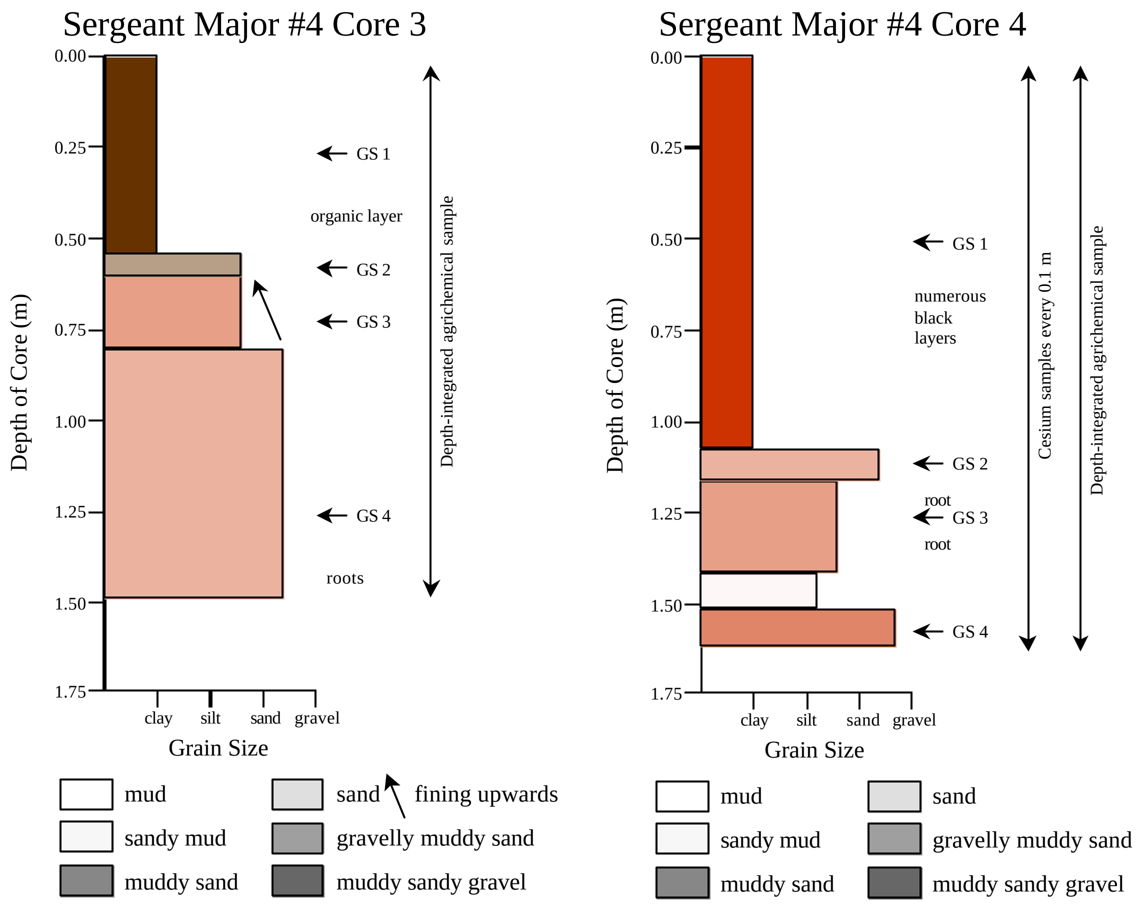

Figure 4-14. Stratigraphic logs of Core 3 (left) and Core 4 (right) obtained at Sergeant Major #4 (see Figure 4-12 for exact location). Also shown are schematic textural and color characteristics of the units and the location of samples obtained for analysis including sediment, ^{137}Cs, and agrichemical analysis.

4.3 Physical and Chemical Characteristics of the Sediment within the Cores

Select physical and chemical characteristics were determined for each of the sediment samples obtained form the major stratigraphic horizons identified in the cores. The purpose of this characterization is to facilitate the correlation of these stratigraphic horizons across the reservoir basin. These physical and chemical characterizations include grain size analysis, magnetic susceptibility, pH, percentage nitrogen and carbon, and color. All results are tabulated in Tables 4-1 and 4-2.

4.3.1 Methods and Procedures

For grain size analysis, approximately 10 g of sediment was treated in H_20_2 and shaken overnight in sodium hexametaphosphate for complete dispersion. Total percent clay (<0.002 mm) by mass was determined by siphoning off 5-mL of the dispersed sediment and using the pipette method (Method 3A1, Soil Survey Staff, 1992). Total percent sand by mass was determined by wet sieving the remaining sample through a 0.053-mm sieve and weighing the dried sediment retained. Total percent silt by mass was calculated by subtracting the masses of sand and clay from the original sample mass.

For magnetic susceptibility, dried and crushed sediment samples were packed into 20-mL glass vials and the mass specific magnetic susceptibility of the sample was measured using a Bartington MS2B susceptibility meter at a frequency of 0.47 kHz (values presented here are in SI units; 10^{-8} m^3/kg; see Lindbo et al., 1997). The magnetic susceptibility of each glass vial was determined prior to use.

Soil pH was measured in a 1:1 soil/distilled water suspension (McLean, 1982). Organic carbon and nitrogen was determined using a Leco CD-12 carbon and nitrogen analyzer using a 2-g sample.

Quantitative sediment color was determined using a chroma meter that employs a self-contained pulsed xenon arc lamp as a light source (Minolta CR-200 Chroma Meter; see Lindo et al., 1998). Water saturated sediment colors using the Munsell system of hue, value, and chroma are reported here (Munsell Color Company, 1994).

4.3.2 Grain Size Analysis Results

For Sugar Creek #12, the grain size results show that the silt-clay dominated stratigraphic units have nearly equal proportions of silt and clay but the percentage of clay (ca. 55% by weight) is typically higher than silt (ca. 40% by weight; Table 4-1). The sand dominated units can have as much as 95% sand by weight, with varying proportions of silt and clay. Poorly sorted sediments, with varying amounts of sand, silt, and clay, tend to occur near the silt-clay dominated layers (Core 3, GS3-2, Table 4-1, Figure 4-8; and Core 9, GS9-1, Table 4-1, Figure 4-11).

For Sergeant Major #4, the grain size results show that much of the sediment is poorly sorted and the percentage of silt by weight is typically much greater than clay (Table 4-

1). The silt-clay dominated units generally have two to three times the amount of silt than clay by weight, and clay percentages rarely exceed 20% by weight. The sandy units are poorly sorted and each has a greater proportion of silt (ca. 50% by weight) than sand (ca. 32% by weight).

4.3.3 Magnetic Susceptibility Results

The magnetic susceptibility of sediment is one measure of how easily the sediment can be magnetized by an external field, expressed as the ratio of the induced magnetization to the applied (Kimbrough et al., 1997). Magnetite has a magnetic susceptibility roughly three orders of magnitude greater than any other naturally occurring mineral (Lindsley et al., 1966), and therefore it largely controls this physical property in sediments. Magnetic susceptibility readings, however, are also weakly dependent on grain size, grain shape, and the presence of other magnetic minerals.

For Sugar Creek #12, magnetic susceptibility ranges from 2 to 87 10^{-8} m^3/kg (Table 4-1). In general, the value of magnetic susceptibility at Sugar Creek is proportional to the amount of silt and clay present (see below). For Sergeant Major #4, magnetic susceptibility ranges from 5 to 27 10^{-8} m^3/kg. In general, the magnetic susceptibility values for Sergeant Major #4 are lower in magnitude and less variable than those values measured at Sugar Creek #12.

4.3.4 Sediment pH and Nitrogen and Carbon Content

The pH of the sediment at Sugar Creek #12 ranges from as low as 6.2 and as high as 8.3 with an average value around 7.5 (Table 4-1). In contrast, the pH of the sediment in Sergeant Major #4 ranges from 7.9 to 9.2, with an average value around 8.5. These values reflect regional variations in climate and soil type.

Very little nitrogen is present in the sediments at Sugar Creek #12, typically much less than 0.1% by weight (Table 4-1). Carbon is observed to range from 0.06 to 2.3% in the same sediments, with an average value around 0.2%. At Sergeant Major #4, the nitrogen content of the sediment is very small, typically less than 0.02% by weight. The amount of carbon in these sediments range from 0.8 to 2.8%, with an average value of around 2%.

4.3.5 Sediment Color

Table 4-2 summarizes the color determinations for all sediment samples. In general, the sediment at Sugar Creek #12 has a hue ranging from 3 to 7YR, whereas the sediment in Sergeant Major #4 has a hue ranging from 1 to 4YR.

4.3.6 Correlation amongst the Physical and Chemical Characteristics

An attempt is made to determine any correlation amongst the physical and chemical characteristics of the sediment. These correlation plots include grain size and magnetic susceptibility (Figure 4-15), grain size and pH (Figure 4-16), grain size and percent nitrogen, (Figure 4-17), grain size and percent carbon (Figure 4-18), percent sand and color (Figure 4-19), percent silt and color (Figure 4-20), percent clay and color (Figure 4-21), magnetic susceptibility and pH, percent nitrogen, and percent carbon (Figure 4-22), magnetic susceptibility and color (Figure 4-23), pH and percent nitrogen and percent carbon (Figure 4-24), pH and color (Figure 4-25), percent nitrogen and color (4-26), percent carbon and color (Figure 4-27), and percent nitrogen and percent carbon (4-28). Table 4-3 summarizes the correlation of these parameters for Sugar Creek #12 and Table 4-4 summarizes the correlation of these parameters for Sergeant Major #4 (denoted as strong, weak, or no correlation).

The main results of this analysis are summarized below. For the sediment at Sugar Creek #12, the amount of silt and clay is positively correlated with the amount of carbon and nitrogen and are associated with high values of magnetic susceptibility (Table 4-3). Hence, the amount of sand is negatively correlated with the amount of carbon and nitrogen and is associated with low values of magnetic susceptibility. Sediment hue is positively correlated and sediment chroma is negatively correlated to silt and clay content. Sediment pH is negatively correlated, though slightly so, with silt and clay content. Carbon and nitrogen are found to be positively correlated.

For Sergeant Major #4, there is little correlation amongst the physical and chemical characteristics of the sediment. Carbon content is positively correlated with silt and clay content and magnetic susceptibility, and carbon is negatively correlated to sand content. Some correlation is observed between color, magnetic susceptibilty, and pH, but these relations are of little significance.

Table 4-1. Physical and chemical characteristics of sediment samples obtained from cores at Sugar Creek #12 and Sergeant Major #4.

Core No.	Sample No.	Textural Composition (% by mass)			Magnetic Susceptibility	pH	Chemical Composition (% by mass)	
		Sand	Silt	Clay	10^{-8} m^3/kg		Nitrogen	Carbon
				Sugar Creek #12				
1	1-1	1.42	44.79	53.79	73.42	7.38	0.178	2.378
	1-2	0.95	47.82	51.22	79.11	6.83	0.142	1.953
	1-3	0.64	34.67	64.69	83.55	7.05	0.184	2.329
	1-4	89.49	5.17	5.34	8.70	8.29	n.d.	0.531
2	2-1	0.29	35.15	64.56	86.72	7.41	0.167	2.140
	2-2	0.22	43.68	56.10	78.76	6.24	0.158	2.093
	2-3	81.86	9.08	9.06	6.15	7.24	n.d.	0.476
	2-4	52.67	35.30	12.03	20.77	7.26	0.015	1.147
3	3-1	3.82	55.02	41.15	69.10	7.4	0.136	2.258
	3-2	45.34	32.12	22.55	37.10	6.75	0.030	1.041
	3-3	2.27	43.04	54.69	80.40	6.42	0.170	2.439
	3-4	78.56	11.85	9.58	8.41	8.26	n.d.	0.228
4	4-1	69.78	17.34	12.88	17.02	7.76	n.d.	0.554
	4-2	95.47	0.03	4.50	5.53	7.49	n.d.	0.095
	4-3	2.76	31.12	66.13	87.02	6.83	0.185	2.481
	4-4	79.34	12.45	8.21	13.85	7.52	n.d.	0.460
	4-5	66.45	22.38	11.18	22.94	6.65	n.d.	0.750
5	5-1	95.25	0.08	4.66	3.66	7.26	n.d.	0.106
	5-2	67.75	16.90	15.35	18.56	7.54	n.d.	0.722
	5-3	2.00	41.91	56.09	86.01	6.47	0.175	2.418
	5-4	95.66	n.d.	5.06	3.53	6.94	n.d.	0.086
6	6-1	3.42	42.61	53.97	83.43	6.85	0.152	2.216
	6-2	76.05	15.26	8.69	13.39	6.5	n.d.	0.683
	6-3	90.30	2.95	6.75	2.54	7.79	n.d.	0.089
7	7-1	1.38	45.21	53.41	76.42	7.56	0.148	2.204

Table 4-1 continued

Core No.	Sample No.	Textural Composition (% by mass)			Magnetic Susceptibility	pH	Chemical Composition (% by mass)	
		Sand	Silt	Clay	10^{-8} m^3/kg		Nitrogen	Carbon
	7-2	81.88	9.59	8.53	6.11	7.42	n.d.	0.196
8	8-1	96.50	1.01	2.49	2.40	8.08	n.d.	0.079
	8-2	76.68	14.87	8.45	13.99	7.62	n.d.	0.48
	8-3	86.17	8.92	4.92	9.28	7.78	n.d.	0.263
	8-4	4.50	56.52	38.98	65.62	6.77	0.108	1.839
9	9-1	71.69	18.52	9.79	20.67	8.09	n.d.	0.491
	9-2	2.78	46.19	51.03	85.63	7.19	0.154	2.331
	9-3	87.35	6.67	5.98	4.02	7.42	n.d.	0.077
	9-4	92.99	3.15	3.86	4.70	6.87	n.d.	0.142
10	10-1	1.20	43.56	55.24	75.94	7.2	0.125	1.896
	10-2	90.34	3.55	6.10	2.54	8	n.d.	0.064
	10-3	89.13	5.44	5.43	3.16	8.71	n.d.	0.194
				Sergeant Major #4				
1	1-1	1.89	71.40	26.71	19.59	8.1	0.028	2.258
	1-2	23.26	57.30	19.44	5.10	8.7	n.d.	2.104
2	2-1	26.24	56.23	17.53	8.07	8.63	n.d.	1.731
	2-2	32.38	47.84	19.79	6.55	8.82	n.d.	2.033
	2-3	34.75	47.50	17.75	6.87	8.99	n.d.	1.889
	2-4	38.68	43.02	18.30	6.04	9.18	n.d.	1.539
3	3-1	20.03	59.17	20.79	22.66	8.03	0.013	2.162
	3-2	58.60	29.97	11.42	26.92	8.35	n.d.	0.777
	3-3	8.55	70.30	21.16	7.40	8.55	n.d.	1.696
	3-4	9.19	69.71	21.10	6.34	8.92	n.d.	1.658
4	4-1	0.46	45.08	54.46	21.80	7.85	0.056	2.335
	4-2	13.21	64.17	22.62	6.45	8.77	n.d.	1.943
	4-3	9.24	67.78	22.97	6.96	8.34	n.d.	1.695
	4-4	14.07	66.81	19.12	5.59	8.8	n.d.	2.756

n.d. not detected

Table 4-2. Color characteristics of sediment samples obtained from cores at Sugar Creek #12 and Sergeant Major #4 using the Munsell system of hue, value, and chroma (Munsell Color Company, 1994).

Core	Sample	Munsell Color Scheme			Core	Sample	Munsell Color Scheme		
No.	No.	Hue (YR)	Value	Chroma	No.	No.	Hue (YR)	Value	Chroma
	Sugar Creek #12					*Sergeant Major #4*			
1	1-1	6.5	2.7	1.9	1	1-1	2.5	3.2	3.6
	1-2	6.0	3.0	1.8		1-2	1.2	3.0	4.3
	1-3	7.0	2.5	1.6	2	2-1	1.4	3.2	4.6
	1-4	5.2	3.0	2.0		2-2	0.8	3.4	4.5
2	2-1	6.5	2.7	1.8		2-3	1.1	3.4	4.5
	2-2	6.4	2.8	1.6		2-4	0.9	3.4	4.8
	2-3	3.7	3.1	3.4	3	3-1	3.9	3.2	3.0
	2-4	5.3	2.9	1.8		3-2	4.3	3.3	2.7
3	3-1	6.4	2.6	1.9		3-3	1.7	3.2	4.3
	3-2	5.1	3.0	2.2		3-4	1.2	3.4	4.6
	3-3	6.3	2.8	1.5	4	4-1	3.1	3.1	3.0
	3-4	3.6	3.1	2.9		4-2	1.0	3.2	4.5
4	4-1	5.6	2.9	2.6		4-3	1.3	3.2	4.1
	4-2	4.3	3.2	3.3		4-4	1.5	2.9	4.1
	4-3	6.5	22.6	1.6					
	4-4	4.3	3.0	2.4					
	4-5	6.5	2.4	1.2					
5	5-1	4.2	3.4	3.5					
	5-2	6.0	2.7	2.3					
	5-3	6.3	2.8	1.4					
	5-4	4.4	3.3	3.4					
6	6-1	6.7	2.5	1.6					
	6-2	5.8	2.5	1.9					
	6-3	2.8	3.5	4.2					
7	7-1	6.5	2.7	1.6					
	7-2	4.0	3.0	3.5					
8	8-1	3.4	3.5	3.6					
	8-2	4.3	3.2	2.8					
	8-3	4.7	3.2	3.0					
	8-4	6.3	2.8	1.8					
9	9-1	5.7	2.7	2.3					
	9-2	6.3	2.7	1.6					
	9-3	3.6	3.2	3.9					
	9-4	4.0	3.2	2.8					
10	10-1	5.8	2.7	1.8					
	10-2	3.7	3.3	4.1					
	10-3	3.9	3.2	3.9					

Table 4-3. Summary of correlation amongst the physical and chemical parameters for Sugar Creek #12. + denotes positive correlation, ++ denotes strongly positive correlation, - denotes negative correlation, - - denotes strongly negative correlation, and NC denotes no correlation.

Parameter	Sand (%)	Silt (%)	Clay (%)	N (%)	C (%)	Hue	Value	Chroma	Magnetic Susceptibility	pH
Sand (%)	•	•	•	––	––	–	NC	+	––	NC
Silt (%)	•	•	•	++	++	+	NC	––	++	–
Clay (%)	•	•	•	++	++	+	–	––	++	–
N (%)	•	•	•	•	++	+	–	–	++	––
C (%)	•	•	•	•	•	+	–	––	++	NC
Hue	•	•	•	•	•	•	•	•	++	––
Value	•	•	•	•	•	•	•	•	––	+
Chroma	•	•	•	•	•	•	•	•	––	++
Magnetic Susceptibility	•	•	•	•	•	•	•	•	•	NC
pH	•	•	•	•	•	•	•	•	•	•

Table 4-4. Summary of correlation amongst the physical and chemical parameters for Sergeant Major #4. + denotes positive correlation, ++ denotes strongly positive correlation, - denotes negative correlation, - - denotes strongly negative correlation, and NC denotes no correlation.

Parameter	Sand (%)	Silt (%)	Clay (%)	N (%)	C (%)	Hue	Value	Chroma	Magnetic Susceptibility	pH
Sand (%)	•	•	•	NC	––	NC	NC	NC	NC	NC
Silt (%)	•	•	•	NC	++	NC	NC	NC	NC	NC
Clay (%)	•	•	•	+	++	+	NC	–	NC	NC
N (%)	•	•	•	•	NC	NC	NC	NC	NC	NC
C (%)	•	•	•	•	•	NC	NC	NC	+	NC
Hue	•	•	•	•	•	•	•	•	++	––
Value	•	•	•	•	•	•	•	•	NC	NC
Chroma	•	•	•	•	•	•	•	•	––	++
Magnetic Susceptibility	•	•	•	•	•	•	•	•	•	NC
pH	•	•	•	•	•	•	•	•	•	•

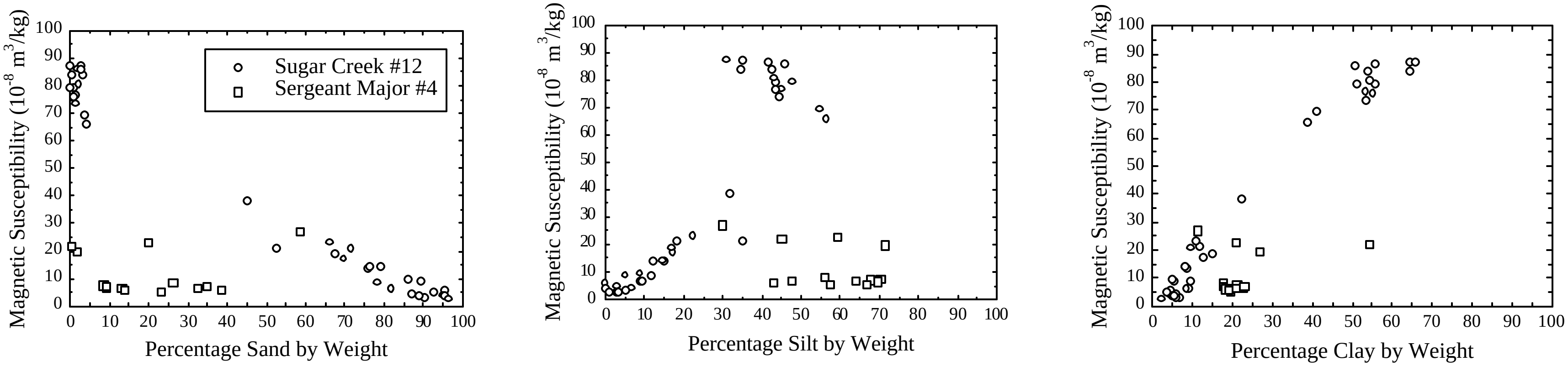

Figure 4-15. Relation between percentage sand, silt, and clay and magnetic susceptibility for all sediment samples.

