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Coastal and Hydraulics Laboratory

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System-Wide Water Resources Program

Effect of Organic Materials on Bulk Density and Erodibility of Fine Sediment Beds

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Coastal and Hydraulics Laboratory
U.S. Army Engineer Research and Development Center
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

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ABSTRACT: Despite more than a century of research on sediment processes, there still exist a number of knowledge gaps regarding key sediment processes. Research is needed on the description and analysis of sediment processes. The objective of research on sediment processes is to provide new knowledge of cohesive sediment erosion processes and release of associated nutrients plus development of improved algorithms for erosion/release rate as a function of bulk density, organic content, and other easily measured parameters.

Most of the fine sediments occurring in natural environments such as lakes, wetlands and estuaries contain organic material. The type and amount of organic contents are site-specific and may vary to a great extent. The bulk density and erosion rates of fine sediment beds are known to be significantly affected by the organic contents; however, their influence has not been adequately quantified. Bulk density and erodibility are the properties of cohesive sediments that are affected by the presence of organic substances. It is essential to know bulk density to be able to predict the erosion rates of cohesive sediment beds because shear strength is often related to bed density of cohesive sediments.

The purpose of this report is to present results of laboratory measurements conducted at CHL on the influence of organic contents on bed density and erodibility of cohesive sediments at various project sites. Background information on the basic properties of fine sediments, their characterization, and fine sediment beds is also given.

A literature review was undertaken to compile information on the effect of organic substances on the properties of cohesive sediments. Laboratory measurements were conducted at the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC), for determining the physical properties of sediments collected from many project sites. These included determining the bed density and erodibility of cohesive sediment beds. This report contains relevant information obtained through literature search and the laboratory results of sediment analysis for many project sites.

Correlation of erosion and nutrient release rate with organic content and other simple parameters will improve the accuracy of numerical models used for prediction of erosion of natural sediments occurring at the U.S. Army Corps of Engineers (USACE) projects. Improved knowledge of the processes and physically accurate models will increase public confidence in our project evaluations and enable USACE to design and operate projects that enhance the aquatic environment.

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BWD	Bulk wet density
TOC	Total organic carbon
TON	Total organic nitrogen
C_S	Solids contents
C_V	Volume concentration of solids
W	Moisture content
ρ_l	Wet density
ρ_l	Liquid density
ρ_S	Sediment particle density
ρ	Bulk density
ρ_r	Relative bed density
$\bar{\rho}$	Average bed density over thickness of bed
k	Permeability
C	Suspension concentration
τ_b	Bed shear stress
τ_d	Critical shear stress for deposition, determined by experiment
τ_c	Critical shear stress for erosion
τ_e	Critical shear stress for erosion
z	Depth below surface
τ_s	Bed shear strength
μ	Microns (10^{-6} meter)

Preface

This study involving the mechanics of sediment transport processes, one of which is related to organic-rich sediments, was conducted at the U.S. Army Engineer Research and Development Center (ERDC) under the Regional Sediment Management (RSM) research of the System-Wide Water Resources Program (SWWRP).

Laboratory measurements were conducted at ERDC's Coastal and Hydraulics Laboratory (CHL) for determining the physical properties of sediments collected from many project sites. These included determining the bed density and erodibility of cohesive sediment beds. A literature review was undertaken to compile information on the effect of organic substances on the properties of cohesive sediments. This report contains relevant information obtained through literature search and the laboratory results of sediment analysis for many project sites. Dr. Trimbak M. Parchure, research hydraulic engineer, was the Principal Investigator for the project. Dr. Parchure prepared this report jointly with Dr. Jack E. Davis. The CHL field data collection team consisting of Mr. Tim Fagerburg, Mr. Howard Benson, and Mr. Chris Callegan collected field data on bed samples. Mr. Doug Brister of CHL conducted laboratory analysis of bed samples under the guidance of Dr. Allen Teeter. Ms. Mary Lynn Bagshaw and Ms. Dorothy King provided assistance in analyzing a large number of sediment samples collected at Sabine Neches project and from the Upper Mississippi River. Mr. Corey Foster assisted in data analysis and report compilation works. Headquarters, U.S. Army Corps of Engineers, provided funding for this study under SWWRP.

The work was conducted under the general supervision of Dr. Robert T. McAdory, Chief, Estuarine Engineering Branch, CHL, Dr. Sandra Knight, Technical Director, CHL, Mr. Thomas W. Richardson, Director, CHL, and Dr. William D. Martin, Deputy Director, CHL.

At the time of publication of this report, Dr. James R. Houston was Director of ERDC, and COL James R. Rowan, EN, was Commander and Executive Director.

1 Introduction

Regional Sediment Management Research Program

Many of the fundamental processes of sediment, nutrient, and contaminant transport that are active in upland streams, river systems, estuaries, and along the coast are not yet fully understood. These processes are often interconnected and always complex because of their nonlinear, turbulent, and stochastic characteristics. Consequently, this lack of understanding prohibits the modeling natural watershed and ecosystem processes and evaluating or predicting the regional response of these systems to the U.S. Army Corps of Engineers' engineering activities. Impacts of Corps activities must be predicted on a range of time scales, from days to years, to make decisions regarding short-term effects on local environmental conditions (such as turbidity and water quality) – and from decades to centuries to understand long-term responses within a regional watershed system.

Comprehensive sediment research has been undertaken at the U.S. Army Engineer Research and Development Center (ERDC) under the Regional Sediment Management (RSM) research program. RSM is one of the pillars of the System-Wide Water Resources Program (SWWRP), a Corps of Engineers research and development initiative designed to assemble and integrate the diverse components of water resources management. RSM research is divided into three major areas: a) long-term dynamics of large-scale sediment systems, b) midterm dynamics of sediment systems, and c) mechanics of sediment processes. Several work units exist under each research area. Research on organic-rich sediments forms a work unit under the mechanics of sediment transport processes.

The objective of the RSM program is to develop and demonstrate concepts, methods, procedures, and data sources to determine, describe, and evaluate the following:

a. Regional-scale sediment production, transport, storage, and digenesis processes within a regional sediment system (watershed, littoral cell, estuary).

b. How engineering works within the regional sediment system affect these sediment processes.

c. How these sediment processes are affected by phenomena of various geographic scales and time-spans (large-scale long-term, phenomena).

d. The importance of these results to the planning, design, and operation of major civil works projects such as flood control, navigation, storm protection, beach nourishment, and environmental mitigation and restoration.

An important research component under sediment transport processes consists of sediment property characterization. It is necessary to develop better knowledge and measuring techniques for a probabilistic description of soil properties that impact transport rates. The characterization of these properties must incorporate spatial variability via probabilistic description. This requires testing of multiple specimens to determine a proper distribution of each parameter to be used in models. This report deals with one parameter, namely the quantity of organic contents in natural sediments and its effect on the behavior of fine sediments.

Mechanics of Sediment Processes

Despite more than a century of research on sediment processes, there still exist a number of knowledge gaps regarding key sediment processes. This effort will focus on the description and analysis of short-term (days to years) sediment and project-induced processes. This type of information is also required for project design, operation, and optimization. A predictive capability for several processes will be developed based on field measurements and/or existing data to answer questions such as:

a. What are the processes affecting water quality and turbidity associated with dredged material placement in the watershed? How do these affect the ecosystem?

b. What are the basic processes that mobilize and transport sediment through the watershed?

c. How are nutrients and contaminants mobilized and transported in the sediment system? Are contaminated sediments in the bed or channel more readily mobilized for a watershed with a sediment deficit?

d. How do freeze/thaw cycles and rainfall affect overland, bluff, bank, and cliff erosion?

The objective of research on sediment processes is to provide new knowledge of cohesive sediment erosion processes and release of associated nutrients plus improved algorithms for erosion/release rate as a function of bulk density, organic content, and other easily measured parameters. It is necessary to standardize a suite of sediment property measurements for fine sediment studies, and provide a cost-based facility for making such measurements available to the interested researchers. The number of sediment properties that can potentially affect transport behavior is prohibitively large. This list must be shortened to a usable subset to be determined as often as possible.

Significance of Organics in Sediments

Most of the fine sediments occurring in natural environments such as lakes, wetlands and estuaries contain organic material. A wide range of materials, derived from both the plant and animal kingdoms, fall under the general category of organic sediments. Twenhofel (1926 revised 1950) has given a broad perspective on these. The type and amount of organic contents are site-specific and may vary to a great extent. The bulk density and erosion rates of fine sediment beds are known to be significantly affected by the organic contents; however, their influence has not been adequately quantified. Organic materials, nutrients, and bacteria are attached predominantly and preferentially to fine sediments due to physical and electrochemical properties of clays. The erosion of fine sediment beds results in bringing millions of fine particles into suspension, which significantly changes the turbidity and chemistry of the water column, thus affecting water quality adversely. Hence, quantification of the process of release of nutrients in the water column is essential.

Bulk density and erodibility are the properties of cohesive sediments that are affected by the presence of organic substances. It is essential to know bulk density to be able to predict the erosion rates of cohesive sediment beds because shear strength is often related to bed density of cohesive sediments.

The purpose of this report is to present results of laboratory measurements conducted at ERDC's Coastal and Hydraulics Laboratory (CHL) on the influence of organic contents on bed density and erodibility of cohesive sediments at various project sites. Background information on the basic properties of fine sediments, their characterization, and fine sediment beds is also given. The report provides brief information on the studies conducted earlier and mainly presents the results of laboratory measurements conducted at CHL. In the context of coastal engineering problems, only cohesive sediments that are fully saturated due to long submergence are relevant. Hence, only such sediments are considered in this report.

Research Benefits

Correlation of erosion and nutrient release rate with organic content and other simple parameters will improve the accuracy of numerical models used for prediction of erosion of natural sediments occurring in connection with Corps projects. Improved knowledge of the processes and physically accurate models will increase public confidence in project evaluations and enable the Corps to design and operate projects that enhance the aquatic environment.

2 Fine Sediments

Basic Properties

Noncohesive and cohesive sediments have widely varying properties governing their erosion, transport, and deposition. Hence, the equations and methods used for determining these characteristics are also different. Mixtures of these two types of sediment prevail at most sites. Appropriate selection of equations needs to be made depending upon the sediment present at the site.

Sediments in any natural environment typically contain a wide range of sediment sizes ranging from gravel and coarse sand (noncohesive sediments) to fine, sometimes organic-rich sediments in the range of clays and silt (cohesive sediments). Clay particles are smaller than 4 μ in size and silt is finer than 62 μ. Some researchers have used 64 or 74 μ as the size for defining silt. Mathematical formulation of transport processes of the cohesive and noncohesive sediments are significantly different. Hence, the two types of sediment need to be analyzed differently for measuring different parameters. The primary parameters to be considered for the noncohesive sediments consist of particle size, density, and critical shear stress for incipient motion. These parameters are used in the equations for estimating bed load and suspended load. For cohesive sediments, the processes of erosion, transport, deposition, and resuspension are different from those for the noncohesive sediments. In particular, the processes of erosion, deposition, and consolidation of the fine sediment take place in a cyclic order (Mehta et al. 1982).

It is essential to know the critical shear stress for erosion and bed density of cohesive sediments to be able to estimate the amount of sediment likely to get in suspension by currents and waves. The rate of erosion is a function of bed shear stress and the erosion-rate-constant. However, at present there is no analytical procedure available for obtaining the exact values of these parameters. It is essential to conduct laboratory tests, at least on a few representative sediment samples from the field, for determining these parameters.

Literature reviews showed the following generally accepted trends in the behavior of cohesive sediments.

a. The rate of erosion is often a parameter of concern in many cohesive sediment studies. Erosion rate is a function of the excess shear stress, which is given by the difference between the fluid-induced bed shear stress and the shear strength of the bed. While the shear stress can be calculated, the shear strength needs to be measured in the laboratory. Thus, shear strength of cohesive sediment bed is a significant property. Owen (1970) showed that the shear strength of cohesive sediment beds generally increases with increasing bulk density.

b. Erosion rate constant generally decreases with increasing bulk density (Hwang 1989).

c. Erosion rate constant decreases with increasing bed shear strength (Lee and Mehta 1994).

d. Cohesive sediment beds are formed mainly by deposition of suspended sediment. Size and density of cohesive sediment flocks and the noncohesive particles is an important parameter that determines their differential settling of sediment mixtures in the water column. Settling velocity for cohesive sediments is a function of suspension concentration (Parchure and Long 1993) in addition to other factors. Noncohesive sediment particles settle individually without forming flocks.

e. The settling velocity increases initially with increasing concentration of sediment in suspension. For concentrations higher than about 1,000 mg/L the settling velocity decreases with increasing concentration. (Hwang 1989).

f. Among other factors, erosion rate of cohesive sediments is a function of excess shear stress, which is the difference between the flow-induced / wave-induced bed shear stress and the critical shear stress.

g. Laboratory tests on erosion of cohesive sediments often indicate two ranges of erosion rates and erosion rate constants, one in the lower range of bed shear stress and the other for the higher bed shear stress. Hence, the same sediment may have two values of these two parameters (Parchure 1980).

Fine Sediment Characterization

Standard sediment classification procedures available in the literature are based predominantly on particle-size distribution. Through arbitrary selection of limiting grain sizes, terms such as clay, fine silt, coarse silt, fine sand, coarse sand, gravel, etc. have been assigned. The entire sediment fraction smaller than 4 μ is classified as clay. Clays are called fine sediments and exhibit cohesive properties whereas the coarser sediments are called noncohesive sediments. Sediment particles between 4 and 10 to 15 μ sometimes form a nebulous zone, which may or may not be cohesive. Also very fine particles of nonclay minerals (such as silica) may exhibit cohesive properties. Presence of organic substances sometimes changes the behavior of fine noncohesive sediments to that of cohesive sediments. Many geotechnical parameters such as moisture content, and Atterburg Limits, such as liquid limit, plastic limit, etc., are commonly used for characterizing field sediment mixtures but have limited applicability to defining erodibility of cohesive sediment beds. The Atterburg Limits are routinely used to describe physical properties of sediments containing fine sediment components.

Several factors need to be considered while dealing with fine sediment processes. Mehta (1992) identified 32 parameters out of about 100 that are crucial for fine sediment characterization. The following are the major parameters:

a. Sediment-related: mineral composition, organic content, bulk density, particle-size distribution, and cation exchange capacity

b. Fluid-related: salinity / chemical composition, pH, temperature

c. Process-related: dispersion, biological processes, settling process, turbulence.

Parchure et al. (2001b) selected use of three sediment-related parameters to characterize fine sediment beds, namely particle-size distribution, organic content, and bulk density because these three parameters have a significant effect on the shear strength of fine sediment beds.

3 General Properties of Fine Sediment Beds

Bed Formation

The most predominant fine sediment processes consist of erosion, transport, deposition and consolidation. Due to their extremely small particle size, cohesive sediments remain in suspension under a small flow-induced turbulence or even under apparently quiescent conditions. Due to their large size and higher specific gravity, coarse sediments settle rapidly under gravitational force within water column and travel as bed load in the direction of flow. Fine sediments are transported mainly in suspension; they flocculate during transport and they deposit when the flocculated particles gain enough weight to settle under gravity by overcoming the lift forces acting on them. Most of the cohesive sediment beds are flow-deposited beds. Under tidal conditions, clay beds undergo cycles of resuspension, transport, and deposition. They also undergo self-weight consolidation when they remain on bed over extended periods of time. Mehta and Lee (1994) have described problems in linking the threshold condition for the transport of cohesionless and cohesive sediment grains.

Bed Characteristics

The upper layers of fine sediment beds that have not undergone consolidation are called soft beds. They often have substantial variation in density and shear strength over depth. These properties change with time as more consolidation takes place. Fine sediment beds are classified into three main categories. The first type is called “uniform bed.” This type of bed has constant shear strength over depth. The second type is called “stratified bed.” This type of bed consists of layers of varying shear strength. The third type is called “fluid mud.” The erosional properties of these three types of beds are different from each other, requiring the use of corresponding mathematical equations for each.

Classification of Fine Sediment Beds

Classification of noncohesive sediments in terms of their particle size and particle density is adequate for describing the beds formed by these sediments.

On the contrary, the process of bed formation is very complex for cohesive sediments and particle size alone as a parameter does not reveal other bed properties.

A large number of parameters need to be determined for adequately characterizing cohesive sediment beds. Even the magnitudes of some of the essential and simple properties such as bed density and erodibility of cohesive sediments cannot be analytically estimated in spite of elaborate laboratory measurement of their fundamental particle properties. Hence, Parchure et al. (2001b) suggested a new terminology for classifying fine sediment beds in order to minimize the time and cost involved in laboratory testing. The method is based on the values of only three basic parameters, namely particle-size distribution, total organic content, and bed density. An innovative protocol is provided for classifying beds of cohesive sediment mixtures into three categories, namely soft, medium and hard to describe their relative erodibility. The approach was used for classifying sediments along the banks of the Mississippi River, which was then used for estimating vessel-induced sediment resuspension in the environmentally sensitive areas (Parchure 2001). This procedure for sediment bed classification is demonstrated in Appendix A.

Fluid Mud

Under tidal conditions in estuaries, the magnitude and direction of flow varies continually. Hence, the time available for the sediment consolidation process is relatively small. Under such conditions a thin and easily erodible layer, usually on the order of a few-centimeters thick, is formed at the surface, which participates in the cyclic process of deposition and resuspension. This thin layer between the water column and firm bed is in the form of fluid mud. The presence of fluid mud makes it difficult to locate the elevation of interface between water column and sediment bed. Fluid mud is defined as a sediment suspension, which has no effective stress (Mehta et al. 1994a.) Under certain combination of flow and sediment properties in the ocean, fluid mud may develop to thickness measuring up to a few meters. Occurrence of fluid mud layer with large thickness is relatively rare and very much site-specific.

Research Results on Bed Formation and Bed Density

Fine sediments settle through water column and form a bed. Unlike coarse sediments, fine sediments are subjected to the process of self-weight consolidation. Hence, whenever a reference is made to the bed density, it needs to be made in the context of time elapsed after the sediment settled to the bed. It is often difficult to determine the exact time when deposition stopped and consolidation began. The consolidation time may extend from a few hours to several months. With long consolidation time, the lower layers tend to reach maximum values of bed density and shear strength, and no significant change occurs in the values with any further lapse of time.

The upper layers of fine sediment beds often have vertically varying properties in terms of bed density and shear strength. The magnitudes are low near the sediment-water interface, and they increase with depth below interface. Hence, the bed density needs to be defined for different layers in natural environment for a realistic representation.

The density parameters include Bulk Wet Density (BWD), Solids Contents (C_S), Moisture Content (w), and Volume Concentration of Solids (C_V). These parameters can be related through relationships involving liquid density (ρ_l) and solid particle densities (ρ_S). If two or more parameters are measured, others can generally be calculated by using the following relationships.

$$BWD = [(C_V)(\rho_S)] + (1 - C_V)(\rho_l) \quad (1)$$

$$(C_S) = (C_V)(\rho_S) \quad (2)$$

$$W = [(\rho_l)(1 - C_V)] / [(C_V)(\rho_S)] \quad (3)$$

If only one parameter is measured, some assumptions must be made in order to convert that into other parameters. One problem with the organic sediments is that the solids density is difficult to estimate. Sediment particle density (ρ_S) is in the range of 2.65 to 2.70 g/cm^3. The wet density of organic matter is often close to 1.0 g/cm^3 and the dry density may be about 1.2 g/cm^3.

Considerable laboratory research has been conducted over the past few decades on the properties of clay minerals and cohesive sediments without any organic contents and their beds. Most of the general properties are also applicable to fine sediments with organic contents. Since findings of this research are relevant to this report, they are listed as follows:

a. Noncohesive sediments undergo compaction to a small extent, but the bulk density of the sediment has no significance in their behavior. On the contrary, cohesive sediments undergo an important process of self-consolidation, which significantly changes their bulk density, moisture content, and the shear strength. The process may continue from a few minutes to several months depending upon several factors related to sediment and fluid. Fine sediment beds are mostly formed from deposition of suspended sediment and subsequent self-weight consolidation. Sill and Elder (1986) have given results of laboratory experiments showing increase in bed density as a function of depth and time. Increase in bed density as a function of time given by Krone (1962) is shown in Figure 1.

b. Bed density of fine sediments increases with depth below sediment-water interface. The depth-variation is substantial for small consolidation times. With longer consolidation time, the bed density over depth gradually becomes uniform. Time and depth variation of bed density profiles given by Owen (1970) are shown in Figure 2. Depth variation of bed density for field sediments from three locations in the United Kingdom is shown in Figure 3 (Thorn and Parsons 1980).

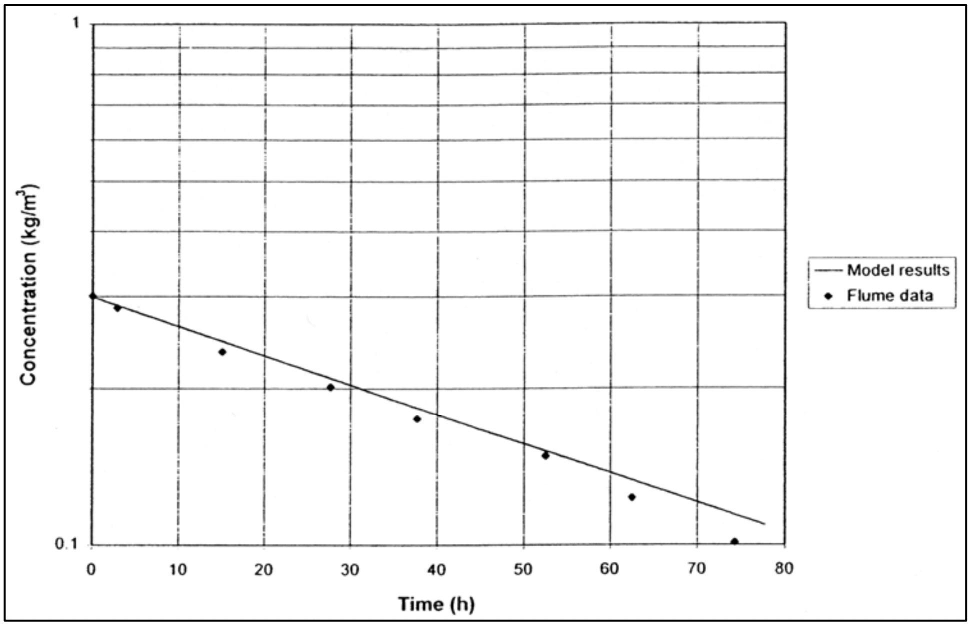


Figure 1. Increase in bed density with time

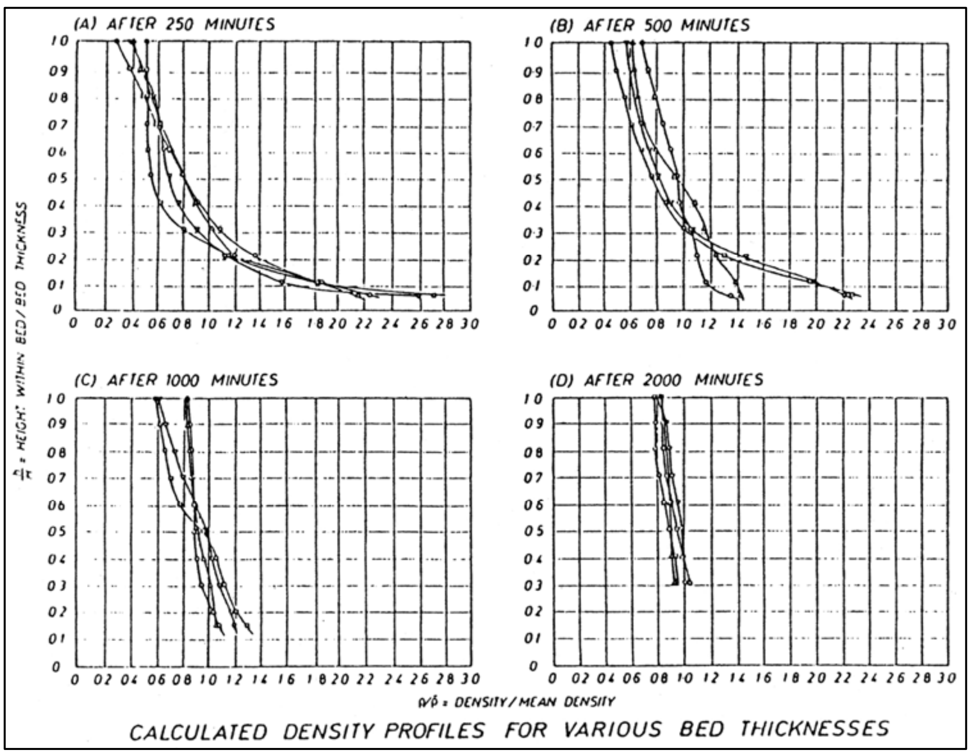


Figure 2. Time and depth variation of bed density profiles

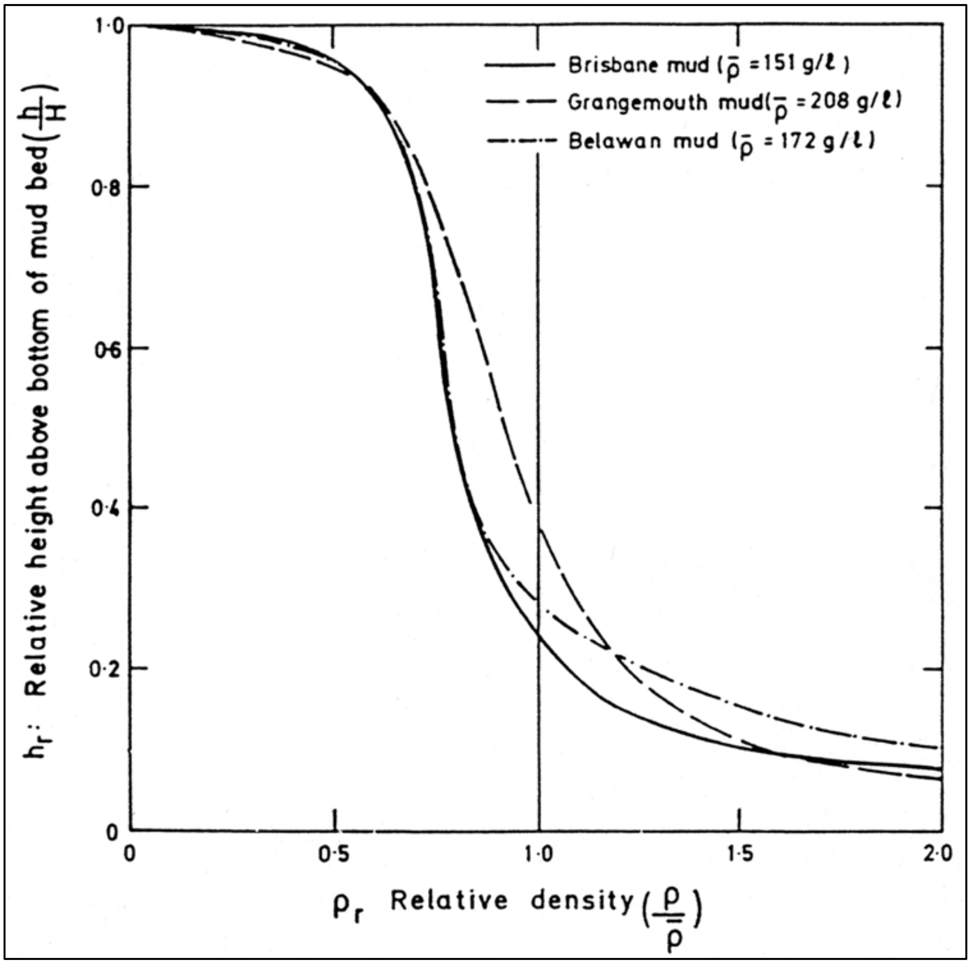


Figure 3. Depth variation of bed density for field sediments

c. A small layer at the sediment water interface often consists of fluid mud. Hwang and Mehta (1989) have reported bulk density of fluid mud layer varying from zero at the interface increasing to 1.002 g/cm^3 at a depth of 11 cm and then increasing to 1.15 g/cm^3 at 20 cm depth (Figure 4).