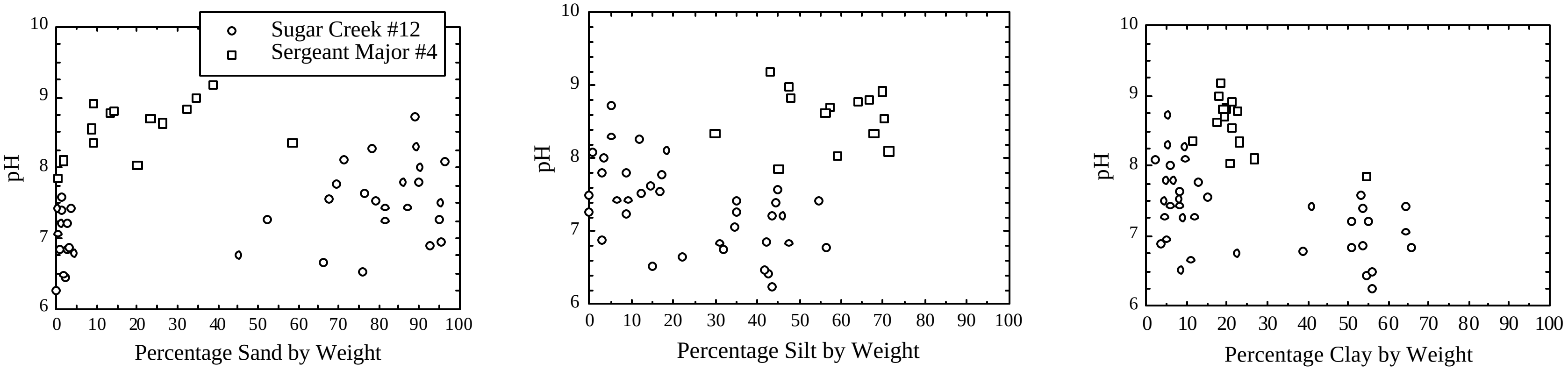

Figure 4-16. Relation between percentage sand, silt, and clay and pH for all sediment samples.

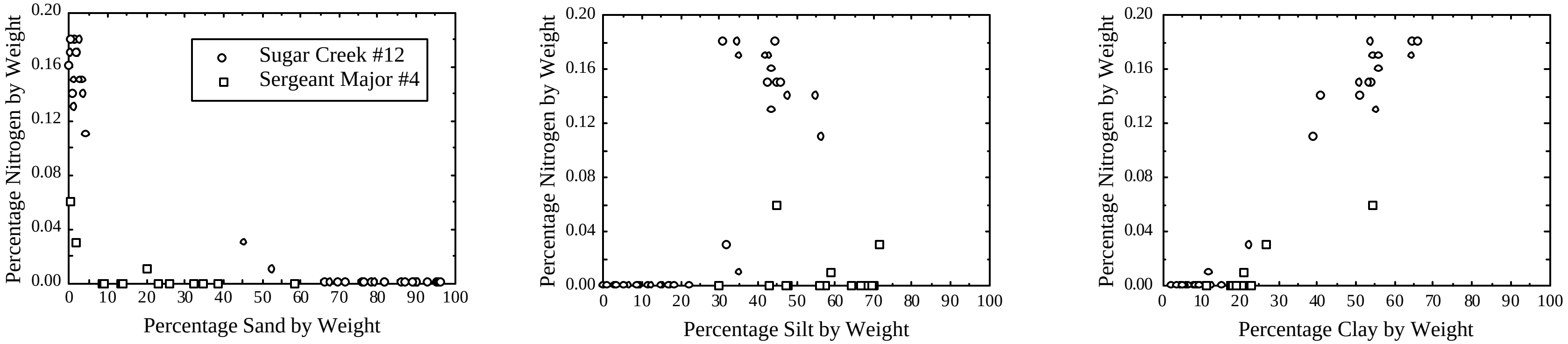

Figure 4-17. Relation between percentage sand, silt, and clay and percentage nitrogen by weight for all sediment samples.

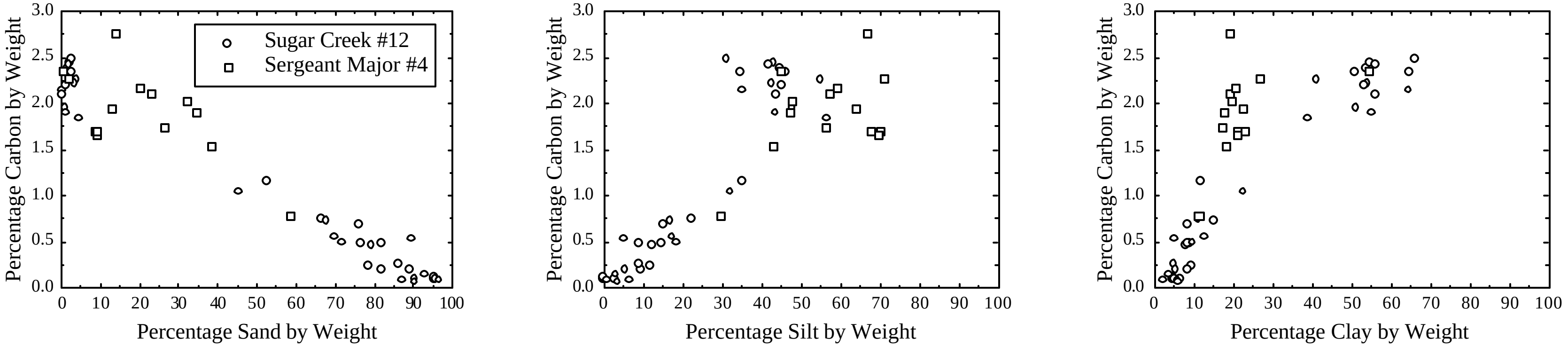

Figure 4-18. Relation between percentage sand, silt, and clay and percentage carbon by weight for all sediment samples.

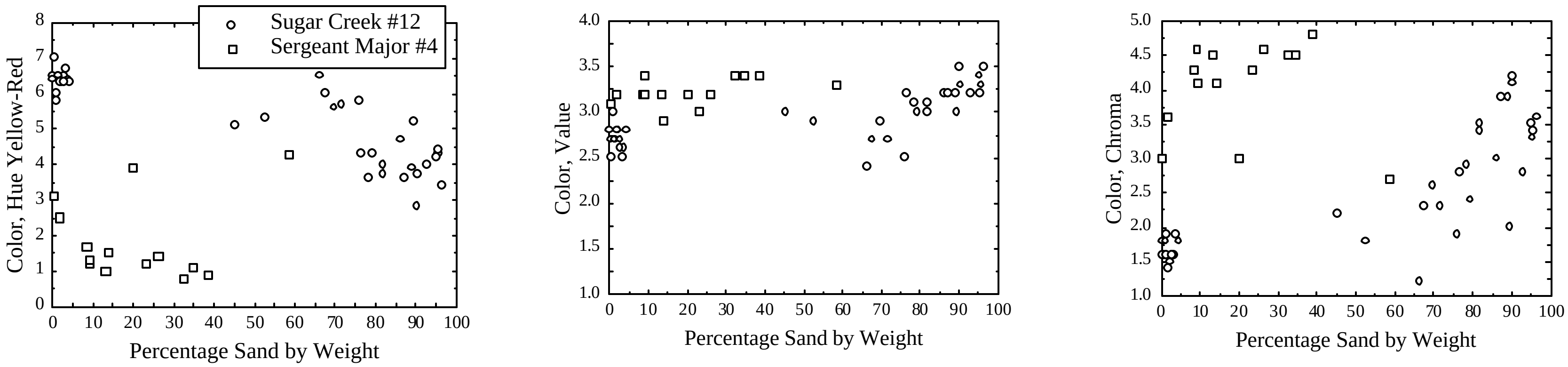

Figure 4-19. Relation between the percentage sand by weight and color (hue, value, and chroma) for all sediment samples.

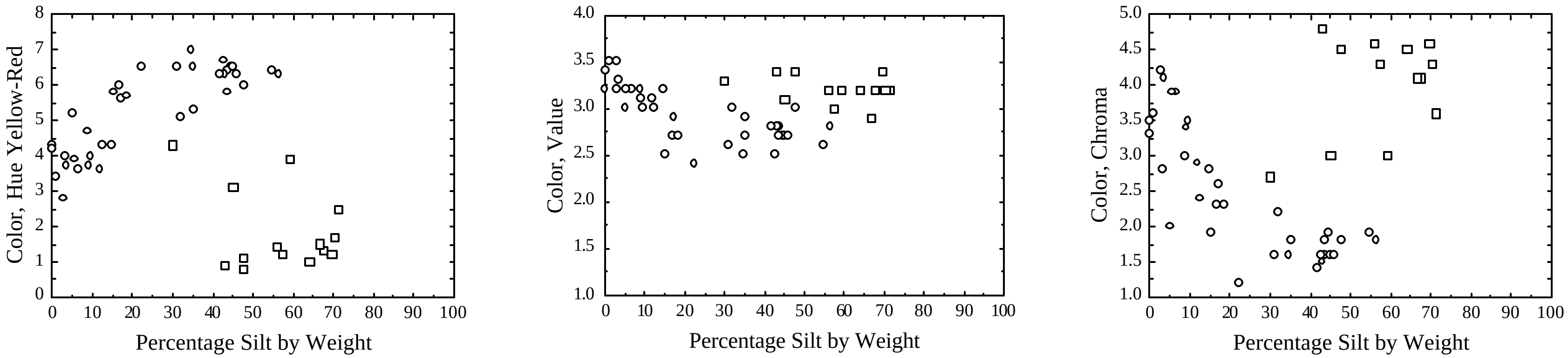

Figure 4-20. Relation between the percentage silt by weight and color (hue, value, and chroma) for all sediment samples.

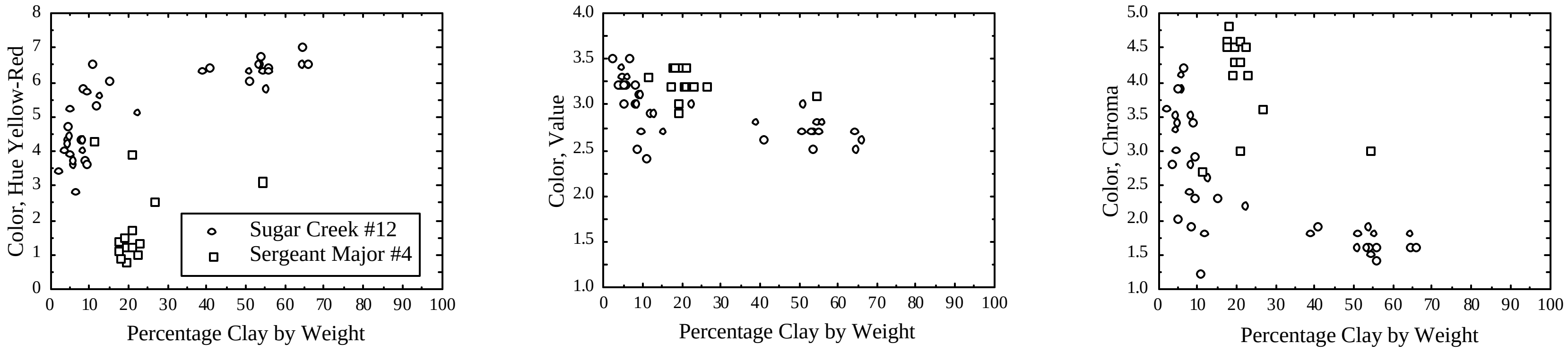

Figure 4-21. Relation between the percentage clay by weight and color (hue, value, and chroma) for all sediment samples.

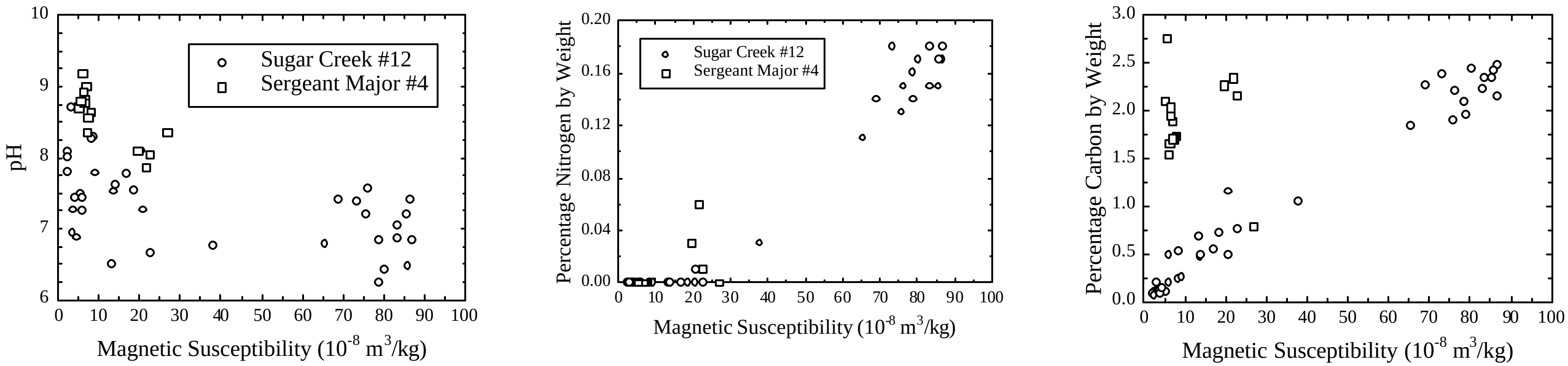

Figure 4-22. Relation between magnetic susceptibility and pH, percentage nitrogen, and percentage carbon for all sediment samples.

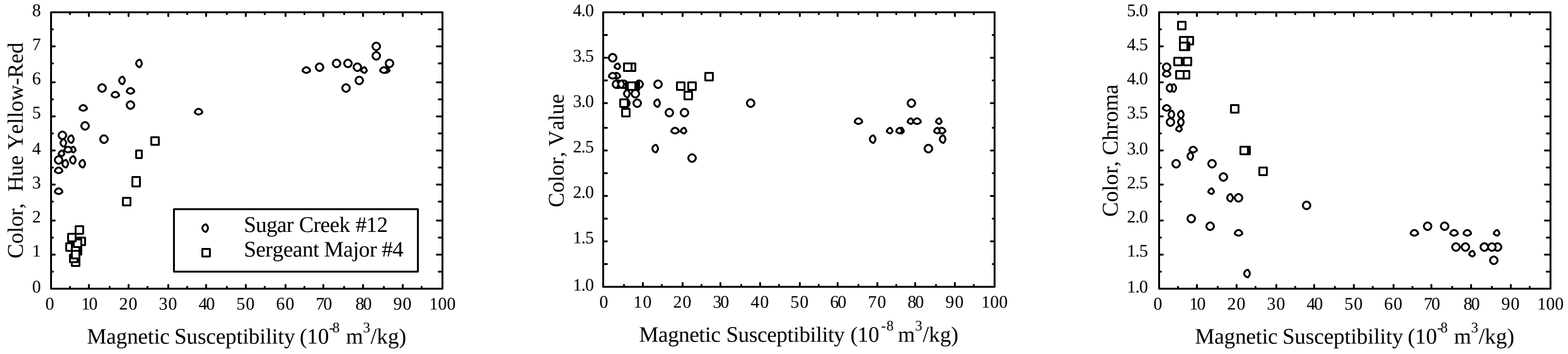

Figure 4-23. Relation between magnetic susceptibility and color (hue, value, and chroma) for all sediment samples.

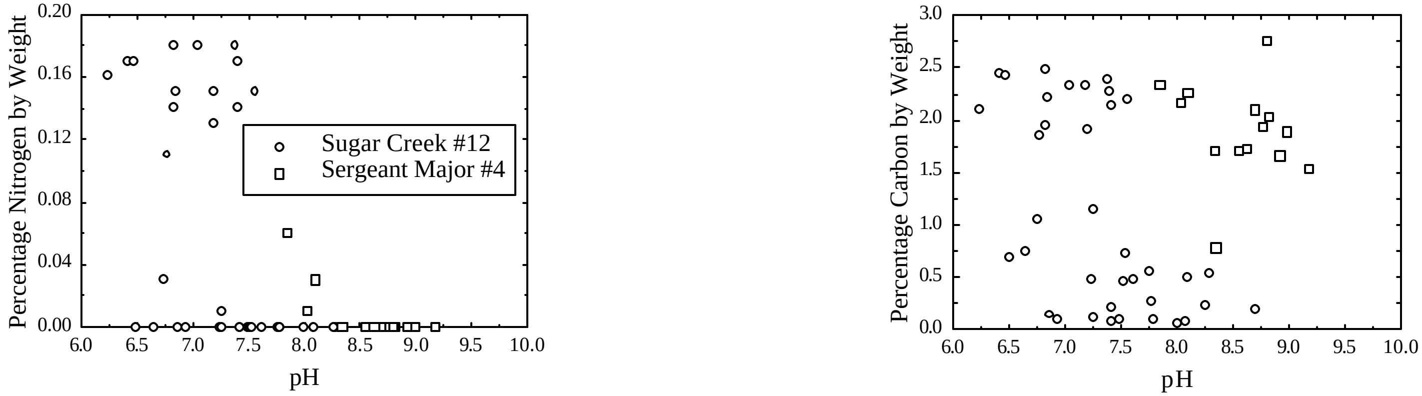

Figure 4-24. Relation between pH and percentage nitrogen and carbon by weight for all sediment samples.

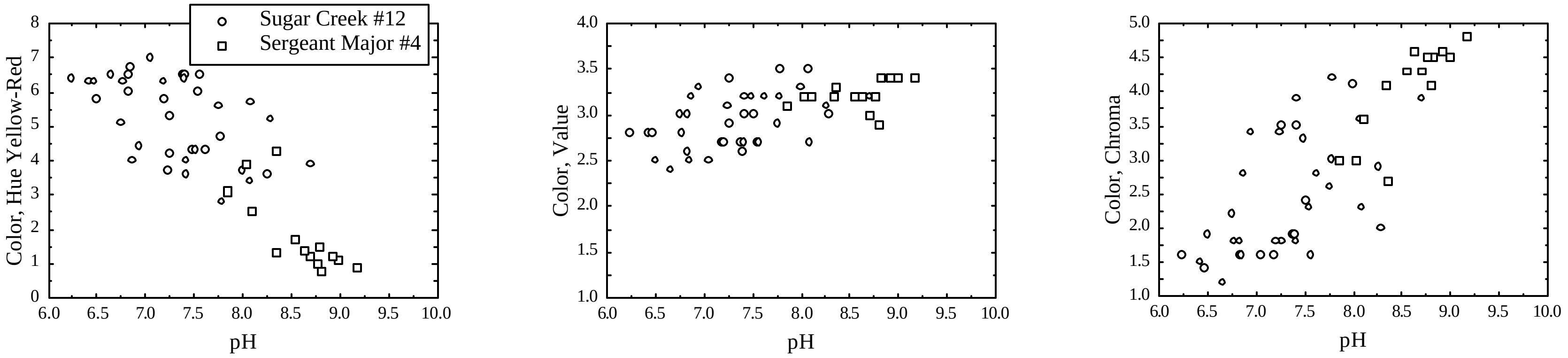

Figure 4-25. Relation between the pH and color (hue, value, and chroma) for all sediment samples.

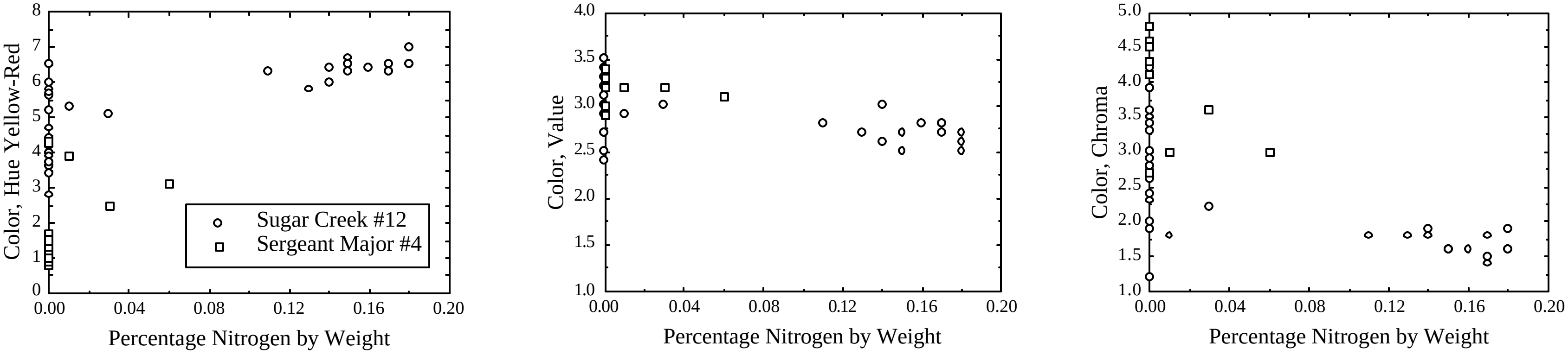

Figure 4-26. Relation between percentage nitrogen by weight and color (hue, value, and chroma) for all sediment samples.