d. Sediment beds formed due to deposition of suspended sediment are called deposited beds, which develop under quiescent conditions. Fine sediment beds formed under a small fluid-induced shear stress are called flow-deposited beds. Depth variation of bed density for such flow deposited beds measured in laboratory by Parchure (1980) for bed shear stress for deposition values of 0, 0.015 and 0.05 N/m^2 are shown in Figure 5. Depth-variation of bulk density of field sediment given by Hwang (1989) is shown in Figures 6 and 7.

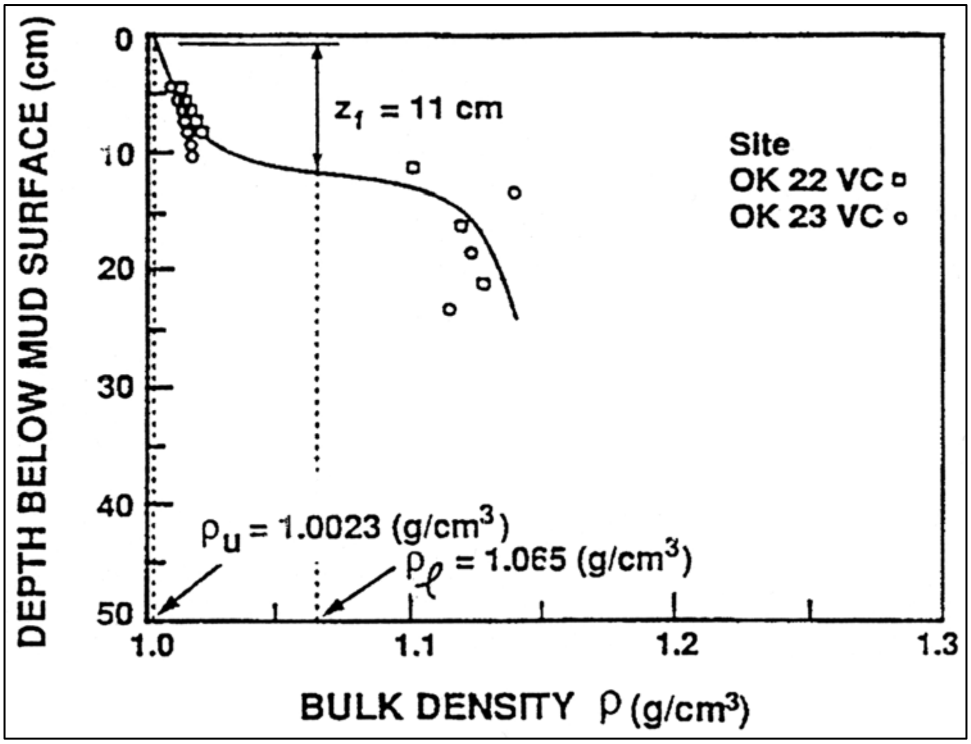


Figure 4. Bulk density profile based on Vibracore data (after Hwang and Mehta 1989)

e. Settling velocity of fine sediment particles is an important parameter in the process of bed formation. The fall velocity of noncohesive sediment particles is a function of particle size, shape, and particle specific gravity. It can be analytically determined by using Stokes Law. Settling flux of fine sediments does not have a constant value. It increases at low values of suspension concentration and then decreases with increasing concentration of suspended sediment due to hindered settling (Figure 8, Hwang and Mehta 1989). This process has significant influence on bed formation.

Research Results on Erodibility and Shear Strength

It is generally observed that compacted cohesive sediment beds have higher density and higher shear strength whereas fluffy cohesive sediment beds have a lower density and lower strength. Several researchers have attempted to correlate bed density to its shear strength.

a. Ockenden and Delo (1991) showed that erosion shear strength of fine sediment beds is correlated to dry density of sediment beds. Correlation of bulk density and shear strength as a function of depth below sediment-water interface measured by Hwang (1989) for Lake Okeechobee, FL is given in Figure 9.

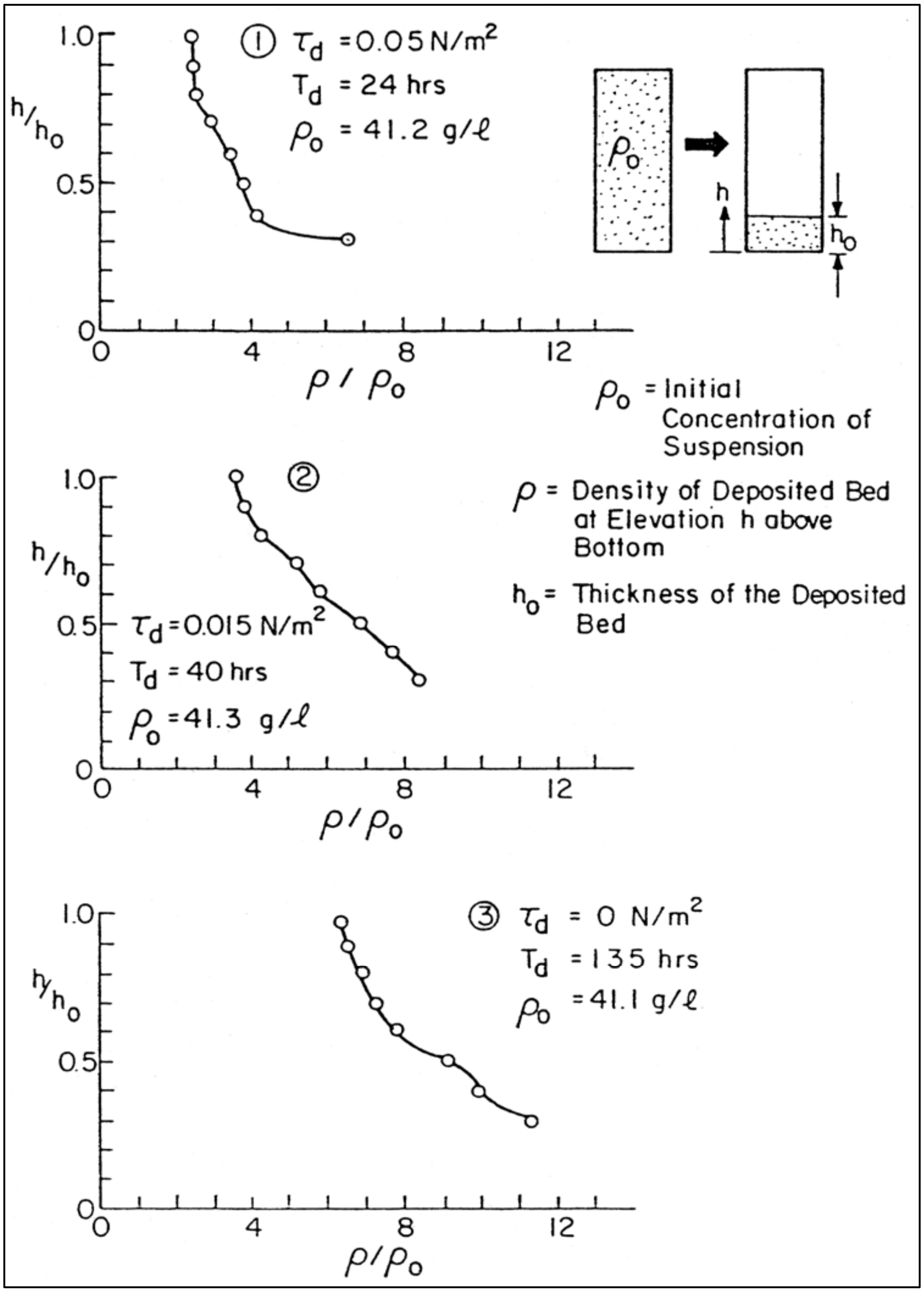


Figure 5. Depth variation of bed density for flow-deposited beds

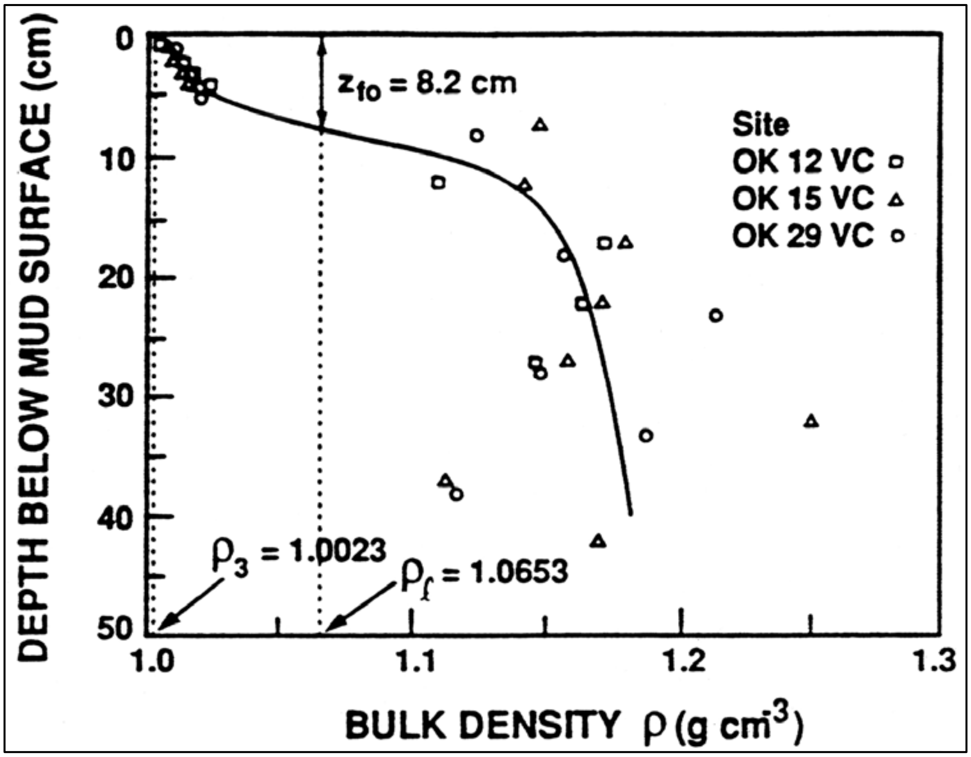


Figure 6. Depth variation of bulk density for Lake Okeechobee (type 3)

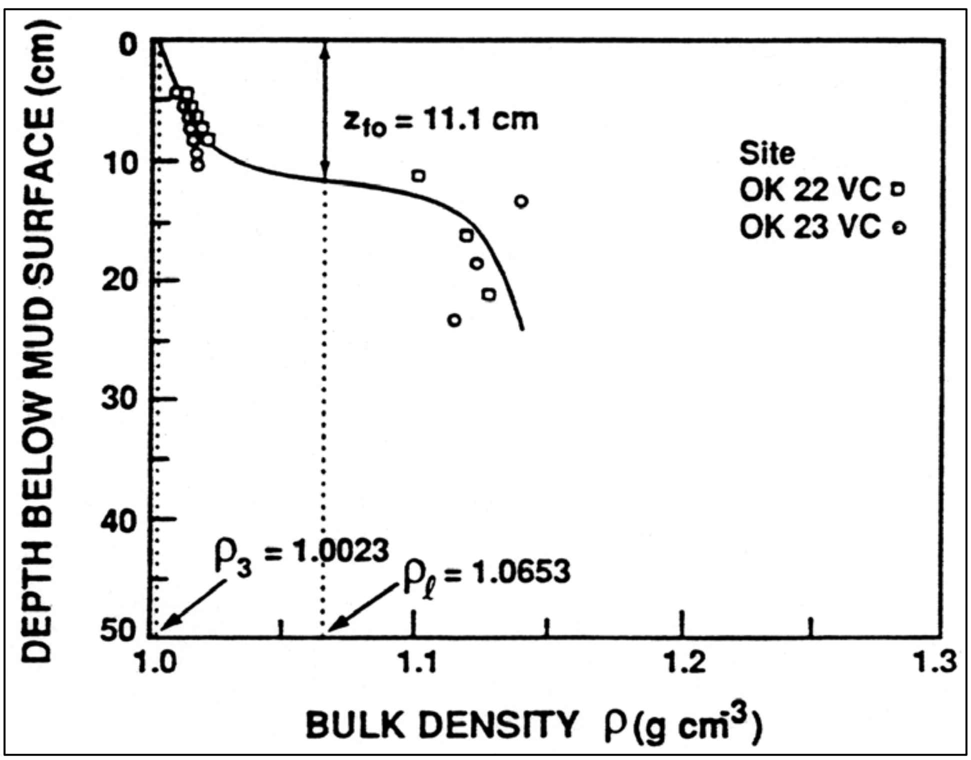


Figure 7. Depth variation of bulk density for Lake Okeechobee (type 4)

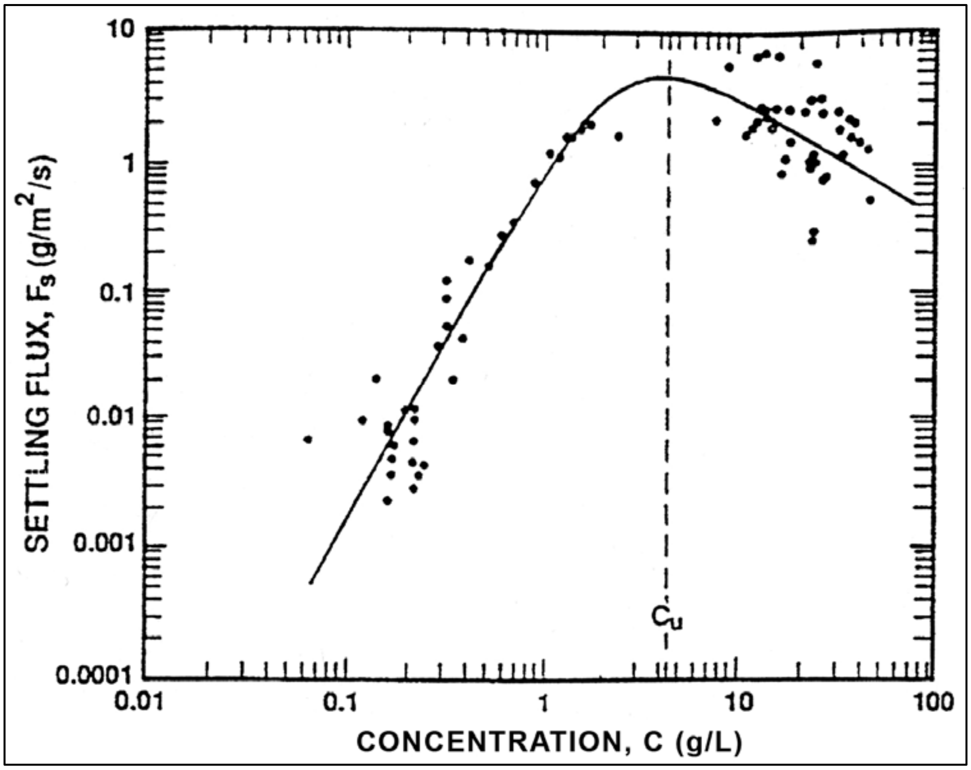


Figure 8. Sediment settling flux as a function of sediment concentration

b. Erosion shear strength of fine sediment beds is correlated to bulk density of sediment beds (Figure 10, Thorn and Parsons 1980.)

c. Bed shear strength of recently deposited cohesive sediment beds increases with depth below the sediment water interface. For short consolidation time, the bed structure has substantial variation in shear strength over depth. With increasing consolidation time, the bed structure becomes more uniform with depth. The vertical density structure modifies with time from nonuniform to uniform as consolidation occurs (Figure 11, Parchure 1980).

d. Nonuniform beds of cohesive sediment are formed by deposition of suspended sediment. Such beds have varying shear strength over its depth. The beds that are initially nonuniform tend to become uniform beds under self-weight consolidation. Erosion rate of nonuniform beds decreases with time because deeper layers have greater shear strength. Erosion rate of uniform beds is constant with time (Figure 12, Parchure 1980). In this figure, measured suspended sediment concentration resulting from bed erosion is used to represent erosion rate as a function of time. Erosion rate is decreasing with time for the bed with a low consolidation time of 1 day. Erosion rate is constant for the bed with a consolidation time of 8 days.

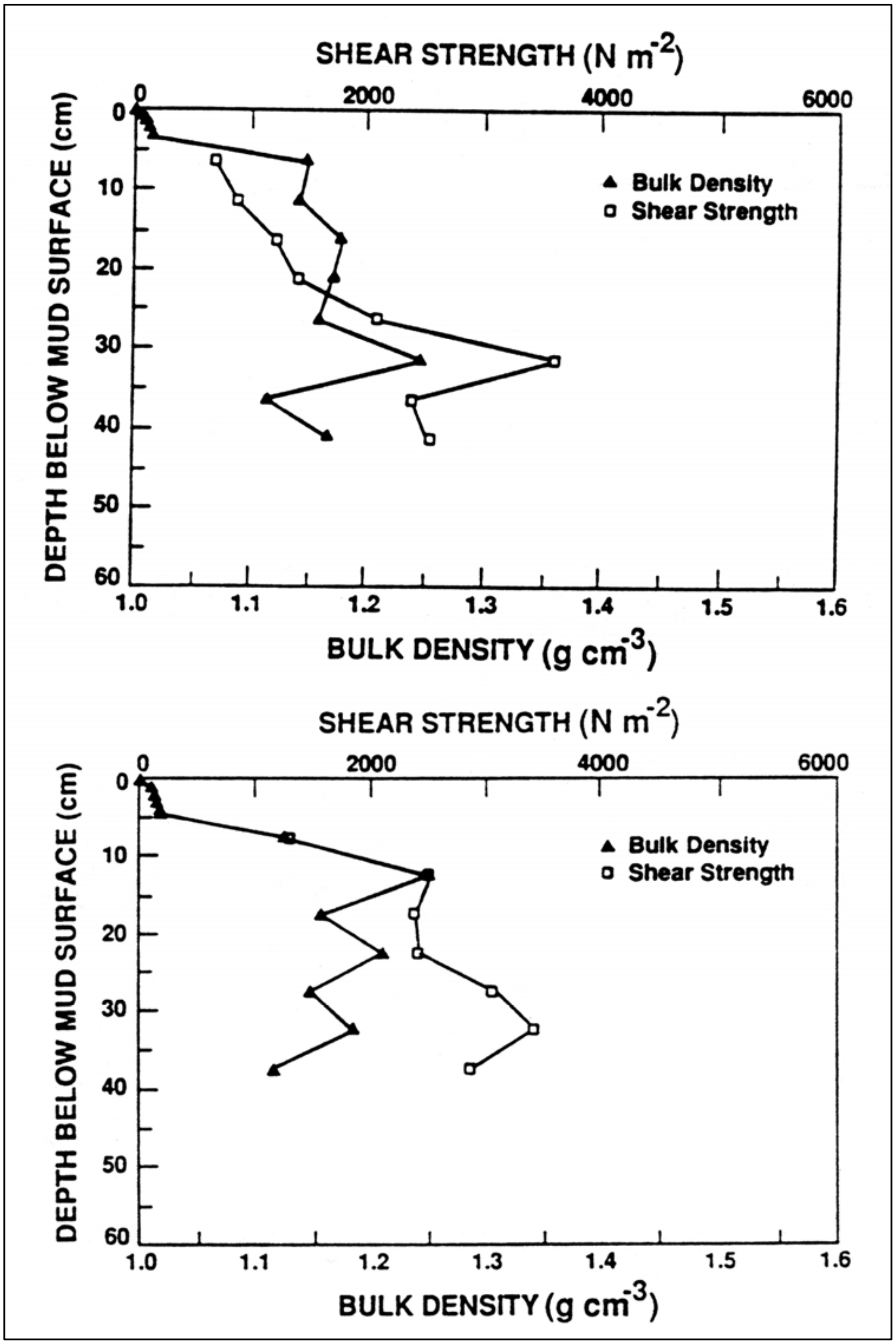


Figure 9. Correlation of shear strength with bed density as a function of depth

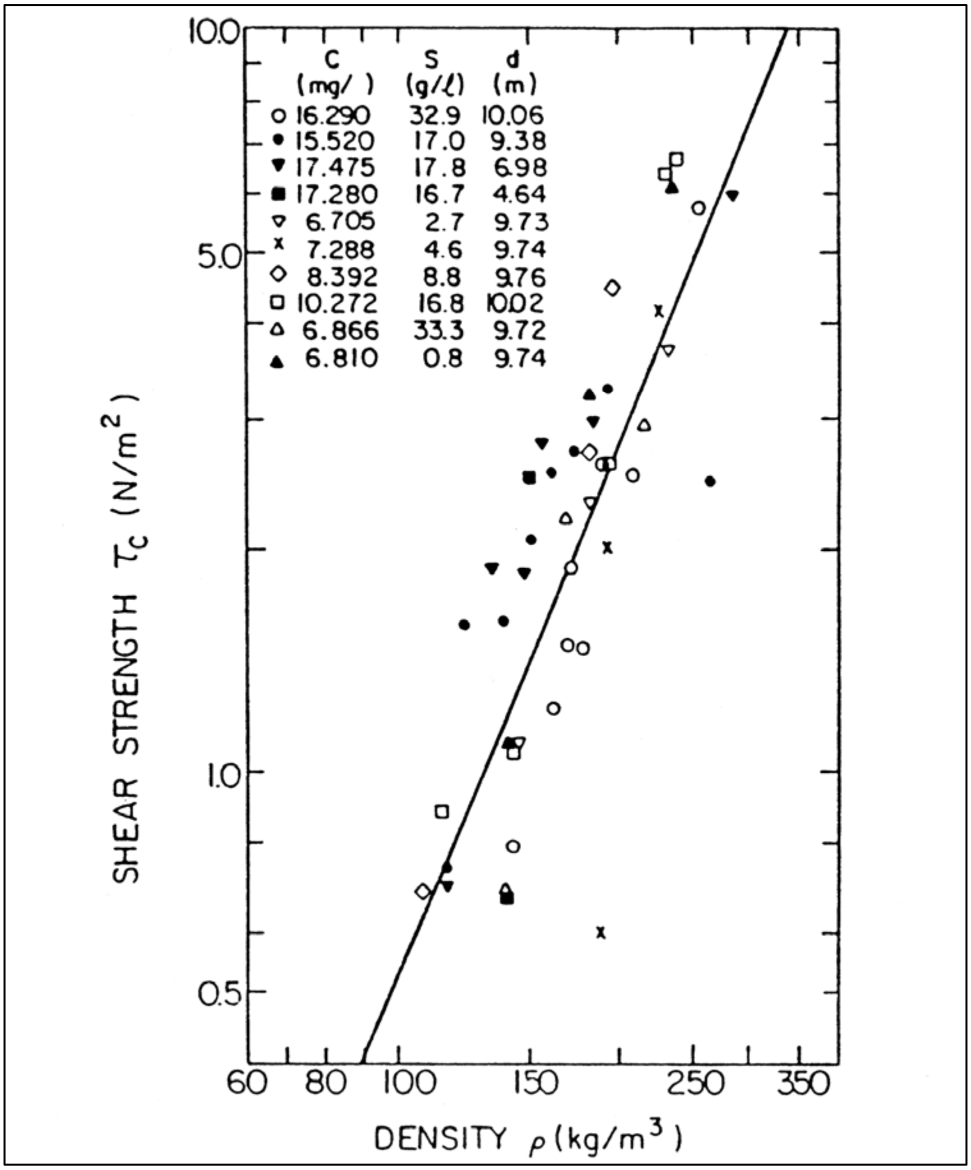


Figure 10. Correlation of shear strength of clay beds with bed density

e. A commonly used form of erosion equation is:

$$E = M\left(\frac{\tau_b - \tau_e}{\tau_e}\right) \tag{4}$$

In this equation E is the erosion rate, M is the erosion rate constant, τ_b is the bed shear stress, and τ_e is the critical shear stress for erosion. The erosion rate constant as well as the critical shear stress for erosion needs to be determined by laboratory experiments for cohesive sediments. However, attempts have been made to establish correlations for these parameters. Mehta (1991) showed that erosion rate coefficient decreases with increasing bulk density (Figure 13.) Lee and Mehta (1994) have shown that the erosion rate constant decreases with bed shear strength (Figure 14.)