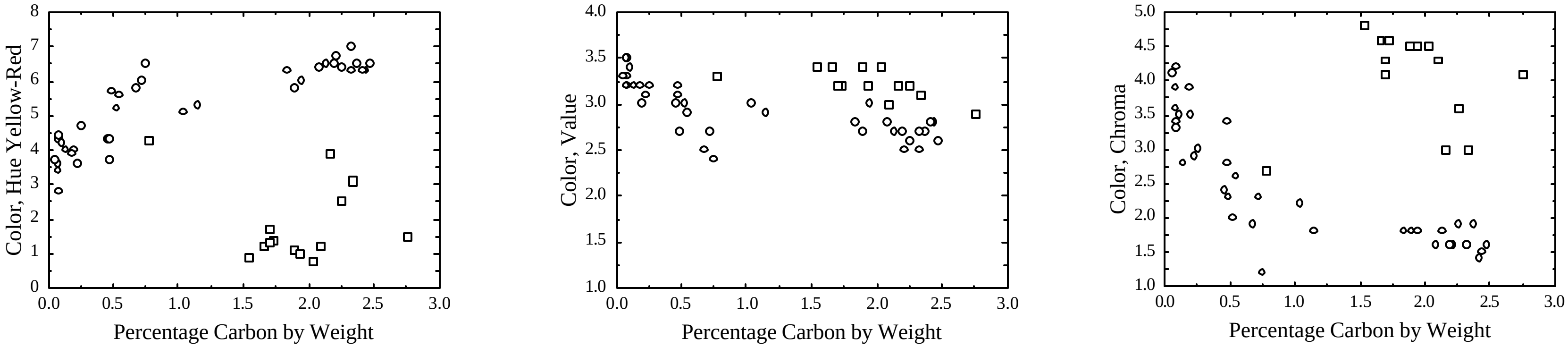

Figure 4-27. Relation between percentage carbon by weight and color (hue, value, and chroma) for all sediment samples.

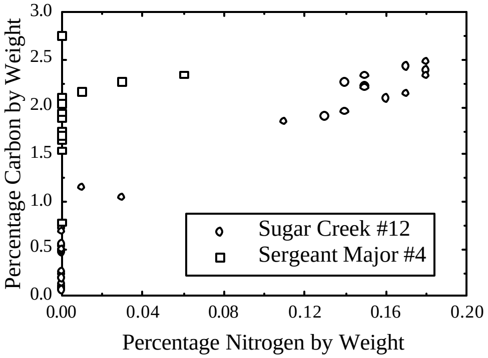

Figure 4-28. Relation between percentage nitrogen and percentage carbon by weight for all sediment samples.

4.4 Discussion

Continuous, undisturbed cores of lake sediment were successfully obtained at Sugar Creek #12 (10 cores) and Sergeant Major #4 (4 cores). These cores ranged in length from 1.3 to 3.1 m and were obtained in water depths ranging from 0.5 to 12 m. Core positions were located with differential GPS recordings and site selection was to coincide precisely with seismic lines previously obtained. Once opened, each core was described and sediment samples were secured for later analysis.

At Sugar Creek #12, very thick accumulations of silt and clay are common, and many of these have thin-bedded sand units within them. These silt-clay units generally have slightly more clay than silt. The amount of silt and clay is positively correlated with the amount of carbon, nitrogen, and magnetic susceptibility.

At Sergeant Major #4, very thick accumulations of silt and clay as well as sand are common. The sediments are poorly sorted, and the amount of silt is generally two to three times greater than clay. Gravel is common near the base of many cores. Little correlation is observed amongst the physical and chemical characteristics of the sediment.

5. Chemical Analysis

5.1 Phase I Results

5.1.1 Sediment Sampling Methods

Phase I sediment sampling was completed during the period of October 26 to October 28, 1999. Sampling sites within each lake were selected to provide representative sediments from areas of deposition in major lake inlets and within the main pool area adjacent to the embankment. At each sampling site, sediment cores were taken to greatest depth possible with manual coring equipment and procedures from an anchored boat (Figures 5-1 and 5-2). Multiple attempts at sampling adjacent to an initially selected site were occasionally necessary when coring was hindered or impossible due to water depths exceeding manual coring equipment capabilities, lack of accumulated sediment, excessive large stony material in sediments, or dense clam or mussel populations.

A sufficient number of four-inch diameter sediment cores were driven at each site, lifted into a clean semi-tubular ruled trough, and separated as necessary for needed analyses (Figures 5-3 and 5-4). For Cesium analysis, 10 cm sections by depth from sediment surface were separated and stored until a minimum of 1 kg of sediment from each interval was acquired. At each site, depth-integrated sediment samples (proportionally representative of entire depth of core) were collected into appropriately prepared containers for agrichemical and contaminant analyses for Group 1 (Priority Pollutant Pesticide/PCB, see Table 1-1) and Group 2 (Oil Field Contaminants, see Table 1-1) contaminants. Since more detailed Cesium analysis was performed in Phase II, the Cesium results from Phase I will not be presented.

5.1.2 Sediment Sampling Locations

Proximate locations of sampling sites for each lake are illustrated on Figures 5-5, 5-6, and 5-7. At total of seven sites were sampled and each is described in Table 5-1. GPS data were collected at each sample location, but due to problems with the base station data these positions could not be differentially corrected.

Figure 5-1. Photograph of the sediment coring tube used to obtain sediment samples (taken at Sugar Creek #12, October 1999).

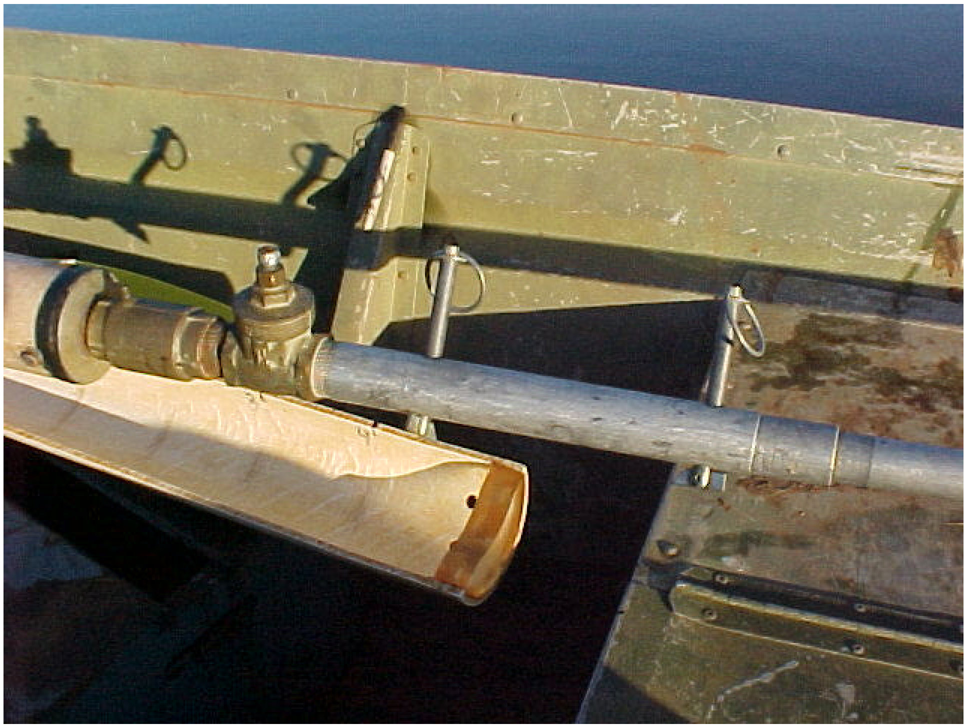

Figure 5-2. Photograph of the sediment coring tube used to obtain sediment samples and the ruled sediment core catcher (taken at Sugar Creek #12, October 1999). Also shown is the aluminum extension necessary to obtain deep-water samples.

Figure 5-3. Photograph of the sediment core being extruded into core catcher (taken at Sugar Creek #12, October 1999). Core is extruded by tipping core and shaking out contents.

Figure 5-4. Photograph of the sediment from core being placed into sample bottles for later analysis (taken at Sugar Creek #12, October 1999).

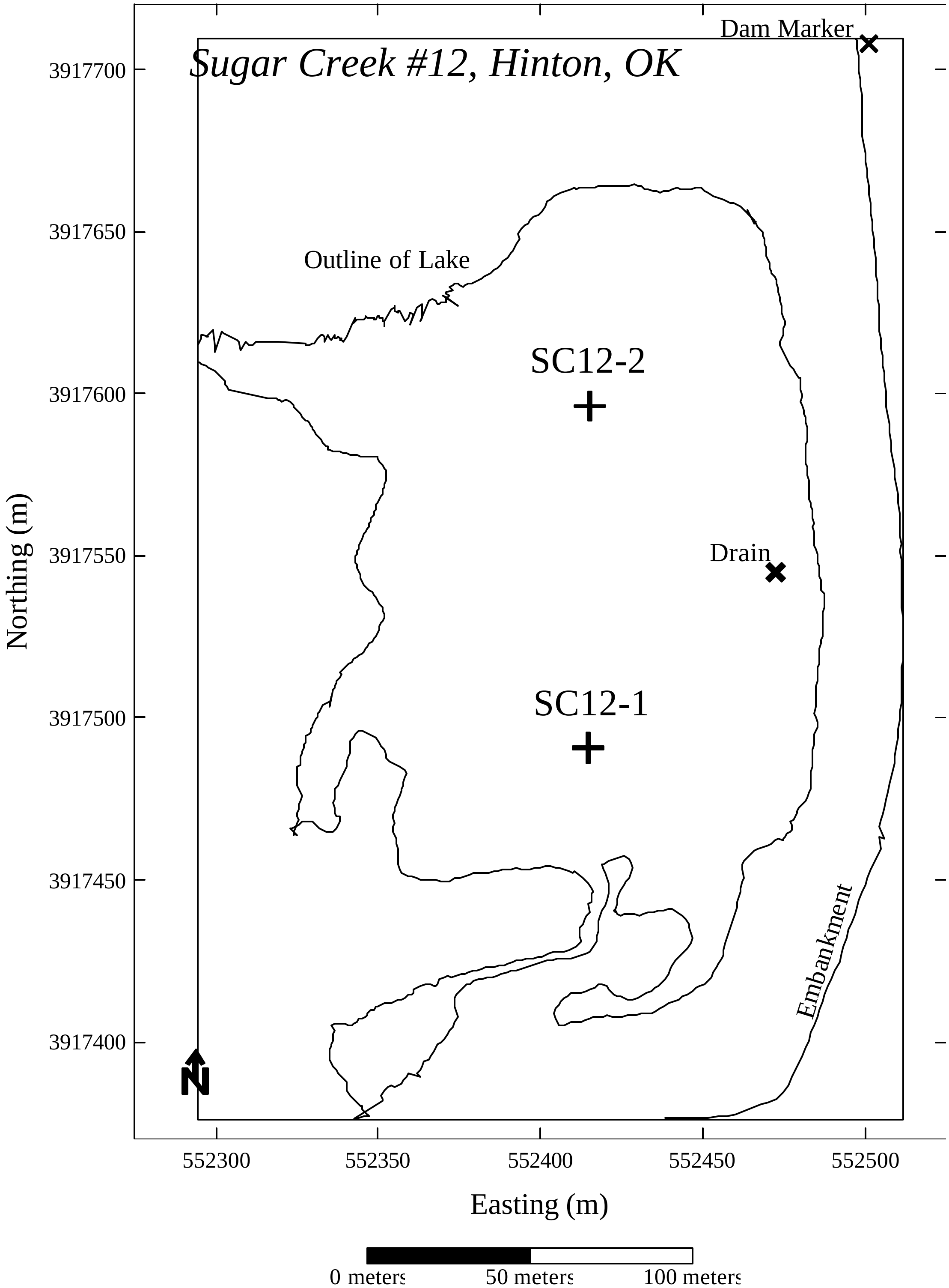

Figure 5-5. Map of Sugar Creek #12 showing sediment sample locations.

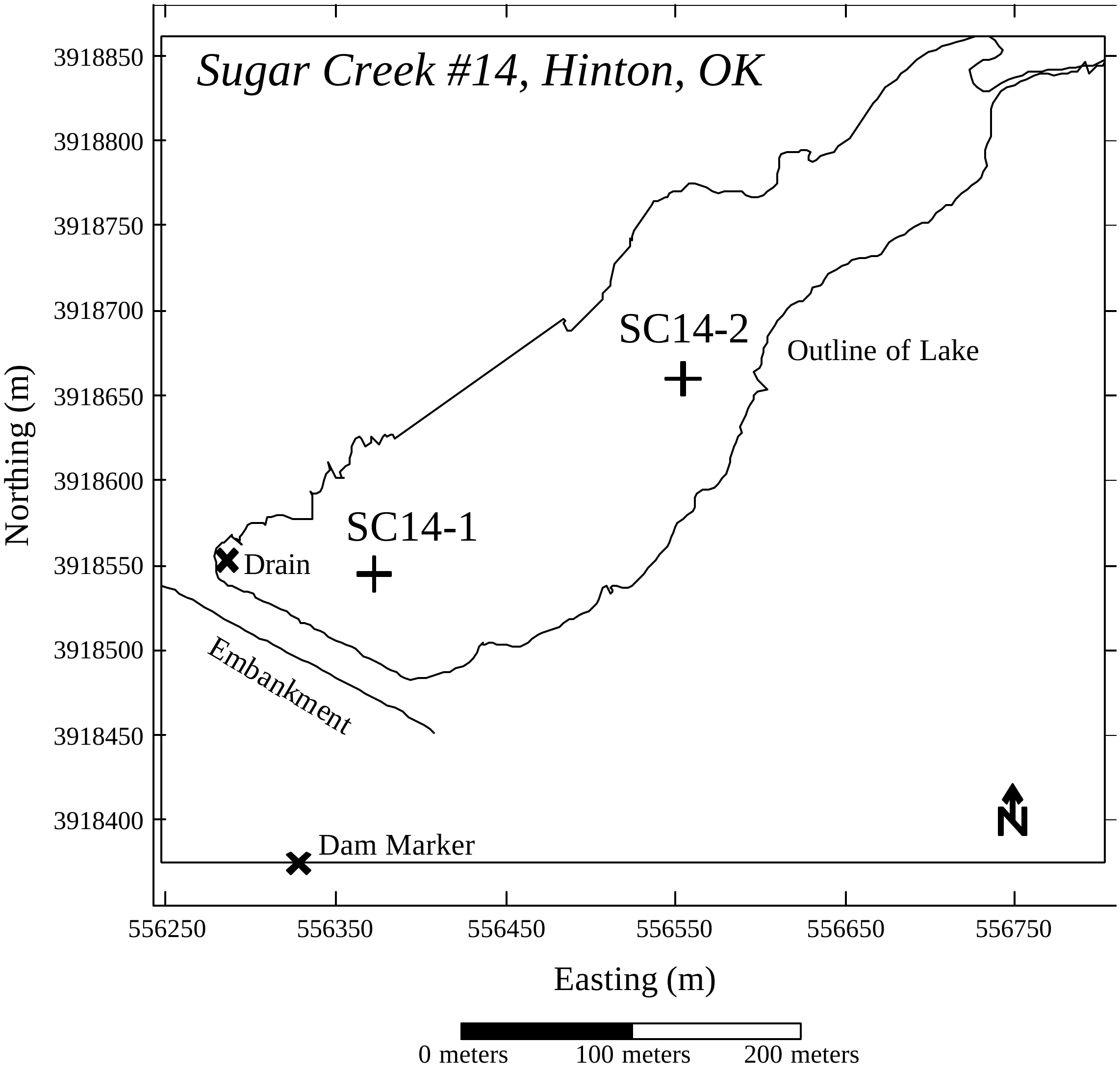

Figure 5-6. Map of Sugar Creek #14 showing sediment sample locations.

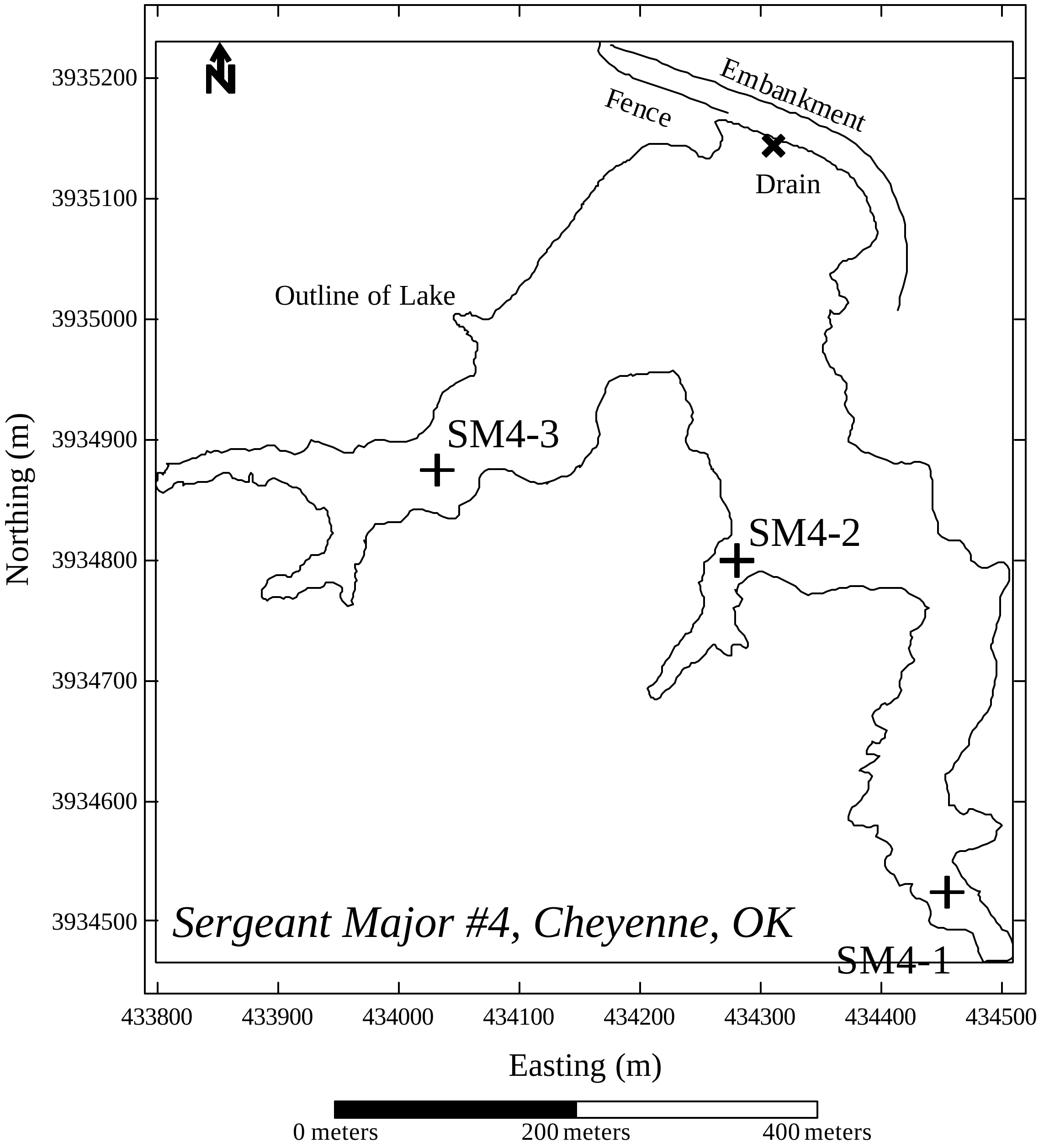

Figure 5-7. Map of Sergeant Major #4 showing sediment sample locations.

Table 5-1. Characteristics of sediment samples obtained by the USDA-ARS at Sugar Creek #12, Sugar Creek #14, and Sergeant Major #4, October 1999.

Sample Number	Location	Water Depth (m)	Thickness of Sediment Core Sampled (m)	Samples Secured
		Sugar Creek #12		
SC12-1	Mouth of major inflow	~0.6	0 to 0.8	8 sections for Cesium dating plus depth integrated sample
SC12-2	Mid-lake	~0.9	0 to 1.0	10 sections for Cesium dating plus depth integrated sample
		Sugar Creek #14		
SC14-1	Mid-lake	~1.2	0 to 0.2	2 sections for Cesium dating plus depth integrated sample
SC14-2	Main pool adjacent to embankment	~2.4	0 to 0.3	3 sections for Cesium dating plus integrated sample
		Sergeant Major #4		
SM4-1	Southeastern arm of lake	~2.4	0 to 0.4	4 sections for Cesium dating plus depth integrated sample
SM4-2	Smaller central inlet arm of lake	~3.7	0 to 0.4	4 sections for Cesium dating plus depth integrated sample
SM4-3	Northwestern arm of lake	~5.5	0 to 0.4	4 sections for Cesium dating plus depth integrated sample

Observations made during Phase I sampling indicate that Sugar Creek #12 has received very high amounts of sediment. Due to its small size, sediment was sampled at only two sites in this reservoir during Phase I. Sample SC12-2 was taken at mid-lake to represent main pool sediments.

Sugar Creek #14 does not appear to have suffered from excessive sedimentation, as coring attempts encountered resistant substrates under shallow sediments throughout the lake. Numerous sampling attempts closer to the inlet area of this lake were unsuccessful due to encounters with a hardened substrate layer under very shallow layers of sediment.

Sergeant Major #4 did not show excessive sediment accumulation, but large stony substrate particles and high-density clam populations were frequently encountered while attempting to sample shoreward sections of inlet arms of this lake. Mouths of inlets near the main body of the lake exceeded the depth capacity of manual coring equipment used (water column depth greater than 25 ft). The main pool was not sampled within Sergeant Major #4 due to unsafe boating conditions caused by excessive wind velocities at the time of the site visit.

5.1.3 Agrichemical and PCB Analysis for Sugar Creek #12 and #14

The results of Phase I agrichemical and PCB analysis is presented in Table 5-2 for Sugar Creek #12 (November 1999) and Table 5-3 for Sugar Creek #14. These tables show that, in general, overall sediment quality is good at each of these lakes. A breakdown product of DDT, DDE, was detectable in the Sugar Creek Watershed with higher concentrations occurring at Sugar Creek #12 than at Sugar Creek #14. In addition, methyl parathion, a common insecticide associated with cotton production, was also detected in trace amounts. No other agrichemicals were found.