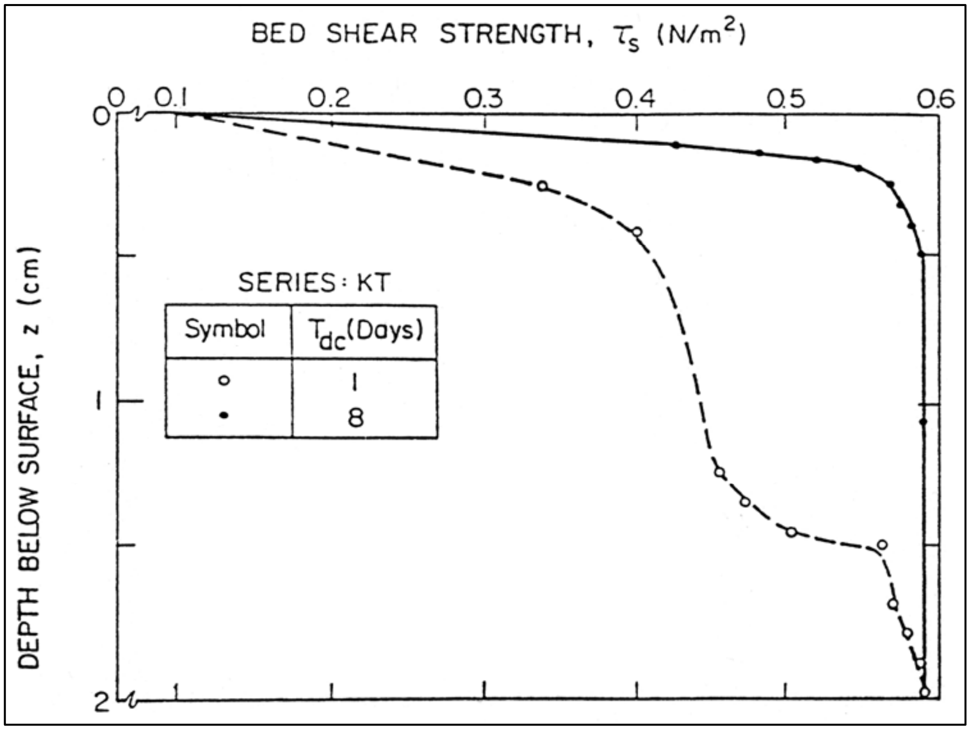


Figure 11. Effect of self-weight consolidation on depth variation of bed shear strength

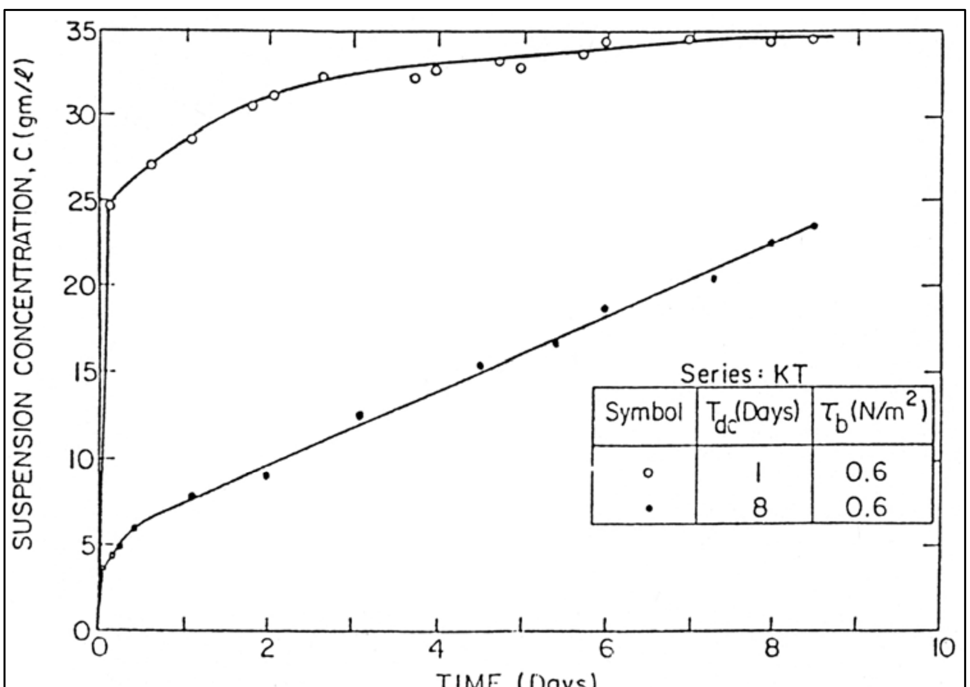


Figure 12. Effect of self-weight consolidation on erosion rate

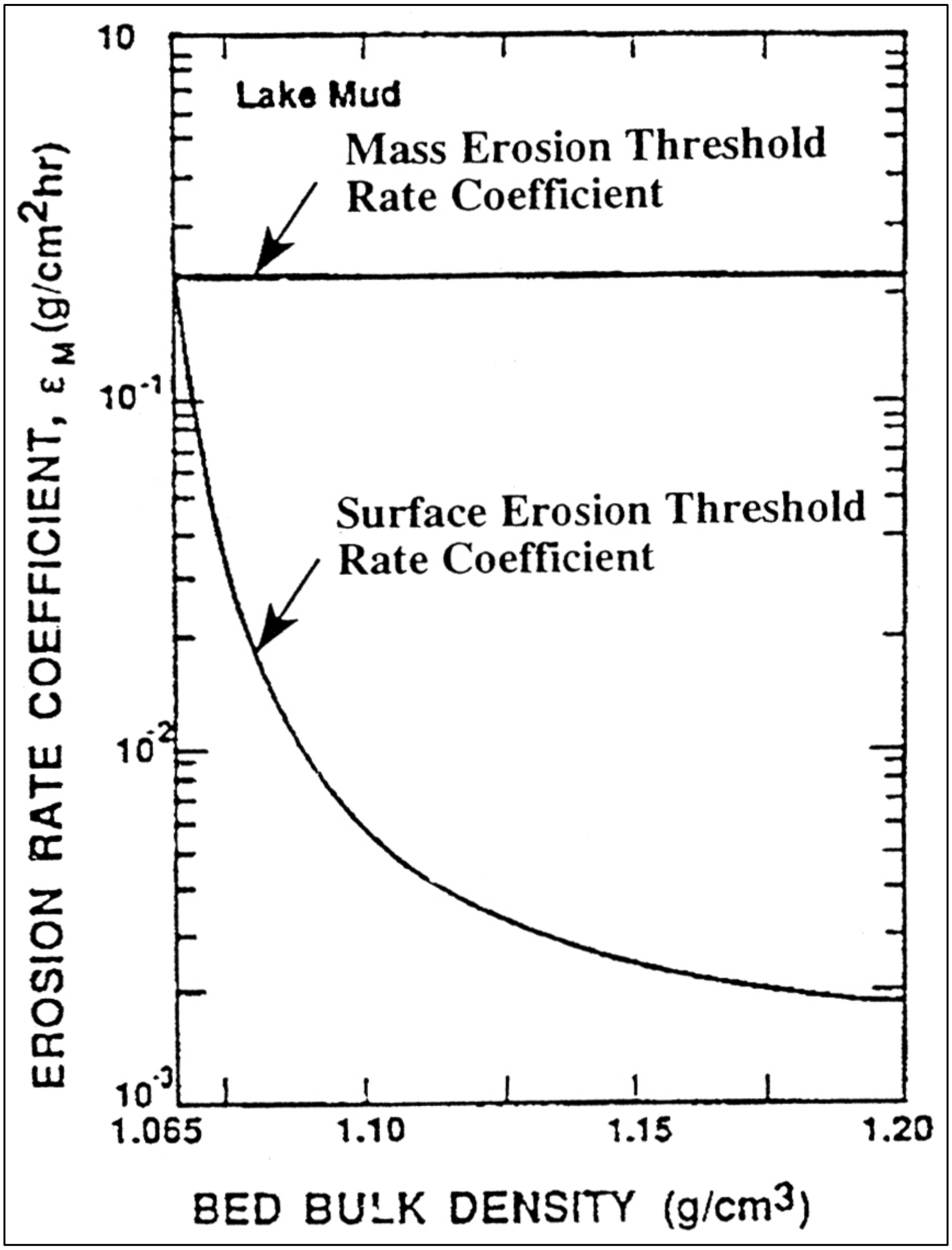


Figure 13. Variation of erosion rate coefficient with bed density

f. Vane shear strength of fine sediment beds increases with bulk density (Figure 15, Hwang and Mehta 1989).

g. Parchure (1980) showed from laboratory measurements that shear strength of flow-deposited Kaolinite beds increases with depth (Figure 16.)

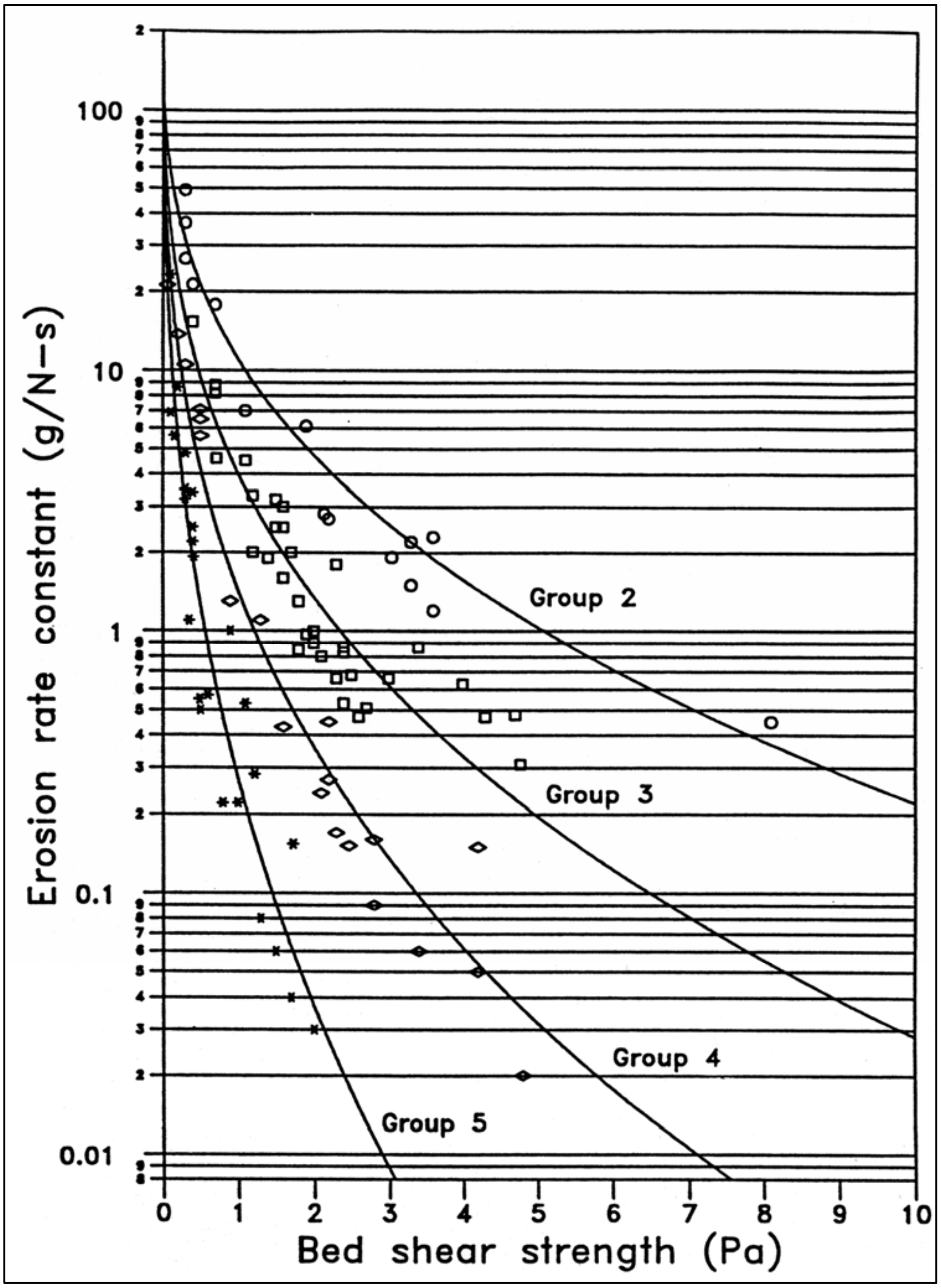


Figure 14. Erosion rate constant related to bed shear strength

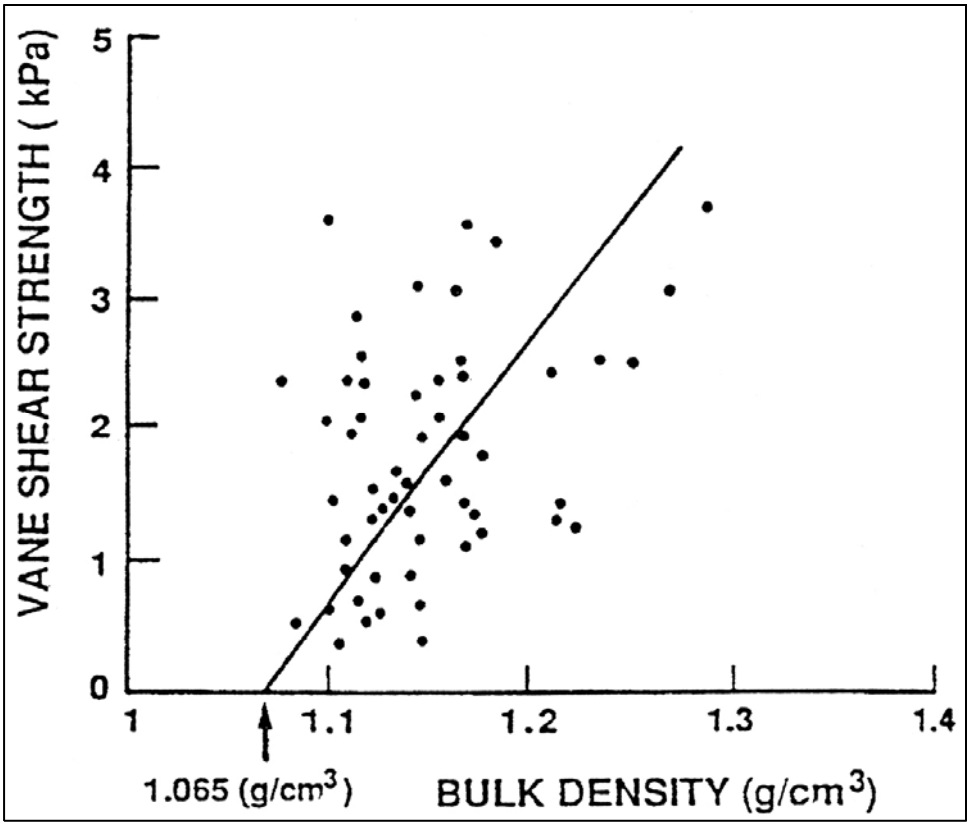


Figure 15. Vane shear strength versus bed density

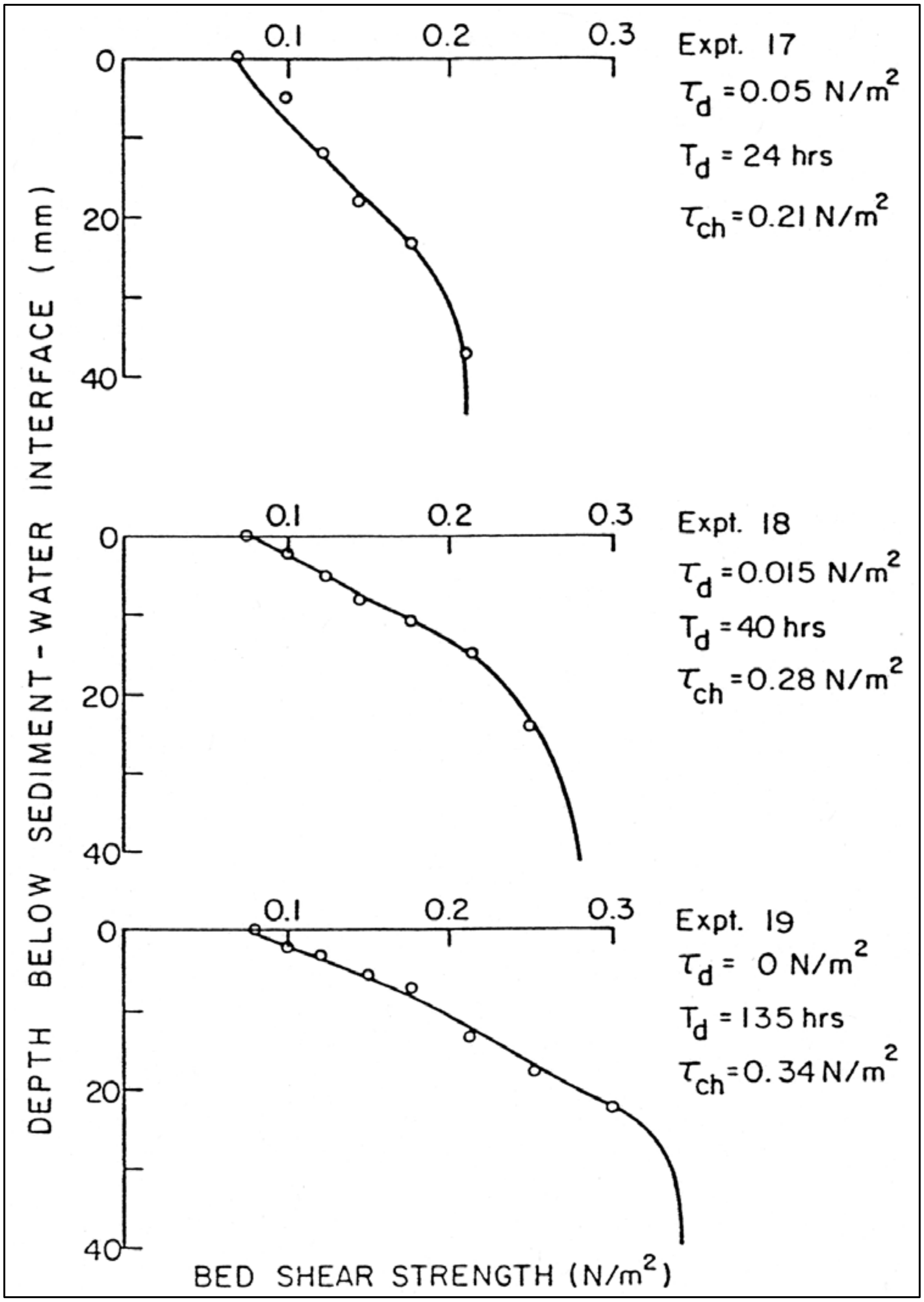


Figure 16. Bed density variation over depth for flow-deposited beds

4 Organic Fine-Grained Sediments

Occurrence

Several organic substances are found in natural sediments. They include bacteria, diatoms, leaves, roots, dead animals, macroscopic and microscopic vegetation, industrial organic compounds, etc. Due to the electro-chemical properties of cohesive sediments, organics are attached to the fine sediment particles. Therefore they are often found with sediments that have a substantial percent of fine sediments such as in estuaries, lakes, wetlands, harbors, marinas and navigation channels. The organic component contained in noncohesive sediment gets washed away with natural forces of currents and waves. Hence, coastal shorelines mostly have sand and coarse sediments that generally do not contain any appreciable organic matter.

Characterization

The routine sediment analysis includes determination of the total organic matter as a percentage of the sediment weight. The procedure involves complete burning of the organic matter and is referred to as the Loss on Ignition (LOI); however, LOI is not always a reliable measurement of total organic matter. Some sediments may include calcium carbonate, which get burnt and add to the loss in weight after ignition. Some organisms contain appreciable ash weight. Hence, LOI results offer only an approximate quantity of organic matter present in sediment. The results are useful in a comparative sense for a specific system.

Other parameters used for characterizing organic contents include the following:

a. Total Organic Carbon (TOC)

b. Total Organic Nitrogen (TON)

c. Total Carbohydrate Contents

Literature

Organic-rich cohesive sediment is a relatively recent topic of research. Hence, only limited information is available in published literature. Major sources of information are listed as follows:

a. Mehta et al. (1997) have given the most extensive treatment on the erodibility of organic-rich sediments collected at various sites in Florida.

b. Mehta, A. J. (2002) has given compilation of studies on erosion and settling of organic-rich sediment from Newnans Lake and other water bodies in Florida.

c. Hwang, K. N., and Mehta, A. J. (1989) have described fine sediment erodibility studies for sediment in Lake Okeechobee.

Research Results

The findings of laboratory and field measurements reported in literature are briefly summarized in this chapter. Emphasis is given on information related to bed density and erodibility of fine sediments containing organic matter.

Gowland and Mehta (2002) measured properties of organic sediment from Newnan's Lake, FL. The amount of organic content varied from 10 percent to 60 percent. It was reported that both the erosion rate and the erosion rate constant are significantly affected by the amount of organic content. Figure 17 (Mehta 2002) shows that for a shear stress of 0.2 Pa, the erosion rate changed from 0.04 $g/m^2/s$ to 0.3 $g/m^2/s$ and the erosion rate constant changed from 0.45 g/N-s to 2.06 g/N-s when the organic contents changed from 10 percent to 60 percent.

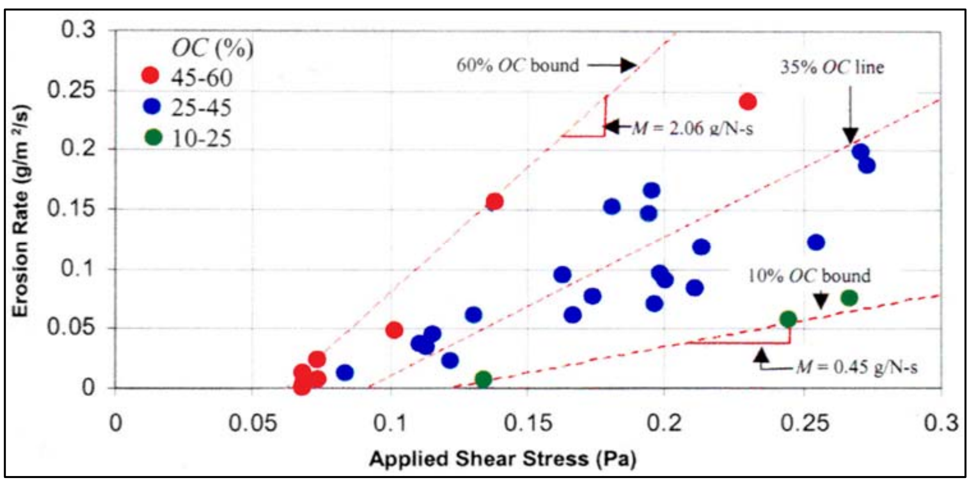


Figure 17. Erosion rate versus shear stress showing dependence on organic content

Organic sediment particulates often have a specific gravity lower than that of sand. Therefore, mixtures of natural sediments and organic substances found in natural water bodies show a lower density. Higher percentages of organics resulting in lower particle density measured for Rodman Reservoir, FL is shown in Figure 18 (Mehta 2002.) At zero organic contents, the particle density is 2,700 kg/m^3 corresponding to sand whereas it dropped to 1,400 kg/m^3 when organic content increased to 75 percent.

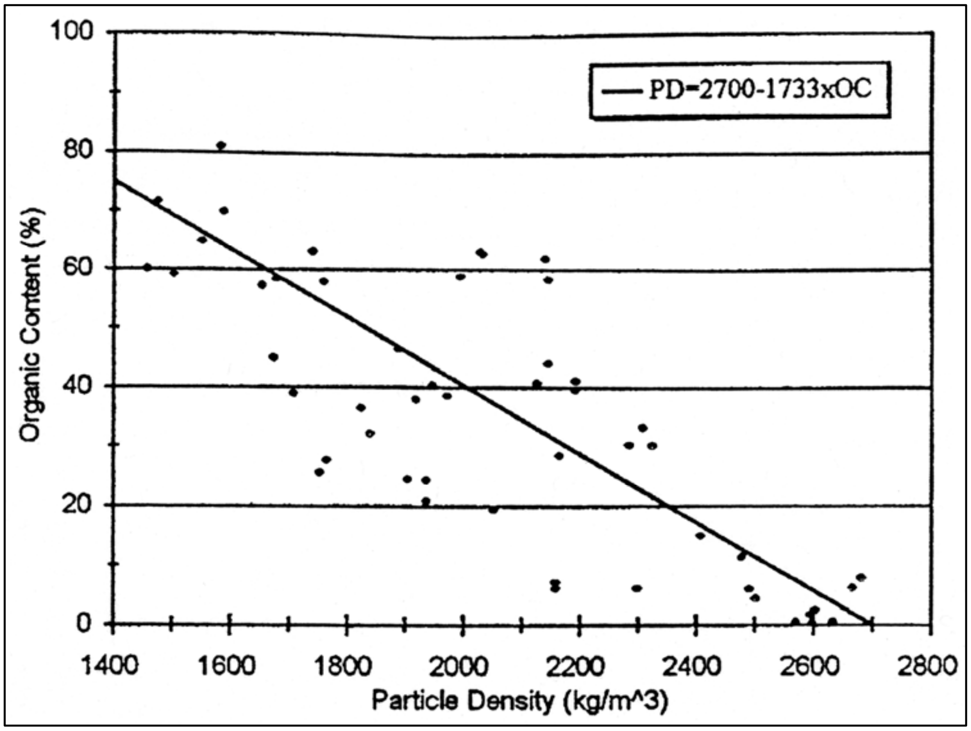


Figure 18. Sediment density variations with organic content

Noncohesive sediment properties are not affected by water because they do not adsorb water. Organic substances retain substantial amount of water. Hence, the particle (or granular) density, bulk density and dry density of organic-rich cohesive sediment mixtures are highly dependent on the amount of organic matter. Figure 19 shows measurements reported by Gowland and Mehta (2002). A small amount such as 5 percent by weight of organic content, the bulk density reduced to 1,700 kg/m^3 and dry density reduced to 1,200 kg/m^3. The value of all the three densities at zero organic matter is 2,600 kg/m^3. With 30 percent organic matter the values drop down to 2200, 1100, and 200 kg/m^3 respectively for the particle, bulk, and dry density.

Hwang (1989) measured settling velocity of organic-rich sediments as a function of suspension concentration for sediment collected at five sites in Lake Okeechobee, FL. The results are shown in Figure 20 for sites 3 and 6, and in Figure 21 for sites 2, 4, and 5. The median diameter varied between 0.3 and 24 μ. The organic contents varied between 36 and 41 percent.