5.1.4 Oil Field Contaminants, Sediment Parameters, Major Element, and Heavy Metal Analysis for Sugar Creek #12 and #14

A variety of other sediment properties and possible contaminants often monitored in association with oil fields were measured. As expected, sediment pH is generally neutral in the more eastern Sugar Creek Watershed and these values agree well with those presented in Table 4-1. Sodium, Potassium, Calcium, and Magnesium concentrations are within expected ranges for sediments. Sediment electrical conductivity (EC), Sodium Absorption Ratio (SAR), Cation Exchange Capacity (CEC), and Exchangeable Sodium Percentage (ESP) are within expected limits at these sites. Observed values for those properties imply a natural balance of sediment elemental ion concentrations. Analysis of oil and grease show the presence of only very small proportions of this contaminant. Heavy metal concentrations are similar in all samples, and fall within expected concentration ranges.

5.1.5 Agrichemical and PCB Analysis for Sergeant Major #4

The results of Phase I agrichemical and PCB analysis is presented in Table 5-4 for Sergeant Major #4 (November 1999). This table shows that overall sediment quality is excellent at this location. Methyl parathion and chlorpyrifos, a common insecticide called Lorsban, was detected in trace amounts, but no other agrichemicals were found.

5.1.6 Oil Field Contaminants, Sediment Parameters, Major Element, and Heavy Metal Analysis for Sergeant Major #4

Sediment pH is generally slightly more alkaline in the more western Sergeant Major Watershed and these values agree well with those presented in Table 4-1. Sodium, Potassium, Calcium, and Magnesium concentrations are within expected ranges for sediments. Sediment electrical conductivity (EC), Sodium Absorption Ratio (SAR), Cation Exchange Capacity (CEC), and Exchangeable Sodium Percentage (ESP) are within expected limits at these sites. Observed values for those properties imply a natural balance of sediment elemental ion concentrations. Analysis of oil and grease show the presence of only very small proportions of this contaminant. Heavy metal concentrations are similar in all samples, and fall within expected concentration ranges.

Table 5-2. Chemical analysis results for sediment samples obtained at Sugar Creek #12. USDA identification numbers are: 1—SC12-1, 2-A—SC12-2-A, etc.

Date		Nov. 1999	Nov. 1999	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000
Sample I.D.		1	2	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B	5-A	5-B	6	7-A	7-B	8	9-A	9-B	10-A	10-B
Compound	Units																				
										Pesticides											
Aldrin	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
BHC-alpha	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
BHC-beta	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
BHC-delta	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
BHC-gamma	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Chlordane	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Toxaphene	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
DDD 4,4'	ppb	ND	ND	X	X	ND	6.8	ND	11.8	9.0	ND	ND	ND	X	X	X	X	13.8	ND	X	X
DDE 4,4'	ppb	58.7	62.3	X	X	77.9	98.7	56.7	125	55.4	ND	26.0	8.6	X	X	X	X	95.7	ND	X	X
DDT 4,4'	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Dieldrin	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Endrin	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Endrin aldehyde	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Endosulfan I	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Endosulfan II	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Endosulfan sulfate	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Heptachlor	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Heptachlor epoxide	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
										PCBs											
Aroclor 1016	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1221	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1232	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1242	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1248	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1254	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X
Aroclor 1260	ppb	ND	ND	X	X	ND	ND	ND	ND	ND	ND	ND	ND	X	X	X	X	ND	ND	X	X

Table 5-2 continued

Date		Nov. 1999	Nov. 1999	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000	July 2000
Sample I.D.		1	2	1-A	1-B	2-A	2-B	3-A	3-B	4-A	4-B	5-A	5-B	6	7-A	7-B	8	9-A	9-B	10-A	10-B
Compound	Units																				
Herbicides and Insecticides																					
Alachlor	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Atrazine	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Bifenthrin	ppb	0.2	0.1	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorfenapyr	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chlorpyrifos	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Cyanazine	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
λ-Cyhalothrin	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Methyl parathion	ppb	1.8	1.6	3.5	5.5	3.3	4.5	ND	3.6	3.8	2.0	ND	ND	3.2	ND	2.9	3.4	1.9	ND	3.0	1.9
Metolachlor	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Pendimethalin	ppb	ND	ND	ND	ND	ND	ND	0.9	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Trifluralin	ppb	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Elements, Compounds, and other Sediment Properties																					
pH		6.9	6.8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
EC	mmhos/cm	1.9	3.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
SAR		0.4	0.4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
CEC		26.4	31.0	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
ESP	%	1.7	1.7	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Sodium	ppm	101	125	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Potassium	ppm	222	288	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Calcium	ppm	3983	4646	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Magnesium	ppm	669	798	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Oil & Grease	%	0.06	0.01	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Moisture	%	5.4	6.1	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Arsenic	ppm	3.9	4.8	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Barium	ppm	151	219	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Cadmium	ppm	3.7	5.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Chromium	ppm	17.8	28.3	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Lead	ppm	10.3	15.2	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mercury	ppm	0.16	0.08	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Selenium	ppm	0.55	0.34	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Silver	ppm	ND	0.37	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Zinc	ppm	34.3	51.4	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

ppm – parts per million; ppb – parts per billion; X – not tested; ND – not detected

Table 5-3. Chemical analysis results for sediment samples obtained at Sugar Creek #14. USDA identification numbers are: 1—SC14-1, etc.

Date Sample I.D. Compound	Units	Nov. 1999 1	Nov. 1999 2
	Pesticides		
Aldrin	ppb	ND	ND
BHC-alpha	ppb	ND	ND
BHC-beta	ppb	ND	ND
BHC-delta	ppb	ND	ND
BHC-gamma	ppb	ND	ND
Chlordane	ppb	ND	ND
Toxaphene	ppb	ND	ND
DDD 4,4'	ppb	ND	ND
DDE 4,4'	ppb	9.8	9.2
DDT 4,4'	ppb	ND	ND
Dieldrin	ppb	ND	ND
Endrin	ppb	ND	ND
Endrin aldehyde	ppb	ND	ND
Endosulfan I	ppb	ND	ND
Endosulfan II	ppb	ND	ND
Endosulfan sulfate	ppb	ND	ND
Heptachlor	ppb	ND	ND
Heptachlor epoxide	ppb	ND	ND
	PCBs		
Aroclor 1016	ppb	ND	ND
Aroclor 1221	ppb	ND	ND
Aroclor 1232	ppb	ND	ND
Aroclor 1242	ppb	ND	ND
Aroclor 1248	ppb	ND	ND
Aroclor 1254	ppb	ND	ND
Aroclor 1260	ppb	ND	ND

Table 5-3 continued

Date		Nov. 1999	Nov. 1999
Sample I.D.		1	2
Compound	Units		
Herbicides and Insecticides			
Alachlor	ppb	ND	ND
Atrazine	ppb	ND	ND
Bifenthrin	ppb	ND	ND
Chlorfenapyr	ppb	ND	ND
Chlorpyrifos	ppb	ND	ND
Cyanazine	ppb	ND	ND
λ-Cyhalothrin	ppb	ND	ND
Methyl parathion	ppb	2.1	3.6
Metolachlor	ppb	ND	ND
Pendimethalin	ppb	ND	ND
Trifluralin	ppb	ND	ND
Elements, Compounds, and other Sediment Properties			
pH		6.8	6.8
EC	mmhos/cm	2.6	3.2
SAR		0.5	0.4
CEC		34.6	45.8
ESP	%	1.8	1.4
Sodium	ppm	141	142
Potassium	ppm	389	427
Calcium	ppm	4879	6972
Magnesium	ppm	1049	1137
Oil & Grease	%	0.07	0.07
Moisture	%	6.43	7.51
Arsenic	ppm	3.9	4.3
Barium	ppm	188.1	210.6
Cadmium	ppm	5.1	6.0
Chromium	ppm	30.5	31.5
Lead	ppm	15.6	17.11
Mercury	ppm	0.1	0.07
Selenium	ppm	0.13	0.47
Silver	ppm	1.34	1.56
Zinc	ppm	80.9	59.7

ppm – parts per million; ppb – parts per billion; X – not tested; ND – not detected

Table 5-4. Chemical analysis results for sediment samples obtained at Sergeant Major #4. USDA identification numbers are: 1—SM4-1, C1—SM4-1, etc.

Date Sample I.D. Compound	Units	Nov. 1999 1	Nov. 1999 2	Nov. 1999 3	July 2000 C1	July 2000 C2	July 2000 C3	July 2000 C4
				Pesticides				
Aldrin	ppb	ND	ND	ND	X	X	X	X
BHC-alpha	ppb	ND	ND	ND	X	X	X	X
BHC-beta	ppb	ND	ND	ND	X	X	X	X
BHC-delta	ppb	ND	ND	ND	X	X	X	X
BHC-gamma	ppb	ND	ND	ND	X	X	X	X
Chlordane	ppb	ND	ND	ND	X	X	X	X
Toxaphene	ppb	ND	ND	ND	X	X	X	X
DDD 4,4'	ppb	ND	ND	ND	X	X	X	X
DDE 4,4'	ppb	ND	ND	ND	X	X	X	X
DDT 4,4'	ppb	ND	ND	ND	X	X	X	X
Dieldrin	ppb	ND	ND	ND	X	X	X	X
Endrin	ppb	ND	ND	ND	X	X	X	X
Endrin aldehyde	ppb	ND	ND	ND	X	X	X	X
Endosulfan I	ppb	ND	ND	ND	X	X	X	X
Endosulfan II	ppb	ND	ND	ND	X	X	X	X
Endosulfan sulfate	ppb	ND	ND	ND	X	X	X	X
Heptachlor	ppb	ND	ND	ND	X	X	X	X
Heptachlor epoxide	ppb	ND	ND	ND	X	X	X	X
				PCBs				
Aroclor 1016	ppb	ND	ND	ND	X	X	X	X
Aroclor 1221	ppb	ND	ND	ND	X	X	X	X
Aroclor 1232	ppb	ND	ND	ND	X	X	X	X
Aroclor 1242	ppb	ND	ND	ND	X	X	X	X
Aroclor 1248	ppb	ND	ND	ND	X	X	X	X
Aroclor 1254	ppb	ND	ND	ND	X	X	X	X
Aroclor 1260	ppb	ND	ND	ND	X	X	X	X

Table 5-4 continued

Date		Nov. 1999	Nov. 1999	July 2000	July 2000	July 2000	July 2000	July 2000
Sample I.D.		1	2	1-A	1-B	2-A	2-B	3-A
Compound	Units							
				Herbicides and Insecticides				
Alachlor	ppb	ND	ND	ND	ND	ND	ND	ND
Atrazine	ppb	ND	ND	ND	ND	ND	ND	ND
Bifenthrin	ppb	ND	ND	ND	ND	ND	ND	3.7
Chlorfenapyr	ppb	ND	ND	ND	ND	ND	ND	ND
Chlorpyrifos	ppb	ND	0.2	ND	ND	ND	ND	ND
Cyanazine	ppb	ND	ND	ND	ND	ND	ND	ND
λ-Cyhalothrin	ppb	ND	ND	ND	ND	ND	ND	ND
Methyl parathion	ppb	3.8	2.6	2.1	ND	ND	ND	3.7
Metolachlor	ppb	ND	ND	ND	ND	ND	ND	ND
Pendimethalin	ppb	ND	ND	ND	ND	ND	ND	ND
Trifluralin	ppb	ND	ND	ND	ND	ND	ND	ND
				Elements, Compounds, and other Sediment Properties				
pH		7.9	8	8.1	7.9	8.6	8.1	7.8
EC	mmhos /cm	1.9	2.1	2.1	0.48	0.24	0.36	0.54
SAR		0.5	0.4	0.6	0.7	0.5	0.6	0.7
CEC		44.4	71.7	57.7	42.6	48.4	50.9	32.8
ESP	%	1.7	1.2	1.8	1.9	1.5	1.9	2.6
Sodium	ppm	176	193	237	188	166	220	195
Potassium	ppm	76	104	130	95	125	94	92
Calcium	ppm	7723	12720	9629	6836	7385	8362	4984
Magnesium	ppm	599	872	1013	924	1277	967	831
Oil & Grease	%	0.08	0.08	0.21	0.06	ND	0.04	0.06
Moisture	%	3.1	2.8	3.7	6.1	1.5	8.8	2.6
Arsenic	ppm	2.6	4.5	4.1	5.27	5.72	4.13	7.29
Barium	ppm	162	180	184	171	226	144	153
Cadmium	ppm	2.4	2.9	3.0	3.2	3.0	3.0	3.5
Chromium	ppm	12	15	15	20	18	18	20
Lead	ppm	6.7	8.6	9.9	5.2	4.0	4.5	5.7
Mercury	ppm	0.04	0.08	0.08	0.002	ND	0.07	0.25
Selenium	ppm	0.54	0.54	ND	ND	ND	ND	ND
Silver	ppm	1.5	1.6	2.4	2.5	2.5	2.5	3.2
Zinc	ppm	25	30	30	43	37	43	42

ppm – parts per million; ppb – parts per billion; X – not tested; ND – not detected

5.2 Phase II Results

5.2.1 Sediment Sampling Methods

As discussed previously, all extracted cores were sampled for later agrichemical and chemical analysis. Approximately 1 to 2 kg of sediment was obtained, integrated over the entire core length or integrated over the lower-half or upper-half. Due to budgetary constraints, not all samples were analyzed. Of the 18 samples obtained at Sugar Creek #12, only 10 were analyzed for priority pesticides and PCBs, all were analyzed for herbicides and specific insecticides, and no samples were analyzed for additional elements and compounds (Table 5-2; see Tables 1-1 and 1-2). Of the 4 samples obtained at Sergeant Major, no samples were analyzed for priority pesticides and PCBs, all were analyzed for herbicides and specific insecticides, and all were analyzed for additional elements and compounds (Table 5-4; see Tables 1-1 and 1-2). Sugar Creek #14 was not part of Phase II part of the project.

5.2.2 Agrichemical and PCB Analysis for Sugar Creek #12

The results of Phase II agrichemical and PCB analysis are presented in Table 5-2 for Sugar Creek #12 (November 1999). This table shows that, in general, overall sediment quality is good at each of these lakes. Two breakdown products of DDT, DDE and DDD, were detectable in the Sugar Creek Watershed. Methyl parathion was also detected in trace amounts. No other agrichemicals were found. In addition, one sample (Core 3, upper-half) was found to contain trace amounts of pendimethalin, a common herbicide called Prowl (Table 5-2).

These results corroborate the results reported in Phase I. However, the concentrations of DDE were found to be both less than and greater than those reported in Phase I (Table 5-2). While DDD was not found in the results of Phase I, it was detected in Phase II. In both cases, these breakdown products are shown to vary significantly across the basin but no spatial trend is observed (see Figure 4-6). The concentrations of methyl parathion reported in Phase II are very similar to those reported in Phase I (Table 5-2), and methyl parathion is nearly ubiquitous in the reservoir sediments.

5.2.3 Oil Field Contaminants, Sediment Parameters, Major Element, and Heavy Metal Analysis for Sergeant Major #4

The analytical results from Phase II are in complete agreement with those from Phase I (Table 5-4). Sediment pH, Sodium, Potassium, Calcium, and Magnesium concentrations are within expected ranges for sediments. Sediment electrical conductivity (EC), Sodium Absorption Ratio (SAR), Cation Exchange Capacity (CEC), and Exchangeable Sodium Percentage (ESP) are within expected limits at these sites. Analysis of oil and grease show the presence of only very small proportions of this contaminant. Heavy metal concentrations are similar in all samples, and fall within expected concentration ranges.

5.3 Phase II Radioactive Cesium Analysis and Results

Select cores were analyzed for radioactive Cesium (^{137}Cs; 30-year half-life) for the purpose of dating sediment horizons. Since ^{137}Cs is produced during nuclear fission, its presence in the environment is due to nuclear testing or releases from nuclear reactors (Ritchie and McHenry, 1990). First global deposition of ^{137}Cs occurred in 1954 and maximum deposition occurred in 1964 in the Northern Hemisphere, related to above ground nuclear testing, and in 1980 (Europe) due to the Chernobyl nuclear accident. Since ^{137}Cs is strongly adsorbed on clay and organic particles and is essentially non-exchangeable, its concentration can be used as a unique tracer for erosion and sedimentation. Rates of sediment accumulation can be calculated by knowing the depth of these different ^{137}Cs horizons.

The following cores were chosen for ^{137}Cs analysis: 4, 7, and 9 from Sugar Creek #12, and 1 and 4 from Sergeant Major #4. Sediment samples were obtained inclusively at increments of 0.15 m at Sugar Creek #12 and 0.1 m at Sergeant Major #4 and encompassed the entire core length. All samples were dried in a greenhouse, crushed, and passed through a 2-mm sieve. A 1-L beaker was filled with sediment, sealed, and a gamma ray spectrometer was used to measure ^{137}Cs emissions for a period of 30,000 seconds, providing measurement precision of ±4 to 6% (Ritchie and Rasmussen, 2000).

All results from ^{137}Cs analysis are presented in Table 5-5. These results in the context of the stratigraphy within each basin will be discussed later.

Table 5-5. Measured concentrations of ^{137}Cs (Bq/g) for select sediment cores from Sugar Creek #12 and Sergeant Major #4.

Core No.	Depth Interval (in)	Depth Interval (m)	^{137}CS (Bq/g)	Error	Core No.	Depth Interval (in)	Depth Interval (m)	^{137}CS (Bq/g)	Error
	Sugar Creek #12					*Sergeant Major #4*			
4	0-6	0-0.15	0.0		1	0-4	0-0.10	6.23	1.61
	6-12	0.15-0.30	2.76	0.57		4-8	0.10-0.20	8.76	1.46
	12-18	0.30-0.46	1.53	3.56		8-12	0.20-0.30	9.33	1.15
	18-24	0.46-0.61	1.65	0.51		12-16	0.30-0.41	7.00	1.27
	24-30	0.61-0.76	5.20	0.57		16-20	0.41-0.51	9.69	1.13
	30-36	0.76-0.91	13.58	0.95		20-24	0.51-0.61	17.17	1.57
	36-42	0.91-1.07	13.82	1.47		24-28	0.61-0.71	17.42	1.22
	42-48	1.07-1.22	22.76	1.52		28-32	0.71-0.81	26.76	1.73
	48-54	1.22-1.37	26.62	1.68		32-36	0.81-0.91	58.14	2.81
	54-60	1.37-1.52	13.70	1.23		36-40	0.91-1.02	18.12	1.56
	60-66	1.52-1.68	36.39	2.52		40-44	1.02-1.12	26.22	1.55
	66-72	1.68-1.83	32.27	1.91		44-50	1.12-1.27	7.07	0.88
	72-78	1.83-1.98	46.43	2.31					
	78-84	1.98-2.13	8.88	0.73	4	0-4	0-0.10	0.0	
	84-90	2.13-2.29	6.75	0.92		4-8	0.10-0.20	0.0	
	90-96	2.29-2.44	3.23	0.60		8-12	0.20-0.30	0.0	
	96-102	2.44-2.59	0.0			12-16	0.30-0.41	11.41	2.03
	102-108	2.59-2.74	0.0			16-20	0.41-0.51	15.46	2.28
	108-114	2.74-2.90	0.0			20-24	0.51-0.61	16.36	1.75
						24-28	0.61-0.71	21.74	1.78
7	0-6	0-0.15	0.0			28-32	0.71-0.81	38.70	2.85
	6-12	0.15-0.30	14.87	2.15		32-36	0.81-0.91	40.46	2.46
	12-18	0.30-0.46	10.97	1.70		36-40	0.91-1.02	23.31	2.05
	18-24	0.46-0.61	16.04	1.37		40-44	1.02-1.12	12.28	1.34
	24-30	0.61-0.76	12.94	1.94		44-48	1.12-1.22	0.0	
	30-36	0.76-0.91	18.50	1.56		48-52	1.22-1.32	0.0	
	36-42	0.91-1.07	17.83	1.70		52-56	1.32-1.42	0.0	
	42-48	1.07-1.22	12.01	1.01		56-60	1.42-1.52	0.0	
	48-54	1.22-1.37	26.92	1.98		60-64	1.52-1.63	0.0	
	54-60	1.37-1.52	21.30	1.71					
	60-66	1.52-1.68	25.94	1.61					
	66-72	1.68-1.83	33.53	2.21					
	72-78	1.83-1.98	24.73	1.67					
	78-84	1.98-2.13	15.78	1.06					
	84-90	2.13-2.29	0.0						
	90-94	2.29-2.39	0.0						
9	0-6	0-0.15	0.0						
	6-12	0.15-0.30	4.85	0.69					

Table 5-5 continued

Core No.	Depth Interval (in)	(m)	^{137}CS (Bq/g)	Error
Sugar Creek #12				
	12-18	0.30-0.46	6.64	0.12
	18-24	0.46-0.61	19.27	1.61
	24-30	0.61-0.76	19.87	1.18
	30-36	0.76-0.91	24.24	1.70
	36-42	0.91-1.07	26.08	2.03
	42-48	1.07-1.22	2.89	0.47
	48-54	1.22-1.37	0.0	
	54-60	1.37-1.52	4.26	0.64
	60-66	1.52-1.68	0.0	
	66-72	1.68-1.83	0.0	
	72-78	1.83-1.98	0.0	
	78-84	1.98-2.13	0.0	
	84-92	2.13-2.34	0.0	

5.4 Discussion

Results from the chemical testing of the sediments from all three reservoirs showed very good overall sediment quality. Contaminant analysis was based on representative compounds likely to indicate contamination from different historical and current land uses. Results of contaminant analysis show minor contamination by residual breakdown products of DDT. The presence of DDE and DDD in sediment, a metabolite of DDT, poses no health issue. Breakdown products of DDT are common in some reservoirs that trap sediments (Cooper, 1991) from land farmed in the 1950's and 1960's. Metabolites degrade quite slowly in anaerobic sediments for decades. The greater concentration observed in Sugar Creek #12 reflects historical use and erosion rates. Methyl parathion, a common insecticide, was found in low concentrations in all three reservoirs. Detection trends followed current land use.

Physical and elemental properties that were measured fall within expected ranges of values for naturally occurring sediments at all three lakes and do not indicate any potential adverse effects on water quality in the reservoirs. Concentrations of metals in reservoir sediments are below known toxic levels, and cation concentrations are balanced.

6. Integration of Results

6.1 Radioactive Cesium Results and Sedimentation Rates

The concentration of ^{137}Cs (becquerels per gram; Bq/g) as a function of core depth is shown in Figure 6-1 for Sugar Creek #12 and Figure 6-2 for Sergeant Major #4. For Sugar Creek #12, a peak in the ^{137}Cs emissions occurs at a subsurface depth of 1.98 m for Core 4, at 1.83 m for Core 7, and at 1.07 m for Core 9 (lower bound of histogram bar). This peak coincides with the 1964 peak in ^{137}Cs fallout. Using this 1964 datum, sedimentation rates from 1964 to the present are 55.0, 50.8, and 29.6 mm/yr or 0.067, 0.062, and 0.036 mm/ha-yr (using drainage basin area) based on Core 4, 7, and 9, respectively. Since the dam was constructed in 1964, the sand deposited below these stratigraphic levels (Figure 6-1) is interpreted as parent (pre-construction) material.

Similar peaks in the distribution of ^{137}Cs and the demarcation of the 1964 datum are observed in the cores taken at Sergeant Major #4 (Figure 6-2): at 0.91 m for both Core 1 and 4. From 1964 to the present, a sedimentation rate of 25.4 mm/yr or 0.017 mm/ha-yr is deduced from these cores. Since the dam was constructed in 1955, the sand and gravel located stratigraphically below the mud layers (Figure 6-2) are interpreted as parent (pre-construction) material. Therefore during the period from 1955 to 1964, sedimentation rates are 28.2 and 18.3 mm/yr or 0.019 and 0.012 mm/ha-yr based on Core 1 and 4, respectively. This proposal is substantiated by the presence of alternating layers (laminae) of black and brown mud interpreted as varves (Leeder, 1982).

In a number of samples near both the top and bottom of the cores, no ^{137}Cs was detected (Figures 6-1 and 6-2). This lack of ^{137}Cs emission is attributed to the presence of sediment that has not been exposed to the atmosphere since 1954.

6.2 Stratigraphic Correlation within Sugar Creek #12

With the aid of the physical and chemical results coupled with the ^{137}Cs analysis, correlation of stratigraphic horizons can be determined across the basin in Sugar Creek #12. Three traverses across the basin shown in Figure 6-3 are illustrated in Figures 6-4, 6-5, and 6-6. Each core was positioned with respect to the elevation of the current lake bottom and the distance across the reservoir (note vertical exaggeration). Also shown on these figures is grain size (top line, given as % sand/silt/clay), magnetic susceptibility (middle line, given as 10^{-8} m^3/kg), and color (on bottom and underlined, given as hue YR value/chroma where YR is yellow red). These correlation methods were only partially successful due to the low number of sediment samples analyzed.

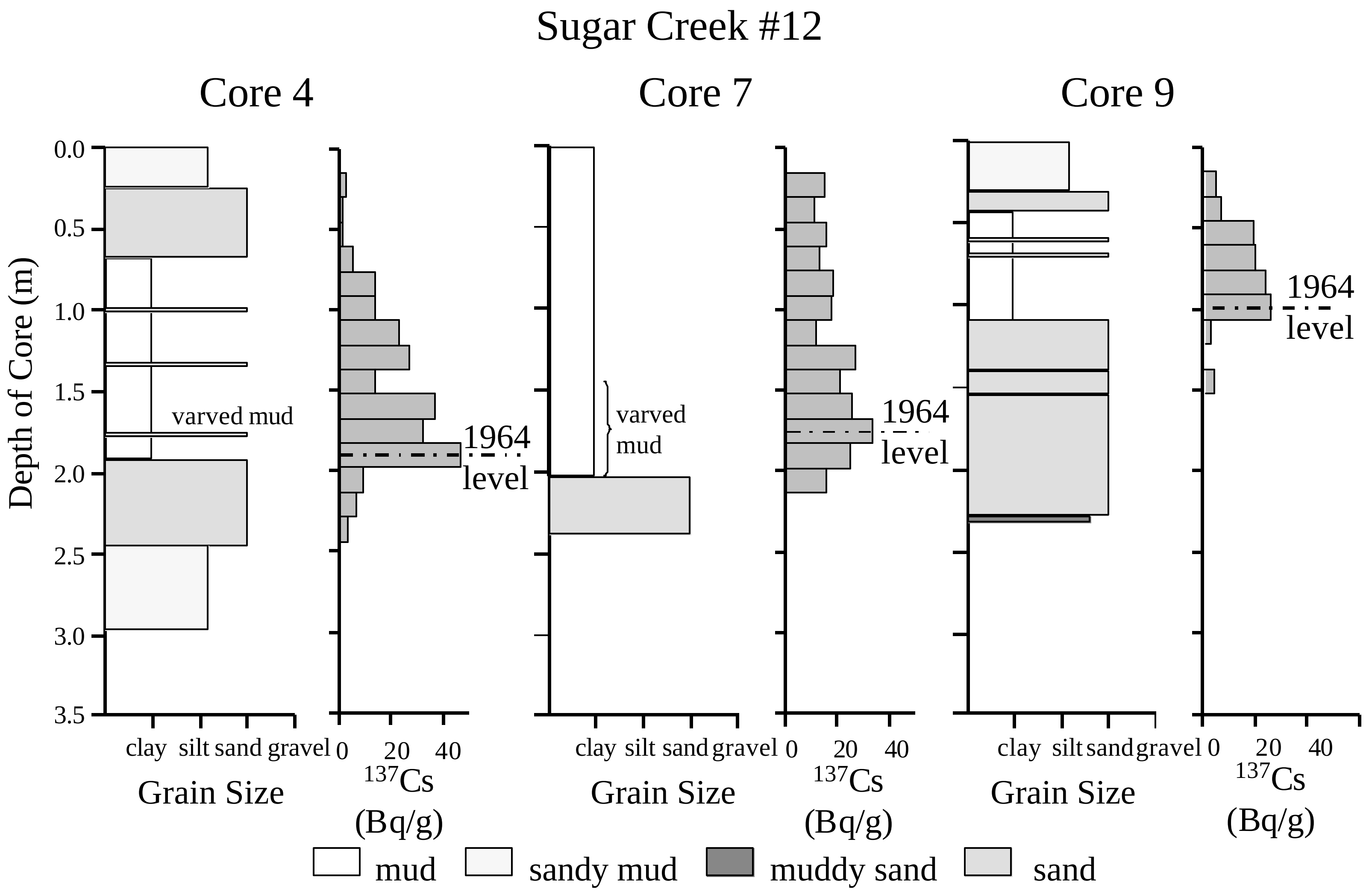

Figure 6-1. Comparison of stratigraphic logs at Sugar Creek #12 with ^{137}Cs results. The 1964 level is identified and shown.

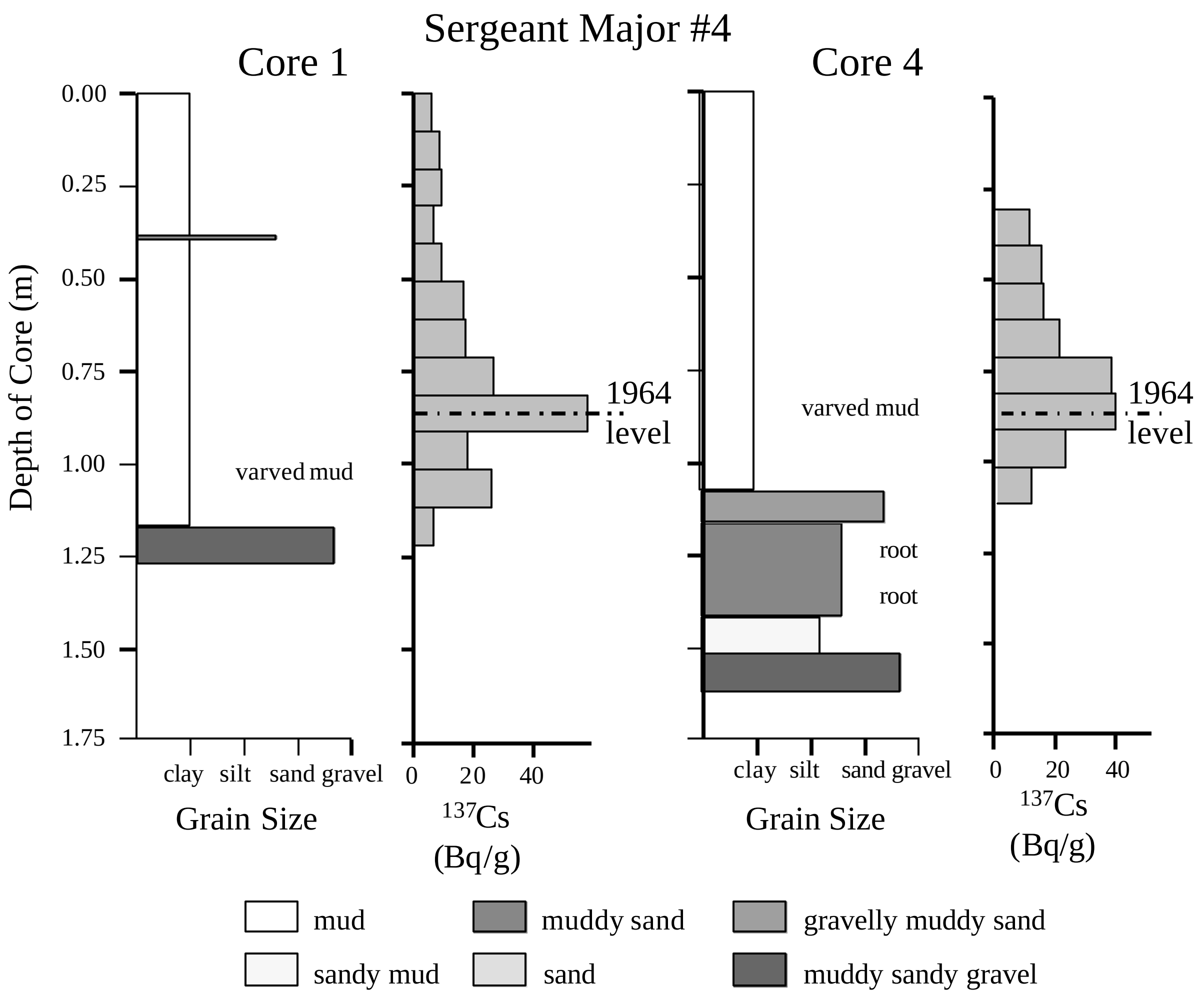

Figure 6-2. Comparison of stratigraphic logs at Sergeant Major #4 with ^{137}Cs results. The 1964 level is identified and shown.

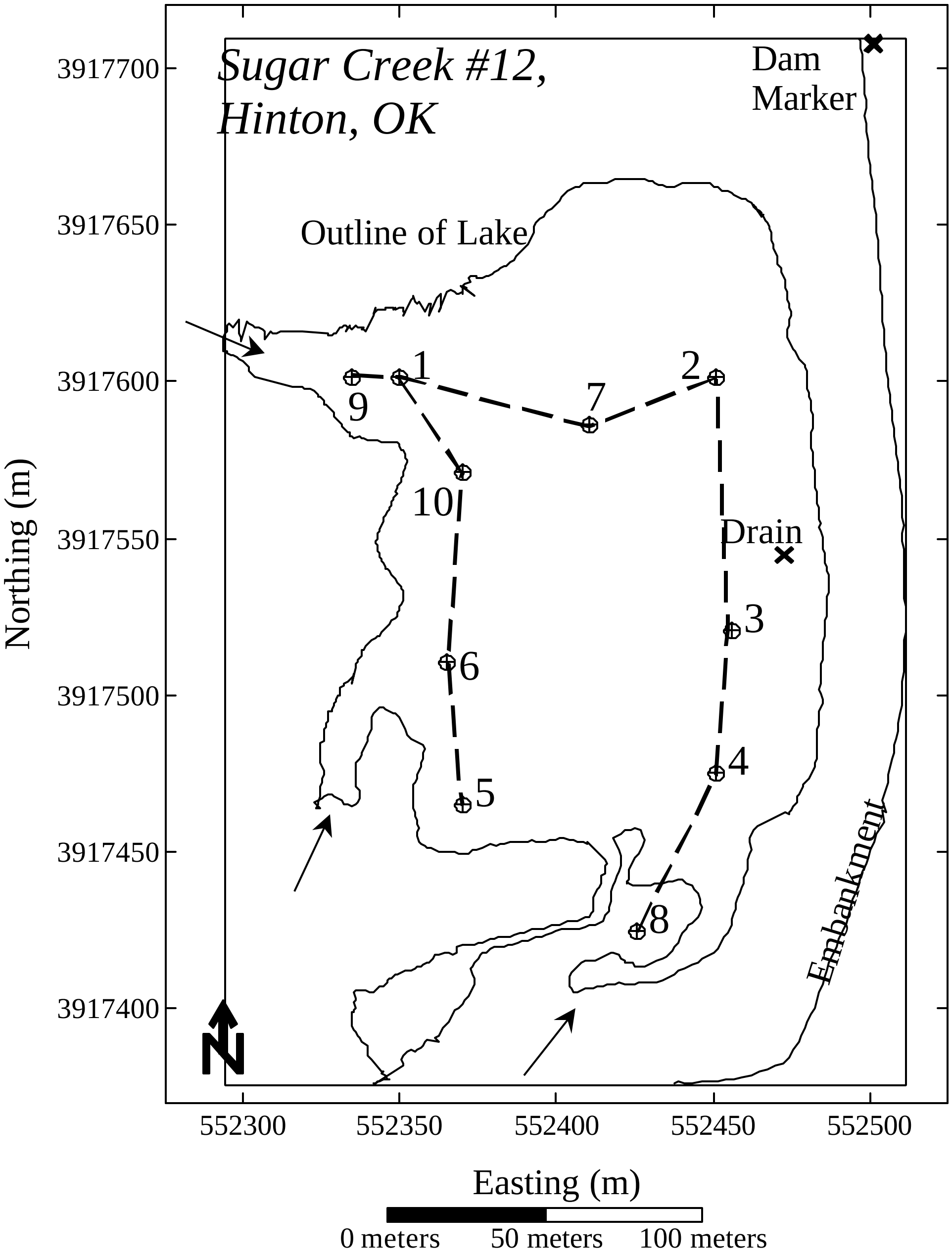

Figure 6-3. Base map of Sugar Creek #12 showing the location of all sediment cores (numbered) and the positions of the stratigraphic cross-sections depicted in Figures 6-4, 6-5, and 6-5 (dashed lines). All positions are in UTM coordinates.

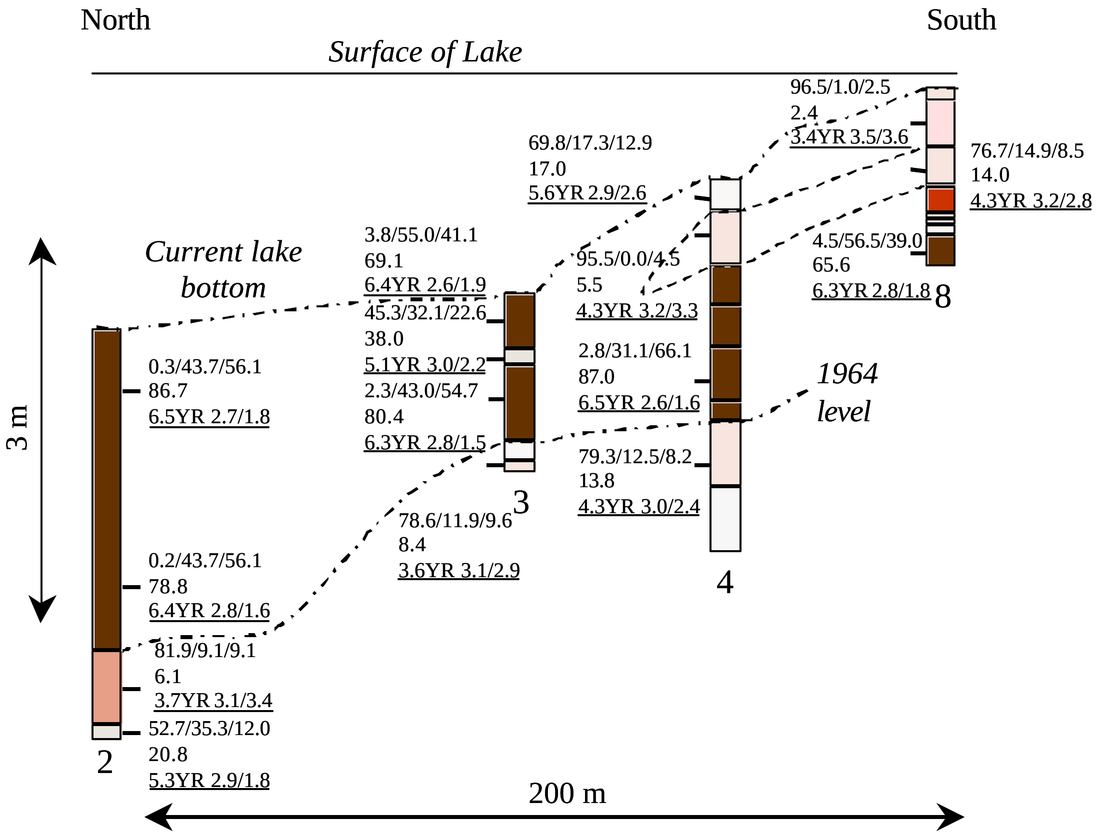

Figure 6-4. A north to south representation of the subsurface stratigraphy obtained at Sugar Creek #12 for Cores 2, 3, 4, and 8, placed relative to the current lake bottom and distance across the reservoir (note vertical exaggeration). Lines show the current lake bottom and the 1964 datum. The location of the sediment samples examined are shown by the tick marks, and the numbers beside each tick give grain size (top line, given as % sand/silt/clay), magnetic susceptibility (middle line, given as 10^{-8} m^3/kg), and color (on bottom and underlined, given as hue YR value/chroma where YR is yellow red). Refer to Figure 4-7 for legend.

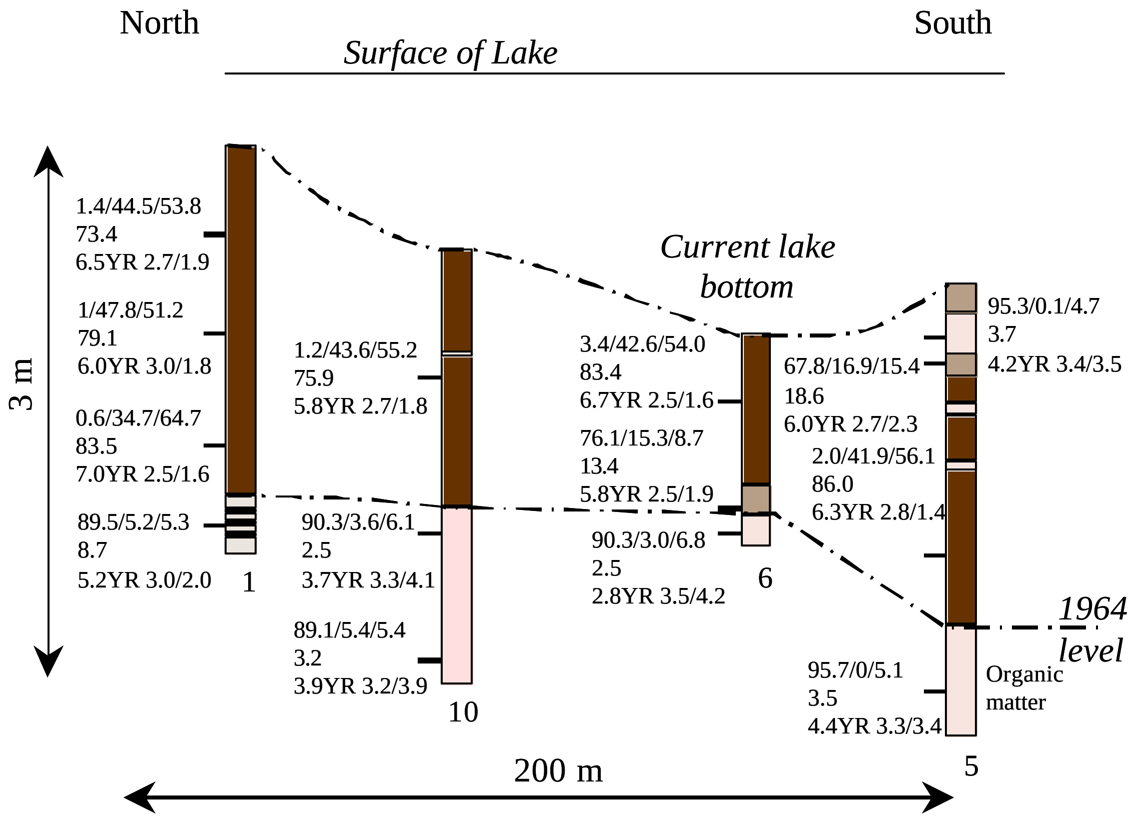

Figure 6-5. A north to south representation of the subsurface stratigraphy obtained at Sugar Creek #12 for Cores 1, 10, 6, and 5, placed relative to the current lake bottom and distance across the reservoir (note vertical exaggeration). Lines show the current lake bottom and the 1964 datum. The location of the sediment samples examined are shown by the tick marks, and the numbers beside each tick give grain size (top line, given as % sand/silt/clay), magnetic susceptibility (middle line, given as 10^{-8} m^3/kg), and color (on bottom and underlined, given as hue YR value/chroma where YR is yellow red). Refer to Figure 4-7 for legend.