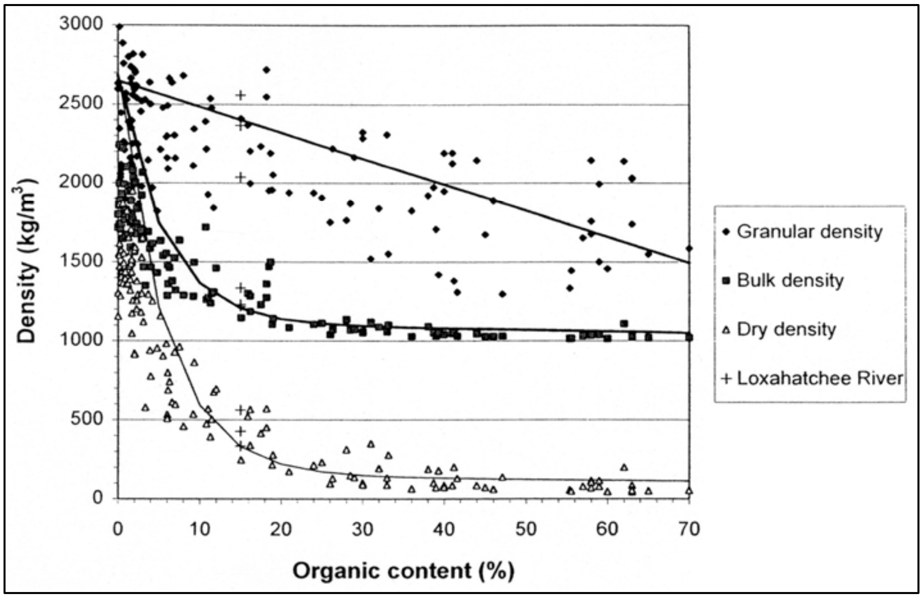


Figure 19. Effect of organic content on particle, dry and bulk density

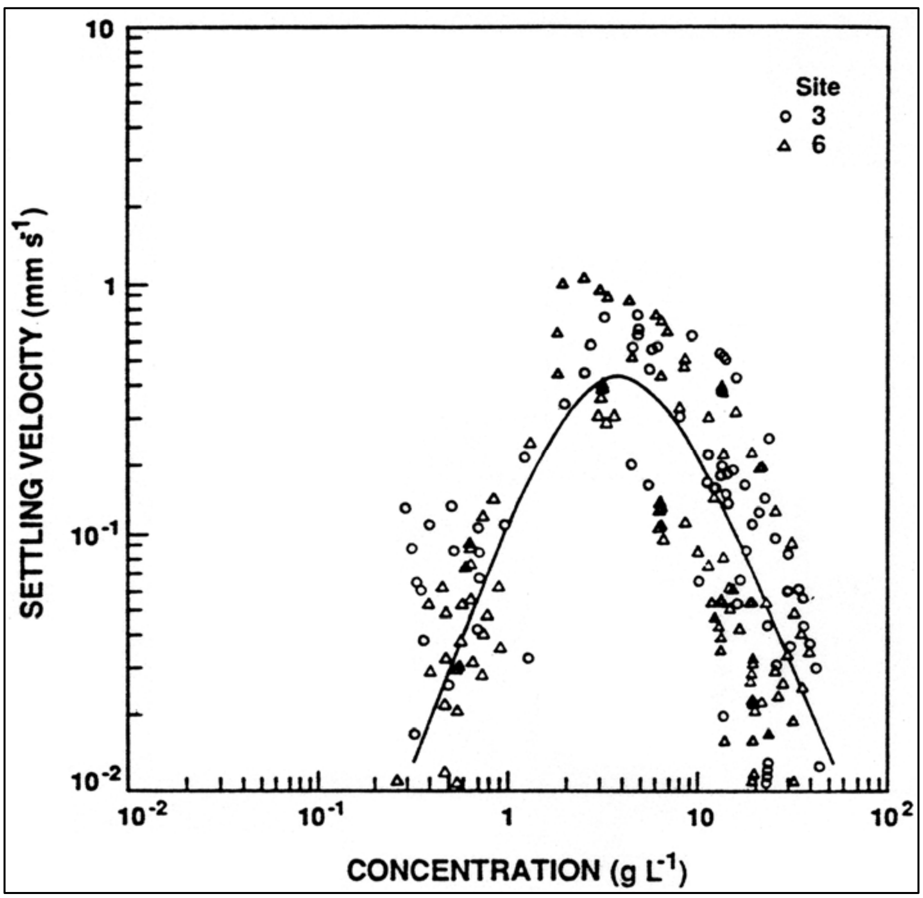


Figure 20. Settling velocity versus suspension concentration for sites 3 and 6 at Okeechobee

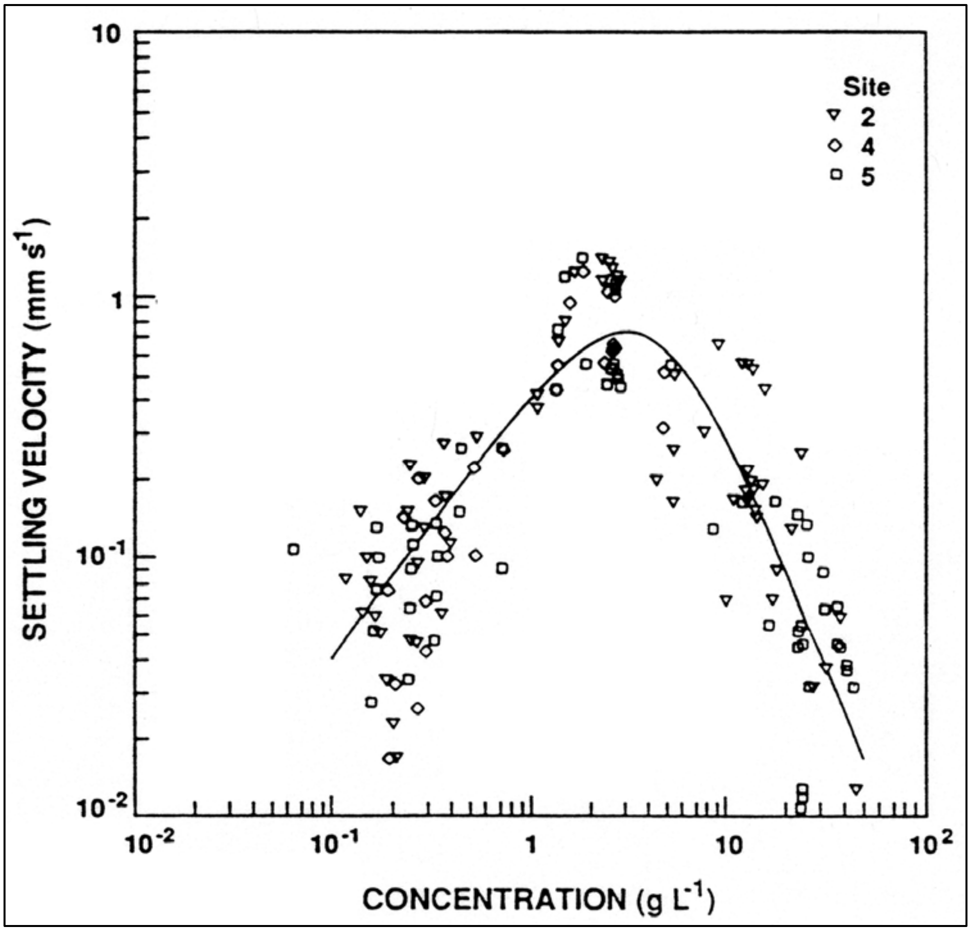


Figure 21. Settling velocity versus suspension concentration for sites 2, 4, 5 at Okeechobee

5 Project Data

Introduction

Sediment studies for real-life projects may have one or multiple objectives. The type and amount of data needed and the methods to be used for solving the problem depend upon the objective of sediment study. The most common objectives are as follows:

a. Prediction of change in shoaling in harbors and navigation channels resulting from project modification. For instance, Teeter and Pankow (1989) conducted schematic numerical modeling of harbor deepening effects on sedimentation at Charleston Harbor, SC. Another example is a desktop study conducted for estimating future shoaling rates for navigation channel deepening at Corpus Christi Project (Parchure et al. 2001a) and for the La Quinta Project (Parchure et al. 2002a).

b. Estimation of current and future rates of shoreline erosion.

c. Estimating the effect of implementing a new project on the erosion of an estuarine bank.

d. Design of sediment traps (Parchure et al. 2002b; Ganju 2001).

e. Design of shoreline protection structures.

f. Reduce or eliminate sediment shoaling from areas of interest.

g. Estimation of sediment resuspension caused by vessel-induced waves (Parchure et al. 2001b).

h. Effect of sediment resuspension on water quality (Parchure et al. 1996).

Such studies often include analytical methods, desktop study or numerical model investigations. Data on sediment properties at the site are essential for all the sediment studies. In addition, past dredging records are needed for navigation channel shoaling studies. When sediment and other data are not readily available, it is necessary to measure field parameters prevailing at the site, collect sediment samples, and conduct sediment characterization study in a laboratory. Determination of all the parameters is expensive and time-consuming, and data on all the parameters may not be necessary. Although selection of parameters depends on the type of problem, data on at least the important sediment properties are essential because they predominantly determine the sediment behavior related to erosion, deposition, and transport. Hence, a few important parameters are selected to characterize sediment processes. Sediment properties are measured and reported through several parameters.

CHL has been collecting bed sediment samples from many projects over the past several years as a part of field data. The number of samples collected and the type of analysis depends upon the site conditions (estuary, coast, river), type of study (numerical, analytical, desktop), funding available, size and importance of project, and objectives of study. Hence, all the sediment-related parameters may not be measured for every project. The sediments are generally analyzed to determine one or more of the following parameters, namely percent silt plus clay, particle-size distribution, total organic matter, and moisture content / bulk density. Erosional and depositional rates of noncohesive sediments can be determined analytically from their primary properties such as grain size, shape and density. However, physical, chemical and electrical properties of fine sediment are much more complex and involve a large number of parameters. Hence, their erosional and depositional characteristics must be determined by conducting laboratory experiments.

Significance of Parameters

Percent silt plus clay

This gives the total percentage of sand and the total percentage of the combined fraction of silt plus clay. Silt is defined as the sediment finer than 64 μ and coarser than 4 μ. Clays are defined as particles finer than 4 μ. The sand-silt split is determined by wet sieving through a 64-μ mesh sieve. From this fraction, percentage of clay needs to be determined separately, if needed, by using laser particle-size analyzer. The results of analysis provide the relative presence of coarse and fine fractions in a given sediment sample. Properties and sedimentary processes of coarse and fine sediments are significantly different. Sediments at any natural project site invariably consist of mixture of both types of sediments. It is therefore essential to know the predominance of the type of sediment for predicting their behavior.

Dispersed grain-size distribution parameters

Organic particles not only have a density different from the density of sediment particles, they also have different particle-size range. Therefore, it becomes necessary to remove all organic particles before determining dispersed grain-size distribution of sediments, particularly when the percentage of organic material in a sample is high. Particle-size distribution parameters such as median diameter (d_{50}) and geometric mean diameter are commonly used to represent the range of particle sizes by one value. Sometimes standard deviation and skewness have been determined on dispersed sediment samples for additional statistical analysis.

Total organic matter

Organic matter in natural sediments is derived from several sources. The nature and extent of effect caused by each type of organic matter is not yet understood and documented. The current practice consists of determining the total quantity of organic matter in sediment samples without trying to distinguish the origin of contents. The laboratory method used to determine this is called the loss on ignition (LOI) method. It consists of first removing the soil moisture and then burning the organic matter at a high temperature in a furnace. Organic matter is known to have significant influence on the properties of fine sediments. Hence, the total amount of organic matter expressed as the percentage of the total weight of sediment sample provides a qualitative indication of the extent of influence of organic matter.

Moisture content and bulk density

These parameters are significant only for the cohesive sediments. Moisture content in sediment samples is determined by using the evaporation method. Bulk wet density of samples can be either measured by using a Pycnometer or it can be calculated from the moisture content data.

Project Information

The results of laboratory determination of sediment-related parameters on selected projects are presented in the following pages. These provide useful information on the range of these parameters at various project sites. They provide values of parameters, which have been used in making calculations or running numerical models for the problem under consideration. Such information is not readily and collectively available elsewhere in the literature.

Project 1: Fluid mud at Sabine Neches Project, TX

Occurrence of fluid mud has been reported over a short reach of the outer navigation channel in the ocean (Figure 22) at the Sabine Neches Project, TX. Sediment samples from this reach have been collected and analyzed; however, the reasons for fluid mud formation at that particular location have not been investigated. The results of sediment analysis are given in Table 1. It may be noted that the fluid mud density varied from 1.053 to 1.233 g/cu cm.