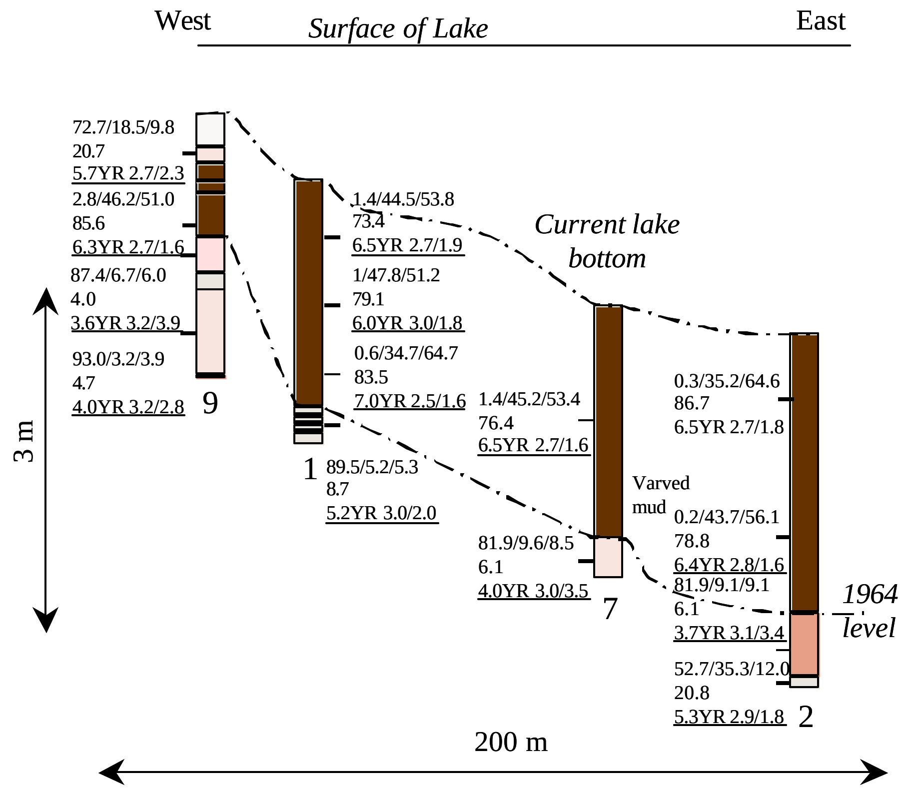

Figure 6-6. A west to east representation of the subsurface stratigraphy obtained at Sugar Creek #12 for Cores 9, 1, 7, and 2, placed relative to the current lake bottom and distance across the reservoir (note vertical exaggeration). Lines show the current lake bottom and the 1964 datum. The location of the sediment samples examined are shown by the tick marks, and the numbers beside each tick give grain size (top line, given as % sand/silt/clay), magnetic susceptibility (middle line, given as 10^{-8} m^3/kg), and color (on bottom and underlined, given as hue YR value/chroma where YR is yellow red). Refer to Figure 4-7 for legend.

6.2.1 North to South Traverse on Eastern Side of Reservoir

This traverse starts near the northeast corner of the basin, runs essentially parallel to the embankment toward the tributary entering the southern end of the reservoir (Figures 6-3 and 6-4). The 1964 datum determined for Core 4 can be extended with certainty toward the north. Several sand layers were deposited after 1964 near the tributary source, some as thin as 10 mm. One sand unit in Core 8 can be correlated to Core 4 (Figure 6-4), and it most likely becomes the muddy sand unit in Core 3. Moreover, the thin-bedded sand units near the base of Core 8, demarcated by alternating red and brown colors, probably correlate with the sand lenses in Core 4 although the latter are separated by decimeter-scale layers of silt and clay. While there are some observable sand deposits, most of the sediment that has accumulated along the traverse is silt and clay in nearly equal proportions (see Table 4-1).

6.2.2 North to South Traverse on Western Side of Reservoir

This traverse starts near the northwest corner of the basin, runs essentially southward toward the tributary entering the southwestern end of the reservoir (Figures 6-3 and 6-5). The 1964 datum deduced for Core 1 in Figure 6-4 can be extended with certainty toward the south. Several sand layers were deposited after 1964 near the tributary source, especially near the top of Core 5. The muddy sand unit near the base of Core 6 probably correlates with one of the sand lenses in Core 5. While there are some observable sand deposits, most of the sediment that has accumulated along the traverse is silt and clay in nearly equal proportions (see Table 4-1).

6.2.3 West to East Traverse

This traverse starts in the northwest corner of the lake near one of the main tributaries and extends eastward toward the deepest part of the reservoir near the embankment (Figures 6-3 and 6-6). The 1964 datum deduced by the ^{137}Cs results can be extended with certainty across the entire basin. As this time line coincides with the construction of the dam, all sand and gravel present at depths greater than about 1.5 m is considered pre-construction material. Near the tributary source (western side), there are several sand deposits younger in age than 1964, some as thin as 30 mm. Yet none of these sand units extends into the deeper part of the basin. Volumetrically, silt and clay in approximately equal proportions dominate the sediment deposit along this traverse.

6.3 Isopach Map of the Sediment Impounded at Sugar Creek #12

With the stratigraphic interpretations complete, a map showing the thickness of the deposited sediment in the reservoir at Sugar Creek #12 can be constructed (Figure 6-7). This map is based on the 10 cores extracted and the contours were constructed using commercially available software. Care was taken not to extend the contour lines outside the data area.

Figure 6-7 shows that sediment is thickest in the northern part of the basin, near the northwest tributary. Locally thick accumulations occur near the southern tributaries.

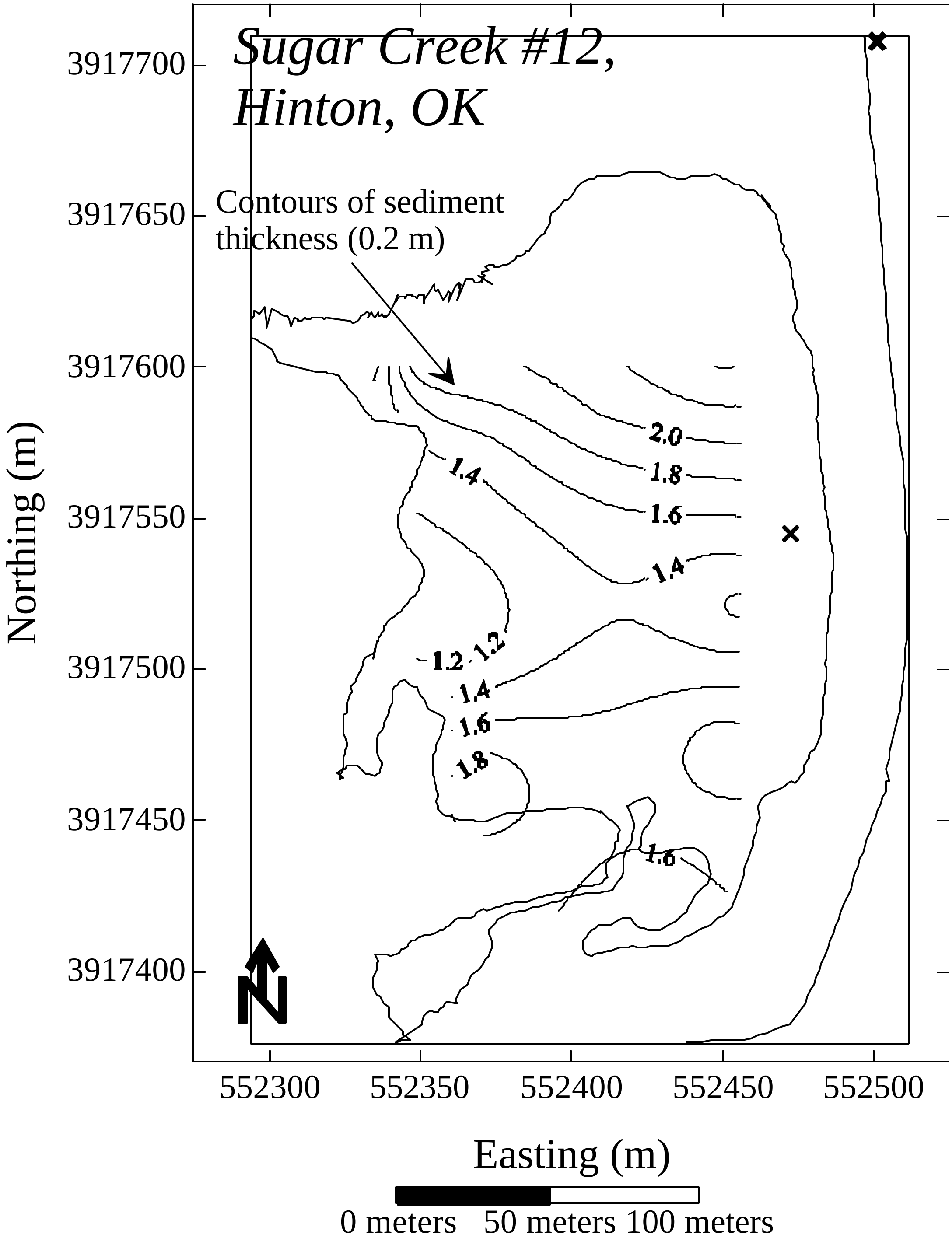

Figure 6-7. Base map of Sugar Creek #12 showing the thickness of deposited sediment (isopachs) based on the interpreted sediment cores. All positions are in UTM coordinates.

6.4 Seismic Stratigraphy in Sergeant Major #4

The seismic records at Sergeant Major #4, which are of higher quality than those at Sugar Creek #12 and #14, are examined here more carefully. Since sediment cores were obtained in the vicinity of the seismic lines, the seismic records may share some of the characteristics displayed in the sediment cores.

The location of three sediment cores (Cores 1, 2, and 3) are the short seismic segments analyzed further are shown in Figure 6-8. These seismic lines were processed as previously described (see §3.2), but the seismic horizons are identified with great rigor and care.

Along the northern tributary (Figure 6-8), three seismic horizons are identified: the fluid-sediment interface and two discontinuous seismic horizons at depth. Core 1 is located approximately near the center of the inset on Figure 6-9, and the seismic horizons are compared to the stratigraphic column in Figure 6-10. The shallow seismic horizon is correlated in space to the thin sand unit within the thick mud layer, while the deeper seismic horizon is correlated to the stratigraphic boundary between the mud and the sand and gravel layer. This sand and gravel layer has been interpreted to be parent (pre-constructional) material (see §6.1).

Along the central tributary (Figure 6-8), three seismic horizons are similarly identified (Figure 6-11). Core 2 is located approximately near the center of the inset on Figure 6-11, and the seismic horizons are compared to the stratigraphic column in Figure 6-12. The shallow seismic horizon is correlated in space to the stratigraphic boundary between the mud and sand, while the deeper seismic horizon is correlated to either the top or bottom of one of the sand units at depth.

The seismogram along the southern tributary (Figure 6-8), shows only two seismic horizons: the fluid-sediment interface and one seismic horizon at depth (Figure 6-13). However, it is quite apparent that additional seismic energy is present at depth. Core 3 is located approximately near the center of the inset on Figure 6-13, but the deeper seismic horizon bears little resemblance to the stratigraphic column (Figure 6-14). One could make a case for identifying a deeper seismic horizon that would correlate to the stratigraphic boundary between the mud and sand (Figure 6-14).

The decimeter-scale variation observed between the seismic horizons and the stratigraphic columns can be related to the assumed velocity within the sediment and the accuracy of the positioning systems. Here a constant velocity for the propagation of seismic waves, 1500 m/s, is used to transform the seismic arrival times into spatial distances. This velocity will depend on at least the physical properties of the water and sediment. In addition, the resolution of the coordinate systems used can be as much as ±4 m. This is especially true for the military-grade receiver that could not be differentially corrected. Such discrepancies in velocity and position could produce variations in the depth and thickness of the seismic horizon. Moreover, there is no presumption that every seismic horizon identified with rigor and care can be correlated to a stratigraphic horizon, and vice versa.

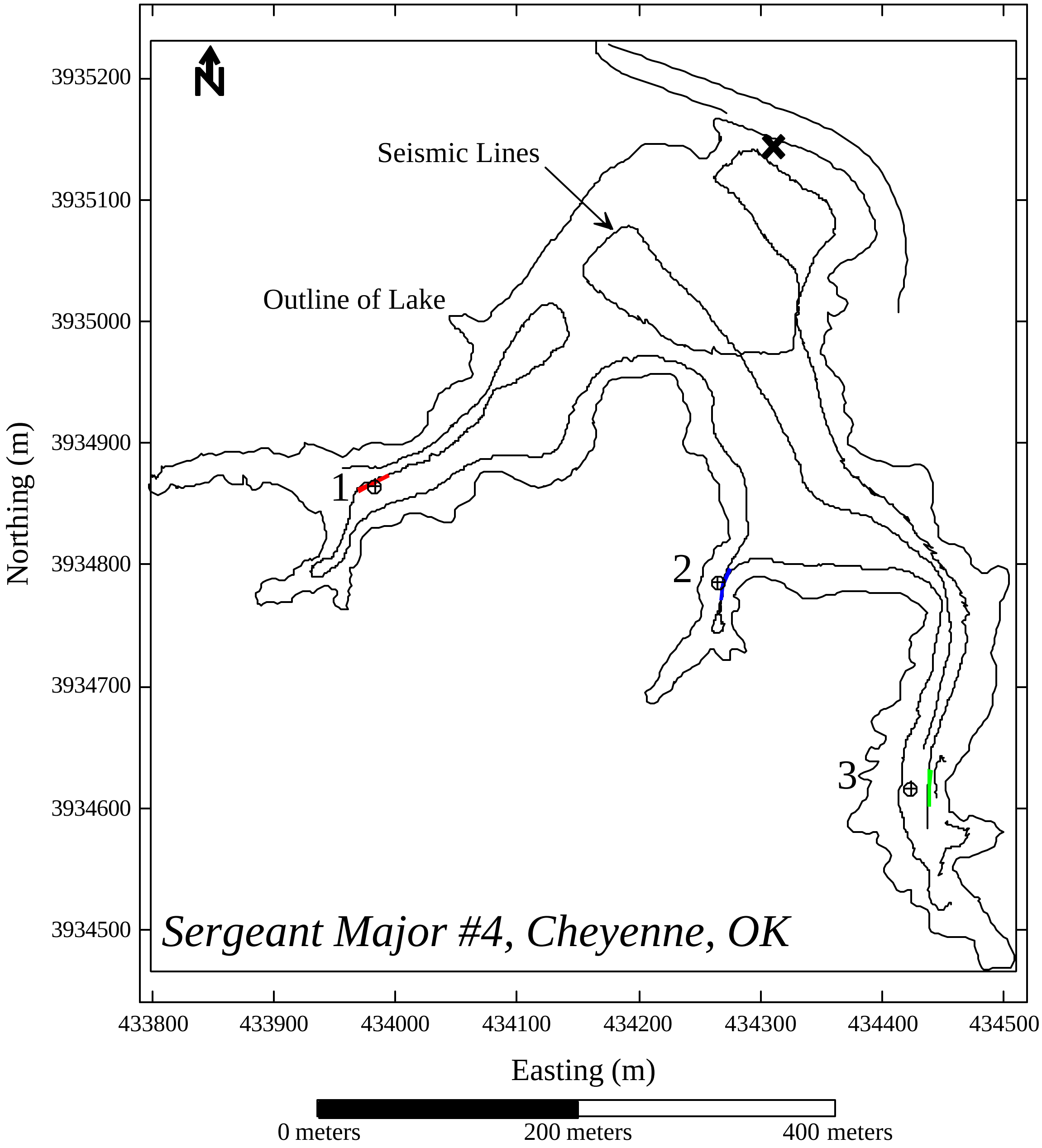

Figure 6-8. Base map of Sergeant Major #4 showing traces for all seismic lines. Three segments close to sediment cores 1, 2, and 3 are discussed in text. All positions are in UTM coordinates.

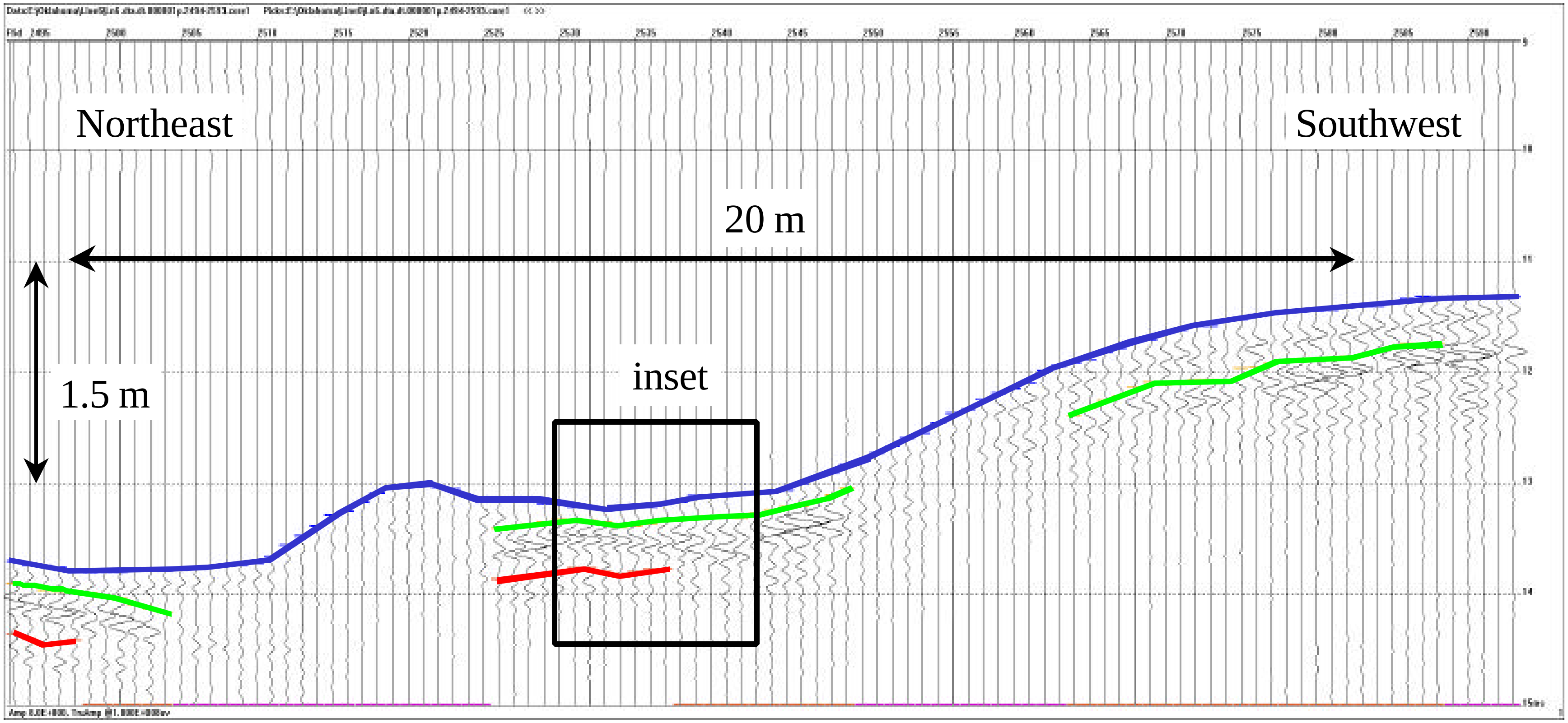

Figure 6-9. Seismogram from Sergeant Major corresponding to Core 1 (Figure 6-8). Solid lines are interpreted seismic reflectors identified and verified. Depth and length scales are shown. Approximate location of Core 1 is within center of inset.

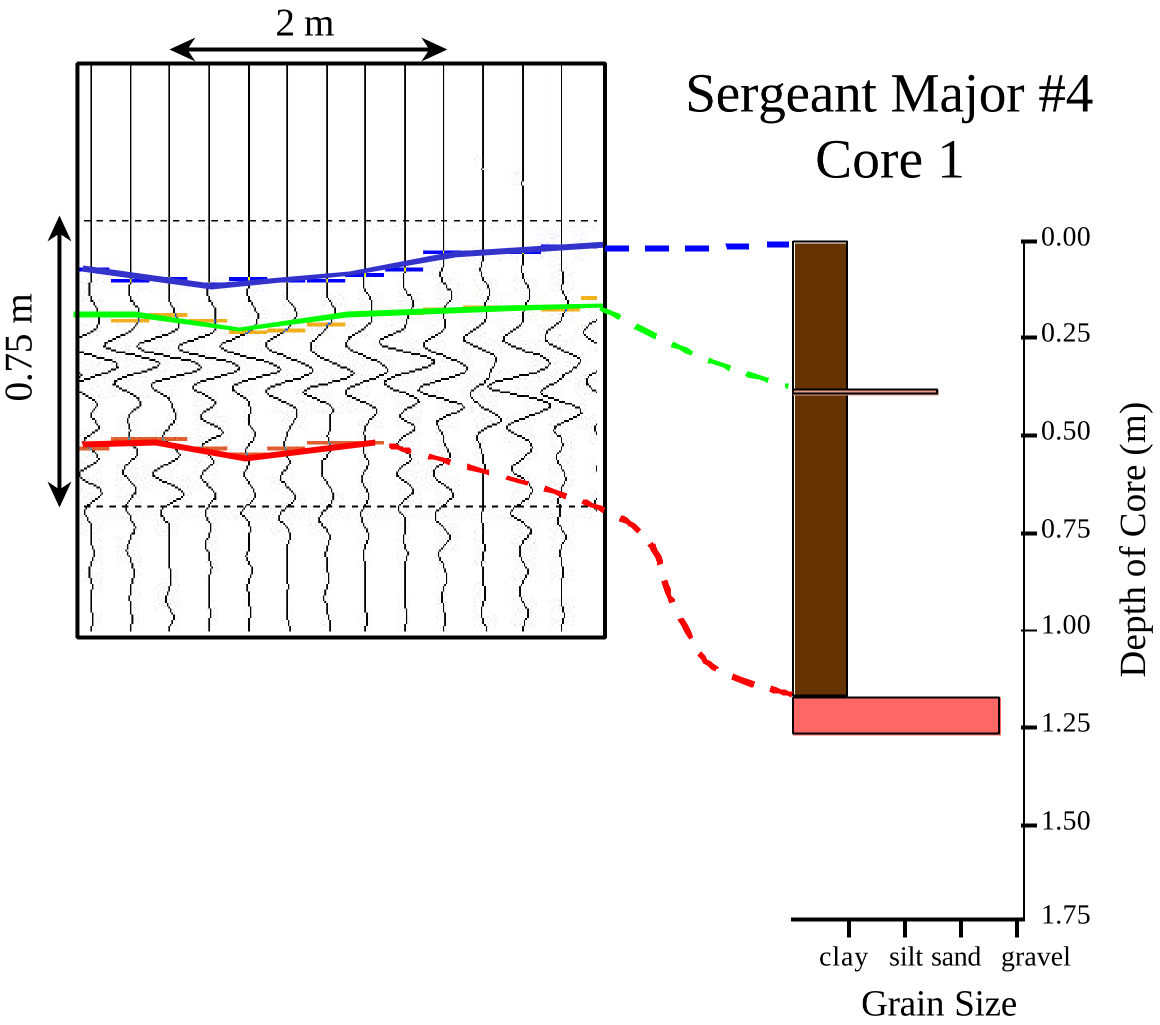

Figure 6-10. Seismogram from Sergeant Major at the approximate location of Core 1 and its interpretation (see Figures 6-8 and 6-9; see Figure 4-13 for stratigraphic legend). Depth and length scales are shown.

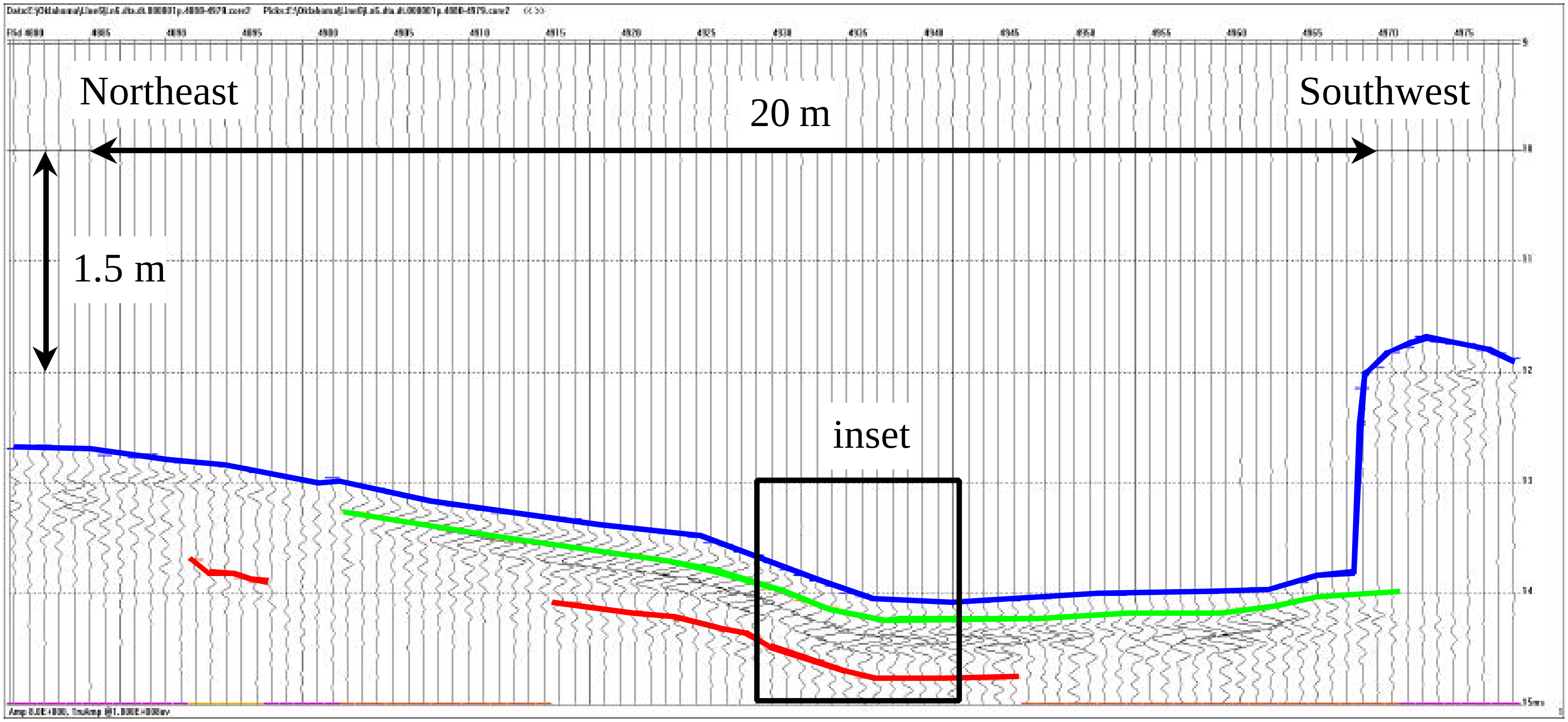

Figure 6-11. Seismogram from Sergeant Major corresponding to Core 2 (Figure 6-8). Solid lines are interpreted seismic reflectors identified and verified. Depth and length scales are shown. Approximate location of Core 2 is within center of inset.

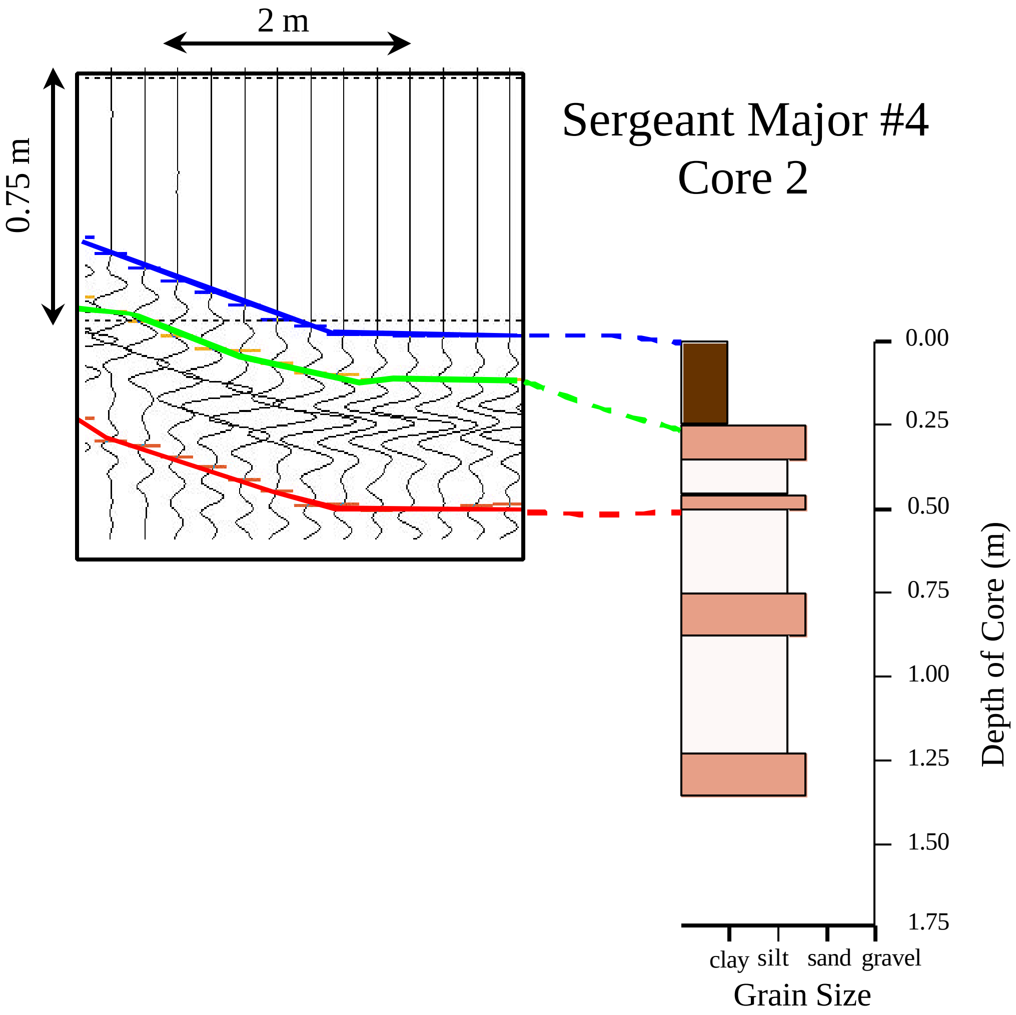

Figure 6-12. Seismogram from Sergeant Major at the approximate location of Core 2 and its interpretation (see Figures 6-8 and 6-11; see Figure 4-13 for stratigraphic legend). Depth and length scales are shown.

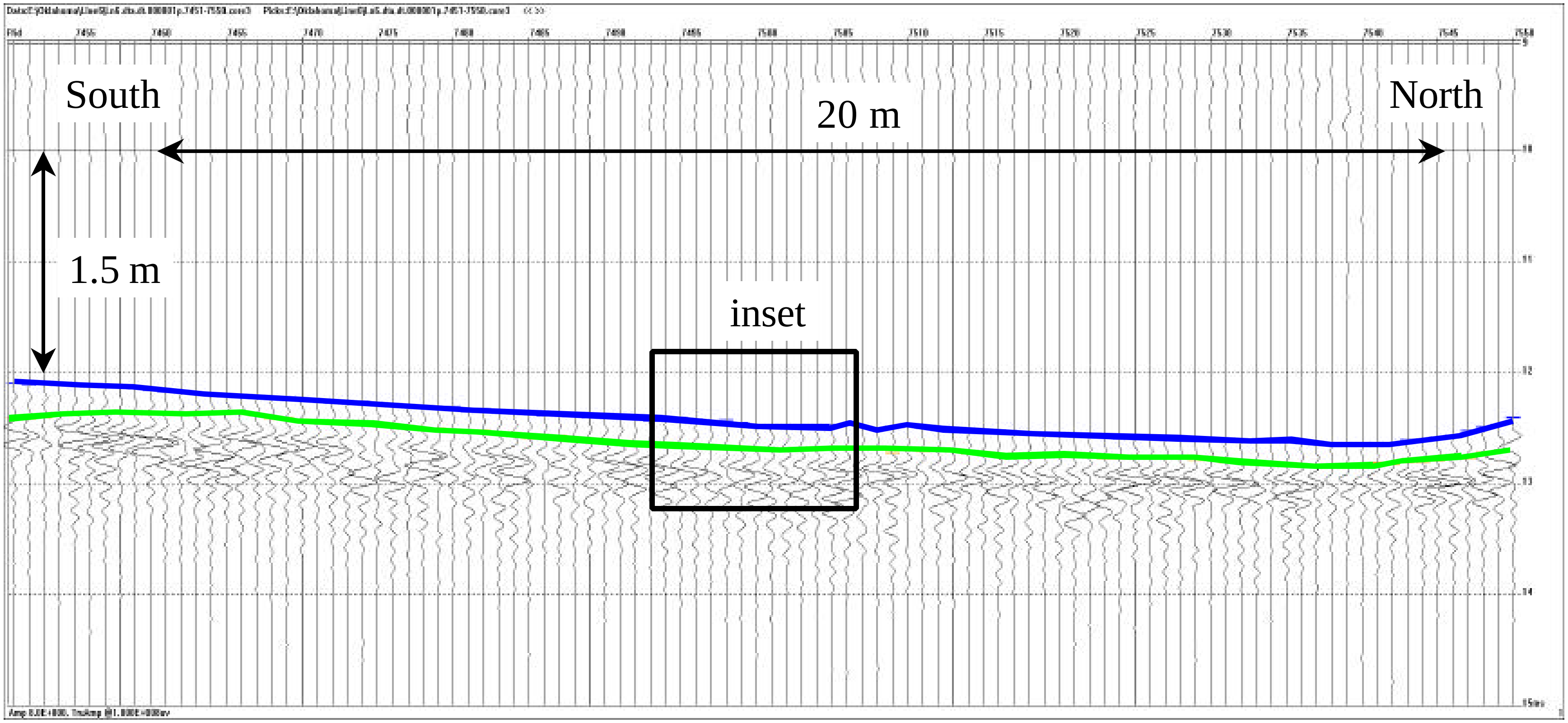

Figure 6-13. Seismogram from Sergeant Major corresponding to Core 3 (Figure 6-8). Solid lines are interpreted seismic reflectors identified and verified. Depth and length scales are shown. Approximate location of Core 3 is within center of inset.

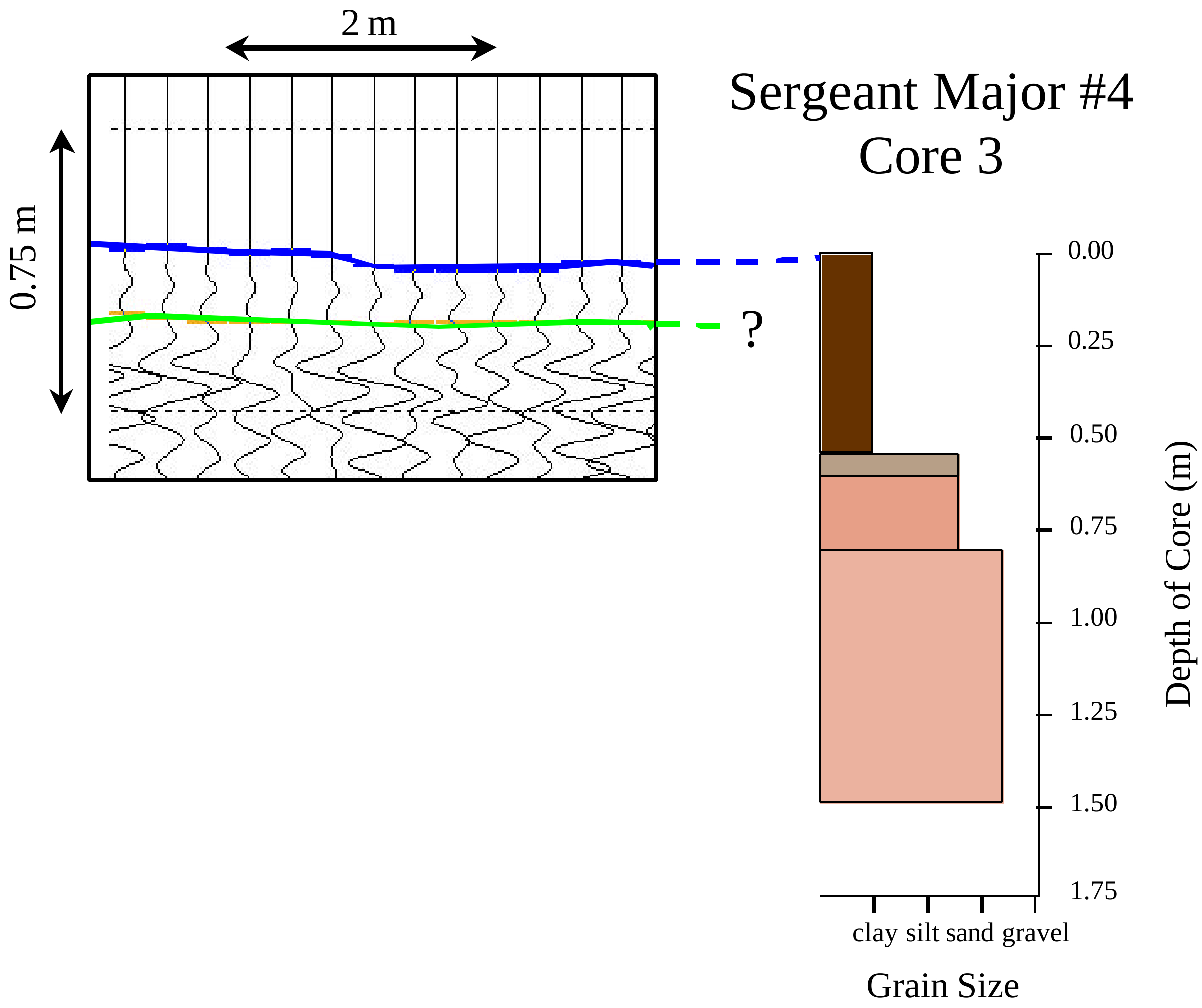

Figure 6-14. Seismogram from Sergeant Major at the approximate location of Core 3 and its interpretation (see Figures 6-8 and 6-13; see Figure 4-13 for stratigraphic legend). Depth and length scales are shown.

6.5 Effect of Land Use on Sedimentation

6.5.1 Sugar Creek #12

Historic land use data for the environs of Sugar Creek #12 shows that between the mid-1960's and the mid-1980's apparently all forested areas were converted to cropland that included peanuts, cotton, and small grains (see §2.1). Since the mid-1980's, approximately 40% of the cultivated land has been converted to pastureland with no change in the amount of grassland and tree-lined drains. Clearly, the conversion of forested areas to cropland would result in higher sediment yields and an increase in reservoir sedimentation. The relatively high rates of sedimentation observed at Sugar Creek #12, 55.0, 50.8, and 29.6 mm/yr or 0.067, 0.062, and 0.036 mm/ha-yr, reflect this basin-wide change in land use.

It should be noted that according to USDA-NRCS personnel, the main stream supplying the reservoir is considered unstable due to the presence of actively migrating knickpoints. These unstable channels can be a significant source of sediment within the watershed. Reported erosion rates for actively degrading stream channels can be as much as 11 million tons of sediment per year (Simon, 1989). In northern Mississippi, about 190,000 tons of sediment per year were discharged from 12.4 km of Hotophia Creek (Little and Murphey, 1981).

6.5.2 Sergeant Major #4

Historic land use data for the environs of Sergeant Major #4 show that since 1960 much of the cropland has been converted almost entirely to seeded native mix (see §2.3). This conversion from a rangeland and cultivated watershed to a predominantly rangeland and grassland watershed with minor amounts of cropland and pastureland would result in lower sediment yields and a decrease in reservoir sedimentation. The relatively low rates of sedimentation observed at Sergeant Major #4, 25.4 mm/yr or 0.017 mm/ha-yr since 1964 and 28.2 and 18.3 mm/yr or 0.019 and 0.012 mm/ha-yr from 1956 to 1964, reflect the land use within the region.

6.6 Discussion

The distribution of radioactive ^{137}Cs emissions facilitated the identification of the 1964 timeline within the sediments at both Sugar Creek #12 and Sergeant Major #4. Since the dam at Sugar Creek #12 was built in 1964, the 1964 timeline also delineated the post-construction sediments from the pre-construction or parent materials. Average sedimentation rates from 1964 to the present time can be calculated and an isopach map of the distribution of deposited sediment can be constructed.

At Sergeant Major #4, the 1964 timeline based on the distribution of ^{137}Cs emissions was determined. Since the dam was constructed in 1956, the sand and gravel deposits located stratigraphically below the 1964 horizon are interpreted as parent material. This interpretation allowed for the calculation of average sedimentation rates to be determined for the period from 1956 to 1964 in addition to rates from 1964 to the present.

The relatively high rates of sedimentation observed at Sugar Creek #12 are related to a basin-wide conversion of forested areas to cropland and knickpoint erosion and channel degradation above the reservoir. The conversion of cropland to native seed grasses within the watershed of Sergeant Major #4 has resulted in relatively low rates of sedimentation.

Most of the sediment that has accumulated in the reservoir at Sugar Creek #12 is composed of silt and clay, with clay in slightly greater proportion. Any deposition of sand is restricted to near the tributary sources. The sediment deposited in Sergeant Major #4 is composed of sand, silt, and clay, with significantly more silt than clay.

Seismic data obtained in the vicinity of the sediment cores at Sergeant Major #4 show some agreement with the stratigraphic columns. However, comparing seismographs to stratigraphic or sedimentological data are inherently problematic because a seismic horizon need not be a stratigraphic boundary.

7. Recommendations

The following are recommendations for future studies based on the experiences presented herein.

1. Geophysical techniques offer unrivaled opportunities to visualize the subsurface stratigraphy within sediment-laden reservoirs. The cost of such systems as used herein can range from $50,000 to $100,000, which is not terribly expensive. However, the geophysical technique and the environment in which it is applied pose additional challenges.

   One difficulty in using any geophysical technique is the amount of prior knowledge the user requires for obtaining the data and the amount of post-processing required to reduce the data to a useable format. The system used herein required little prior knowledge to operate, almost plug-and-play, but it did require extensive knowledge and training for processing the collected data. In addition, post-processing software or the contracting of such processing can be very expensive, tens of thousands of dollars or upwards of $500 per day.

   In addition, shallow water environments require very specialized equipment for optimal performance. The system used here did not perform well in water depths less than about 0.6m (2-ft) because the seismic source was too powerful, the shot length was too long, and the position between the seismic source and receiver was too large. Because of this, the seismic receiver was already recording incoming information while the seismic source was still discharging it and reverberations or multiple signals were too numerous. Modifications can be made to accommodate these shallow water environments typically of flood control reservoirs, but this would take additional resources.

   It should be noted that another device is currently available for subsurface data collection. Dunbar et al. (1999) have developed a self-contained multifrequency acoustic profiling system that employs a high frequency precision fathometer, four lower frequencies for sediment profiling, an in-line DGPS system, and processing software. With the sediment acoustic velocity calibrated, successful acoustic profiles were obtained at Waco Lake in water depths up to 18 m and with sediment thickness less than 2 m. Under optimum conditions, sub-centimeter vertical resolution is possible.

2. A vibracoring system is a much-used and simple technique for obtaining continuous, undisturbed sediment cores within reservoirs as well as many other environments. Such systems can be purchased or constructed for $10,000 to $20,000. No other technique ensures that the complete sediment column is recovered undisturbed. All sediment sampling and characterization can be routinely made once a complete core is extracted. The system used here performed reasonably well.

3. The decision to run particular chemical analyses were based on (a) known historical land use practices, information such as crops and treatments and (b) screenings of common agrichemicals and contaminants typically found in agricultural regions. Environmental chemistry laboratories are quite common across the U.S., each offering an array of services to determine the quality of sediment. Typically, laboratories offer pre-defined screenings of major element, contaminants, or agrichemicals. These screenings normally include heavy metals and other elements, herbicides, organophosphorus pesticides, and priority pollutant pesticides (organochlorine pesticides) and PCBs. Each screening may cost from \$100 to \$500, but one sample may require multiple screenings. Moreover, there are dozens of commonly used agrichemicals that are not analyzed in these pre-defined screenings, each costing an additional \$100 to \$200. It is easy to see that chemical analysis can become quite expensive. Knowledge of historic land use could focus the analytical work, thus improve the assessment of sediment quality. Without any information on previous land use, typical screenings offered by environmental chemistry laboratories is recommended.

   The interpretation of chemical results would be greatly facilitated by knowing the toxicity levels of the element or compound in question. A detailed listing of toxicity levels has been provided in the Appendix, but these may be superceded by local or state regulations. In addition, there is at present no definitive source for acquiring such information on recommended limits. State environmental agencies and the U.S. Environmental Protection Agency should be consulted for guidance on these matters.

   One additional concern is the question of "representability" (*sic*). All samples analyzed herein are depth-integrated; that is, the sediment was averaged over length of core. The composite sample was further subdivided by the laboratory technician. Hence, there may exist specific horizons with chemicals present that were not identified or concentrations in excess of those reporting. This question of securing a representative sediment sample for analysis is not trivial.

8. Conclusions

Since 1944, the USDA-NRCS has constructed over 10,000 upstream flood control dams in 2000 watersheds in 47 states, each with a design life of 50 years. The watershed projects, which represent a $14 billion infrastructure, have provided flood control, municipal water supply, recreation, and wildlife habitat enhancement. Because of population growth and land use changes through time, sediment pools are filling, some structural components have deteriorated, safety regulations are stricter, and the hazard classification for some dams has changed.

Before any rehabilitation strategy can be designed and implemented, the sediment impounded by these dams must be assessed in terms of the structure's efficiency to regulate floodwaters and the potential hazard the sediment may pose if reintroduced into the environment. To this end, a demonstration project was designed to evaluate technologies, methodologies, and protocols for the cost-effective characterization of sediment.

For a given lake within an embankment flood control structure, the USDA-NRCS needs to determine (1) the thickness of sediment deposited, (2) the rates of sedimentation, (3) the quality of sediment with respect to agrichemicals (related to agricultural practices) and petrochemicals (related to hydrocarbon extraction, drilling, and well development), and (4) the spatial distribution of the sediment quality. Based on visits to the reservoirs in Oklahoma and discussions with the USDA-NRCS, the USDA-ARS National Sedimentation Laboratory and its colleagues recommended the use of seismic surveying, vibracoring, and detailed chemical analysis to characterize the quality and quantity of sediment within these reservoirs.

Three field sites were chosen for this demonstration project. Sugar Creek #12 is located near Hinton, OK, and it is a relatively small lake with a mud bottom and fairly shallow water depths. The main stream supplying the lake is considered unstable due to the presence of actively migrating knickpoints, and excessive sedimentation rates have significantly decreased storage capacity. Moreover, historic land use of cultivated fields of cotton and peanuts suggests that agrichemicals may be present in the lake sediments. Sugar Creek #14 is also located near Hinton, OK, and it is a relatively small lake with a mud bottom and fairly shallow water depths. Historic land use includes a small amount of cultivated fields of cotton and peanuts, but preliminary surveys indicate that sedimentation rates were not as high here as they were at Sugar Creek #12. Sergeant Major #4 is located near Cheyenne, OK and is a moderately sized structure with a reservoir covering an area of about 35 acres. This site was chosen because it has become the sole municipal source of water for the town of Cheyenne, and preserving water quality is a major concern.

In November 1999, seismic surveys of each lake were conducted and shallow sediment cores were collected for preliminary quality analysis. In June 2000, continuous, undisturbed sediment cores were obtained at Sugar Creek #12 and Sergeant Major #4 using a vibracoring system. The physical, chemical, agrichemical, and contaminant characteristics of the sediment within these cores were determined. Below are the major conclusions of the study.

1. Seismic profiles were successfully obtained in each of the three reservoirs in Oklahoma. However, the very shallow water depths at Sugar Creek #12 and Sugar Creek #14 caused unwanted noise in the seismic signal, and the processed data are virtually impossible to interpret.

2. The seismic profiles at Sergeant Major #4 show a number of distinct interpreted seismic reflectors in the subsurface. These reflectors range in thickness from 0.1 to 0.5 m and occur at depths of up to 1.5 m below the sediment bed. Several reflectors can be traced up to 80 m across the lake, while others appear to be restricted to the topographically low regions. Reflector thickness appears to be greatest along the northwestern tributary arm, while the thinnest reflectors occur along the small central tributary arm. Nonetheless, reflectors were ubiquitous in all regions of the lake. These reflectors, however, are unverified.

3. Ten continuous, undisturbed cores of lake sediment were successfully obtained at Sugar Creek #12. These cores ranged in length from 1.3 to 3.1 m and were extracted from water depths ranging from 0.5 to 3 m. In general, the cores are composed of sand, silt, and clay. In places, alternating layers of black and brown silt and clay are present, and these are interpreted as varves. Very thick accumulations, up to 2.4 m, of silt and clay are common and virtually no gravel is observed. These silt-clay units generally have slightly more clay than silt. The amount of silt and clay is positively correlated with the amount of carbon, nitrogen, and high values of magnetic susceptibility.

4. Four continuous, undisturbed cores of lake sediment were successfully obtained at Sergeant Major #4. These cores ranged in length from 1.3 to 1.6 m and were extracted from water depths ranging from 1 to 12 m. In general, the cores are composed of gravel, sand, silt, and clay. Very thick accumulations, up to 1.1 m, of silt and clay are common, but also common are large sand accumulations of up to 1 m. The sediments are poorly sorted, and the amount of silt is generally two to three times greater than clay. Gravel is common near the base of many cores. Little correlation is observed amongst the physical and chemical characteristics of the sediment.

5. The analysis of sediment quality include examining for 18 different priority pollutant pesticides, 7 different PCBs, 11 different insecticides and herbicides, and 14 different heavy metals, elements, and other contaminants. A total of 34 sediment samples from Sugar Creek #12, 6 sediment samples Sugar Creek #14, and 17 sediment samples from Sergeant Major #4 were analyzed in this study. Results from testing sediments from all three reservoirs show very good overall sediment quality. Results of contaminant analysis show minor contamination by residual breakdown products of

DDT. The presence of DDE and DDD in sediment, a metabolite of DDT, poses no health issue and is common to many reservoirs that trap sediments from land farmed in the 1950's and 1960's. The greater concentration observed in Sugar Creek #12 reflects historical use and erosion rates. Methyl parathion, a common insecticide, was found in low concentrations in all three reservoirs. Detection trends followed current land use. General analysis of oil and grease shows the presence of only small proportions of this contaminant. Physical and elemental properties that were measured fall within expected ranges of values for naturally occurring sediments at all three lakes and do not indicate any potential adverse effects on water quality in the reservoirs. Concentrations of metals in reservoir sediments are below known toxic levels, and cation concentrations are balanced.

6. Peaks in the concentration of ^{137}Cs emissions, corresponding the 1964 datum, occur in subsurface sediments at both Sugar Creek #12 and Sergeant Major #4. Using this 1964 datum, sedimentation rates from 1964 to the present in Sugar Creek #12 are 55.0, 50.8, and 29.6 mm/yr or 0.067, 0.062, and 0.036 mm/ha-yr based on core data. Similar peaks in the distribution of ^{137}Cs and the demarcation of the 1964 datum are observed in the cores taken at Sergeant Major #4. From 1964 to the present, a sedimentation rate of 25.4 mm/yr or 0.017 mm/ha-yr is deduced from these cores. Since the dam was constructed in 1955, the sand and gravel located stratigraphically below the mud layers are interpreted as parent (pre-construction) material. Therefore during the period from 1955 to 1964, sedimentation rates are 28.2 and 18.3 mm/yr or 0.019 and 0.012 mm/ha-yr based on core data.

7. Correlation of sediments within the reservoir at Sugar Creek #12 was made possible using all of the physical and chemical information available. Most of the sediment that has accumulated within this basin is silt and clay in nearly equal proportions, while sand deposition is restricted to the tributary sources. A contour map of deposited sediment thickness shows that sediment is thickest in the northern part of the basin, near the northwest tributary. Locally thick accumulations occur near the southern tributaries.

8. The relatively high rates of sedimentation observed at Sugar Creek #12 are related to a basin-wide conversion of forested areas to cropland and knickpoint erosion and channel degradation above the reservoir. The conversion of cropland to native seed grasses within the watershed of Sergeant Major #4 has resulted in relatively low rates of sedimentation.

9. Select, higher quality seismic records from Sergeant Major #4 are shown to correlate to some of the stratigraphic boundaries observed in the sediment cores. However, comparing seismographs to stratigraphic or sedimentological data are inherently problematic.

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Appendix: Summary of carcinogenic levels for chemicals and compounds.

<u>IMPORTANT DISCLAIMER</u>

The USDA-ARS National Sedimentation Laboratory does not advocate nor enforce the suggested regulatory levels for the chemicals and compounds listed. Other federal and state regulatory bodies with proper authority and jurisdiction can and will supersede the information provided herein. These data should not be used for any purpose other than for background information. The USDA-ARS National Sedimentation Laboratory is exonerated from any errors or inaccuracies reported herein.

Introduction

Summarized in table form is a listing of all chemicals and compounds analyzed in the report. There is no definitive source for toxicity levels for the chemicals and compounds, only sparse recommendations. The majority of the information comes from the U.S. Environmental Protection Agency Office of Water and can be found at the web address www.epa.gov/safewater/mcl.html (see also www.epq.gov/reg6rcei). Additional information can be obtained from Linda Faulk, EPA Region 6, falk.linda@epa.gov, tel. 214-665-8535.

Tables are subdivided into use of chemical (H is a herbicide, I is an insecticide), where and in what capacity the material is located (residential soils, Table A-1; industrial soils for an indoor worker, Table A-2; industrial soils for an outdoor worker, Table A-3; and ambient air and tap water, Table A-4), and the type of exposure (inhalation, application to skin (dermal), and ingestion). If there are no values listed for a particular chemical of compound, there are three possible reasons: (1) it may not be regulated by the EPA, and/or (2) it may be on the National Recommended Water Quality Criteria, and/or (3) it may be on the Final Revisions to the Unregulated Contaminant Monitoring List.

Key Definitions

The **National Primary Drinking Water Regulations** (NPDWRs or primary standards) are legally enforceable standards that apply to public water systems. Primary standards protect drinking water quality by limiting the levels of specific contaminants that can adversely affect public health and are known or anticipated to occur in public water systems.

Contaminants not included in the primary standards may be found in the **National Secondary Drinking Water Regulations** (NSDWRs or secondary standards). These standards are non-enforceable guidelines regulating contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards to water systems but does not require systems to comply. However, states may choose to adopt them as enforceable standards.

MCLG – Maximum Contaminant Level Goal is the maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on the health effect of persons would occur, and which allows for and adequate margin of safety. MCLGs are non-enforceable health goals.

MCL – Maximum Contaminant level is the permissible level of a contaminant in water, which is delivered to any user of a public water system. MCLs are enforceable standards. The margins of safety in MCLGs ensure that exceeding the MCL slightly does not pose significant risk to public health.

Cancer Risk – All levels reported are based on carcinogenicity risk of 10^{-6}. Alternate risk levels may be obtained by moving the decimal point.

Table A-1. Summary of carcinogenic levels for chemicals and compounds found in residential soils.

Compound/Chemical Name	Trade Name	Use	Inhale (ppm)	Dermal (ppm)	Ingest (ppm)
Alachlor	Lasso	H	110000	25	8
Aldrin	Aldrex	I	520	0.12	0.038
Arsenic (noncancer endpoint)					
Arsenic (cancer endpoint)			590	4.5	0.43
Atrazine	(multiple)	H	40000	9.1	2.9
Barium and compounds					
BHC Alpha		I			
BHC Beta		I			
BHC Delta		I			
BHC Gamma	Lindane	I			
Bifenthrin	Talstar	I			
Cadmium and compounds			1400		
Chlordane	(multiple)	I	25000	14	1.8
Chlorfenapyr	Pirate				
Chlorpyrifos	Lorsban	I			
Total Chromium (1/6 ratio Cr VI/ Cr III)			210		
Cyanazine		H	11000	2.4	0.76
λ-Cyhalothrin	Karate	I			
DDD	TDE	I	37000	28	2.7
DDE		I	26000	20	1.9
DDT	(multiple)	I	26000	20	1.9
Dieldrin	Dieldrex	I	550	0.13	0.04
Endosulfan-alpha	Endosulfan	I			
Endosulfan-beta		I			
Endosulfan Sulfate					
Endrin	Endrex	I			
Endrin Aldehyde					
Heptachlor	(same)	I	1900	0.45	0.14
Heptachlor Epoxide	(same)	I	970	0.22	0.70
Lead					
Mercury and compounds					
Mercury (elemental)					
Methyl Parathion	(same)	I			
Metolaclor	Dual	I			
Pendimethalin	Prowl	H			
Polychlorinated Biphenyls			4400	0.72	0.32
Aroclor 1016	PCBs		130000	21	9.1
Aroclor 1221	PCBs		4400	0.72	0.32
Aroclor 1232	PCBs		4400	0.72	0.32
Aroclor 1242	PCBs		4400	0.72	0.32

Table A-1 continued

Compound/Chemical Name	Trade Name	Use	Inhale (ppm)	Dermal (ppm)	Ingest (ppm)
Aroclor 1248	PCBs		4400	0.72	0.32
Aroclor 1254	PCBs				
Aroclor 1260	PCBs		4400	0.72	0.32
Selenium					
Silver and compounds					
Toxaphene	(multiple)	I	7900	1.8	0.58
Trifluralin	Treflan	H			
Zinc					

Table A-2. Summary of carcinogenic levels for chemicals and compounds found in industrial soils for an indoor worker.

Chemical/Compound Name	Trade Name	Use	Inhale (ppm)	Ingest (ppm)
Alachlor	Lasso	H	240000	100
Aldrin	Aldrex	I	1100	0.48
Arsenic (noncancer endpoint)				
Arsenic (cancer endpoint)			1300	5.5
Atrazine	(multiple)	H	86000	37
Barium and compounds				
BHC Alpha		I		
BHC Beta		I		
BHC Delta		I		
BHC Gamma	Lindane	I		
Bifenthrin	Talstar	I		
Cadmium and compounds			3000	
Chlordane	(multiple)	I	54000	23
Chlorfenapyr	Pirate			
Chlorpyrifos	Lorsban	I		
Total Chromium (1/6 ratio Cr VI/ Cr III)			450	
Cyanazine		H	22000	9.7
λ-Cyhalothrin	Karate	I		
DDD	TDE	I	78000	34
DDE		I	55000	24
DDT	(multiple)	I	55000	24
Dieldrin	Dieldrex	I	1200	0.51
Endosulfan-alpha	Endosulfan	I		
Endosulfan-beta		I		
Endosulfan Sulfate				
Endrin	Endrex	I		
Endrin Aldehyde				
Heptachlor	(same)	I	4100	1.8
Heptachlor Epoxide	(same)	I	2100	0.90
Lead				
Mercury and compounds				
Mercury (elemental)				
Methyl Parathion	(same)	I		
Metolaclor	Dual	I		
Pendimethalin	Prowl	H		
Polychlorinated Biphenyls			9400	4.1
Aroclor 1016	PCBs		270000	120
Aroclor 1221	PCBs		9400	4.1
Aroclor 1232	PCBs		9400	4.1
Aroclor 1242	PCBs		9400	4.1

Table A-2 continued

Chemical/Compound Name	Trade Name	Use	Inhale (ppm)	Ingest (ppm)
Aroclor 1248	PCBs		9400	4.1
Aroclor 1254	PCBs			
Aroclor 1260	PCBs		9400	4.1
Selenium				
Silver and compounds				
Toxaphene	(multiple)	I	17000	7.4
Trifluralin	Treflan	H		
Zinc				

Table A-3. Summary of carcinogenic levels for chemicals and compounds found in industrial soils for an outdoor worker.

Compound/Chemical Name	Trade Name	Use	Inhale (ppm)	Dermal (ppm)	Ingest (ppm)
Alachlor	Lasso	H	290000	67	44
Aldrin	Aldrex	I	1400	0.32	0.21
Arsenic (noncancer endpoint)					
Arsenic (cancer endpoint)			1600	12	2.4
Atrazine	(multiple)	H	110000	24	16
Barium and compounds					
BHC Alpha		I			
BHC Beta		I			
BHC Delta		I			
BHC Gamma	Lindane	I			
Bifenthrin	Talstar	I			
Cadmium and compounds			3700		
Chlordane	(multiple)	I	67000	39	10
Chlorfenapyr	Pirate				
Chlorpyrifos	Lorsban	I			
Total Chromium (1/6 ratio Cr VI/ Cr III)			560		
Cyanazine		H	28000	6.5	4.3
λ-Cyhalothrin	Karate	I			
DDD	TDE	I	98000	75	15
DDE		I	69000	53	11
DDT	(multiple)	I	69000	53	11
Dieldrin	Dieldrex	I	1500	0.34	0.22
Endosulfan-alpha	Endosulfan	I			
Endosulfan-beta		I			
Endosulfan Sulfate					
Endrin	Endrex	I			
Endrin Aldehyde					
Heptachlor	(same)	I	5200	1.2	0.79
Heptachlor Epoxide	(same)	I	2600	0.60	0.39
Lead					
Mercury and compounds					
Mercury (elemental)					
Methyl Parathion	(same)	I			
Metolaclor	Dual	I			
Pendimethalin	Prowl	H			
Polychlorinated Biphenyls			12000	1.9	1.8
Aroclor 1016	PCBs		340000	55	51
Aroclor 1221	PCBs		12000	1.9	1.8
Aroclor 1232	PCBs		12000	1.9	1.8
Aroclor 1242	PCBs		12000	1.9	1.8

Table A-3 continued

Compound/Chemical Name	Trade Name	Use	Inhale (ppm)	Dermal (ppm)	Ingest (ppm)
Aroclor 1248	PCBs		12000	1.9	1.8
Aroclor 1254	PCBs				
Aroclor 1260	PCBs		12000	1.9	1.8
Selenium					
Silver and compounds					
Toxaphene	(multiple)	I	21000	4.9	3.3
Trifluralin	Treflan	H			
Zinc					

Table A-4. Summary of carcinogenic levels for chemicals and compounds found in ambient air and tap water.

			Ambient Air	Tap Water		
Compound/Chemical Name	Trade Name	Use	Cancer Risk (ppb)	MCLG (ppb)	MCL (ppb)	Cancer Risk (ppb)
Alachlor	Lasso	H	0.084		2.0	0.84
Aldrin	Aldrex	I	0.00039			0.004
Arsenic (noncancer endpoint)					50	
Arsenic (cancer endpoint)			0.00045			0.045
Atrazine	(multiple)	H	0.031	3.0	3.0	0.3
Barium and compounds				2000	2000	
BHC Alpha		I				
BHC Beta		I				
BHC Delta		I				
BHC Gamma	Lindane	I				
Bifenthrin	Talstar	I				
Cadmium and compounds			0.0011	5.0	5.0	
Chlordane	(multiple)	I	0.019		2.0	0.19
Chlorfenapyr	Pirate					
Chlorpyrifos	Lorsban	I				
Total Chromium (1/6 ratio Cr VI/ Cr III)			0.00016	100	100	
Cyanazine		H	0.0080			0.080
λ-Cyhalothrin	Karate	I				
DDD	TDE	I	0.028			0.28
DDE		I	0.020			0.20
DDT	(multiple)	I	0.020			0.20
Dieldrin	Dieldrex	I	0.00042			0.0042
Endosulfan-alpha	Endosulfan	I				
Endosulfan-beta		I				
Endosulfan Sulfate						
Endrin	Endrex	I		2.0	2.0	
Endrin Aldehyde						
Heptachlor	(same)	I	0.0015		0.10	0.015
Heptachlor Epoxide	(same)	I	0.00074		0.20	0.0074
Lead					15	

Table A-4 continued

Compound/Chemical Name	Trade Name	Use	Ambient Air Cancer Risk (ppb)	Tap Water MCLG (ppb)	Tap Water MCL (ppb)	Tap Water Cancer Risk (ppb)
Mercury and compounds				2.0	2.0	
Mercury (elemental)						
Methyl Parathion	(same)	I				
Metolaclor	Dual	I				
Pendimethalin	Prowl	H				
Polychlorinated Biphenyls			0.0034		0.50	0.034
Aroclor 1016	PCBs		0.096			0.96
Aroclor 1221	PCBs		0.0034			0.034
Aroclor 1232	PCBs		0.0034			0.034
Aroclor 1242	PCBs		0.0034			0.034
Aroclor 1248	PCBs		0.0034			0.034
Aroclor 1254	PCBs					
Aroclor 1260	PCBs		0.0034			0.034
Selenium				50	50	
Silver and compounds						
Toxaphene	(multiple)	I	0.0060		3.0	0.061
Trifluralin	Treflan	H				
Zinc						