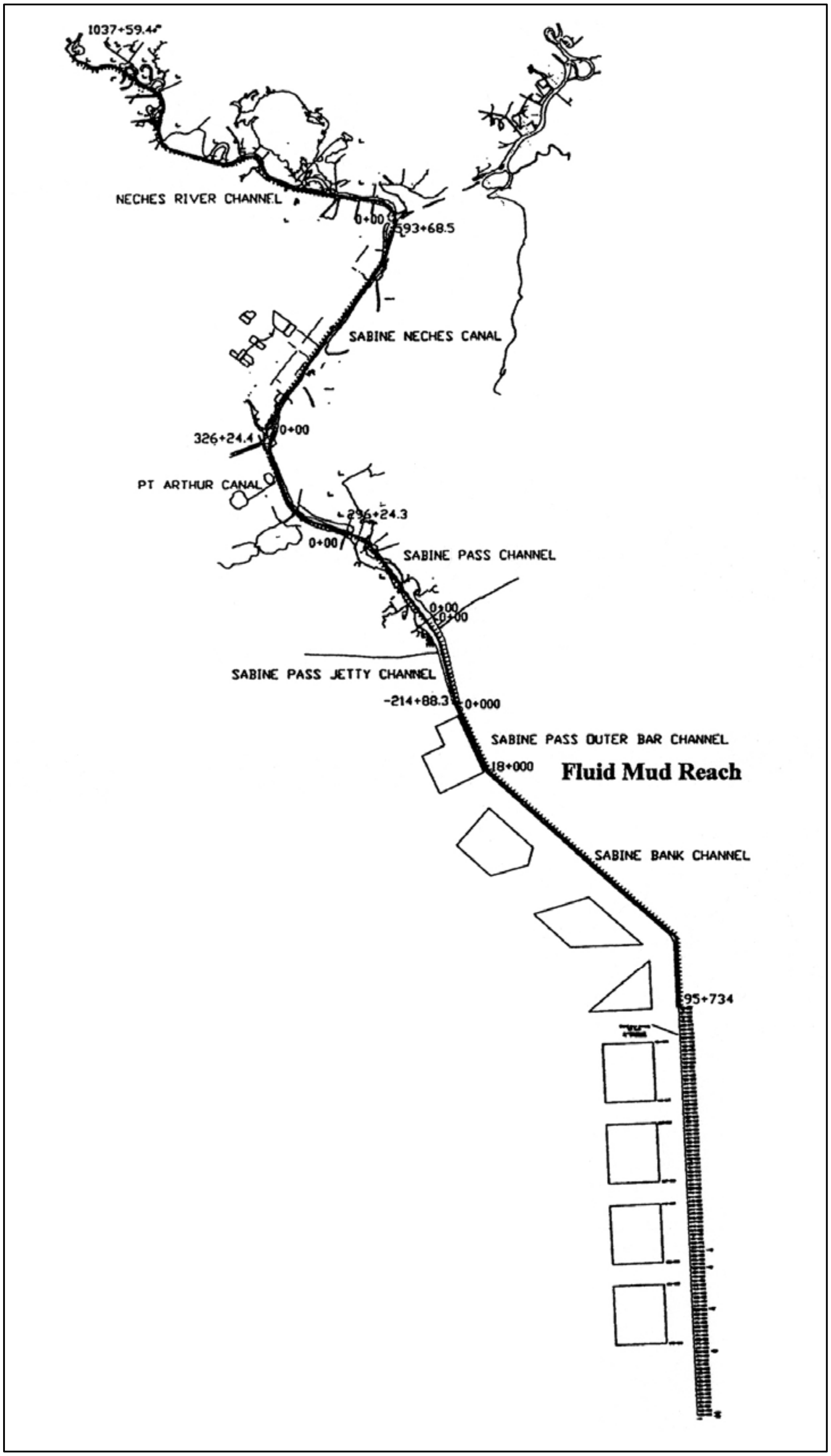


Figure 22. Fluid mud reach at Sabine Neches Project, TX

Table 1
Results of Fluid Mud Survey at Sabine Neches Project (1992 Data)

Line	Station	Depth Index	Fluid Mud Density, g/cu cm
3	1	C	1.164
3	1	D	1.110
3	11	A	1.095
3	11	B	1.097
3	11	C	1.128
3	11	D	1.127
3	21	B	1.098
3	21	C	1.151
3	21	D	1.175
3	31	A	1.087
3	31	B	1.118
3	31	D	1.196
3	41	D	1.123
5	1	D	1.171
5	11	A	1.148
5	11	B	1.482
5	11	C	1.175
5	21	B	1.114
5	21	C	1.125
5	21	D	1.233
5	41	D	1.187
7	1	B	1.073
7	1	C	1.163
7	1	D	1.205
7	11	D	1.180
7	21	C	1.072
7	21	D	1.149
7	31	C	1.116
2	1	D	1.171
2	2	D	1.110
2	3	D	1.188
2	4	D	1.171
2	5	D	1.167
4	1	C	1.095
4	1	D	1.177
4	2	A	1.098
4	2	B	1.183
4	2	C	1.196
4	2	D	1.172
4	3	B	1.063
4	3	C	1.097
4	3	D	1.121
4	4	B	1.115
4	4	C	1.117
4	4	D	1.073
4	5	D	1.178
4	1	D	1.167
4	1	C	1.053

Note: A, B, C, and D are notations used for elevation of sediment sample above bed.

Project 2: Navigation channel at Sabine Neches Project, TX

The navigation channel at the Sabine Neches Project is traditionally divided into seven reaches for reporting dredging quantities. These seven reaches are shown in Figure 23. Bed samples from the field were collected from these reaches along the navigation channel and also along the shoreline of Pleasure Island. Two samples were collected at each location, one above the waterline (T) and the other below the waterline (B). All the locations are shown in Figure 24. Pleasure Island locations are marked with a prefix P. All the bed sediment samples were analyzed for determining the sand-silt split, percent organic matter, and moisture content (Parchure et al., in preparation). The results of bed sample analysis are presented in Table 2 for these seven reaches. Table 3 gives the average percentages of sand, silt plus clay and percent organic matter in bed sediment in each reach. The amount of organic contents changes the moisture content and bulk bed density of natural sediments. The percent organic content versus moisture content is plotted in Figure 25 for the sediment samples collected at Sabine Neches project. It is noted that the moisture content generally increases with increasing percent of organic matter. Very high moisture content measured in a few samples may be due to ambient water entering the bed sample and, hence, may not be representative of the actual site conditions. The specific gravity of organic substances is lower than that of sediments. Lower specific gravity together with increased moisture content results in decreased bulk density with increased percentage of organic matter in natural sediments.

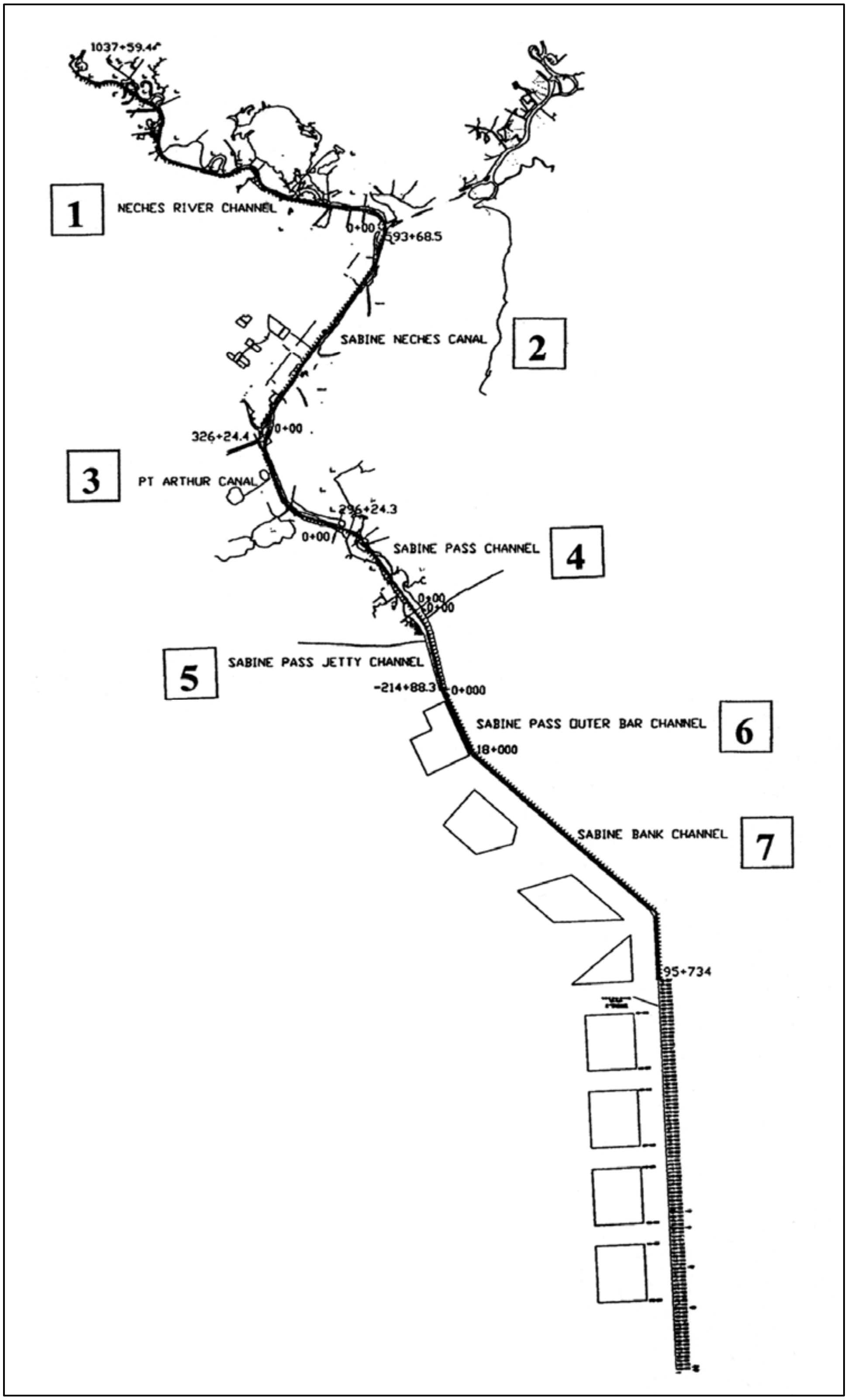


Figure 23. Seven reaches at Sabine Neches Project, TX

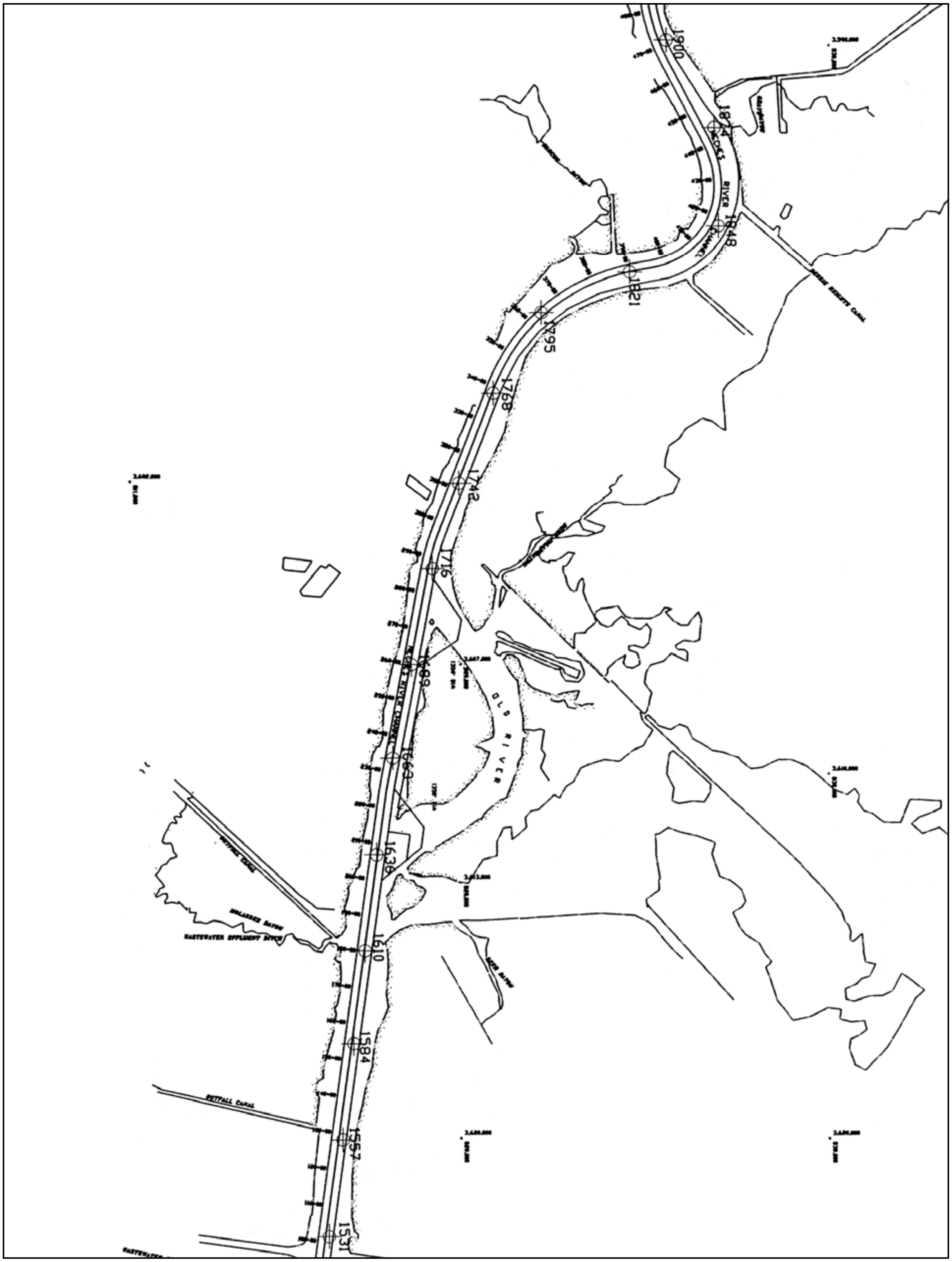


Figure 24. Locations of bed samples at Sabine Neches Project (Sheet 1 of 9)

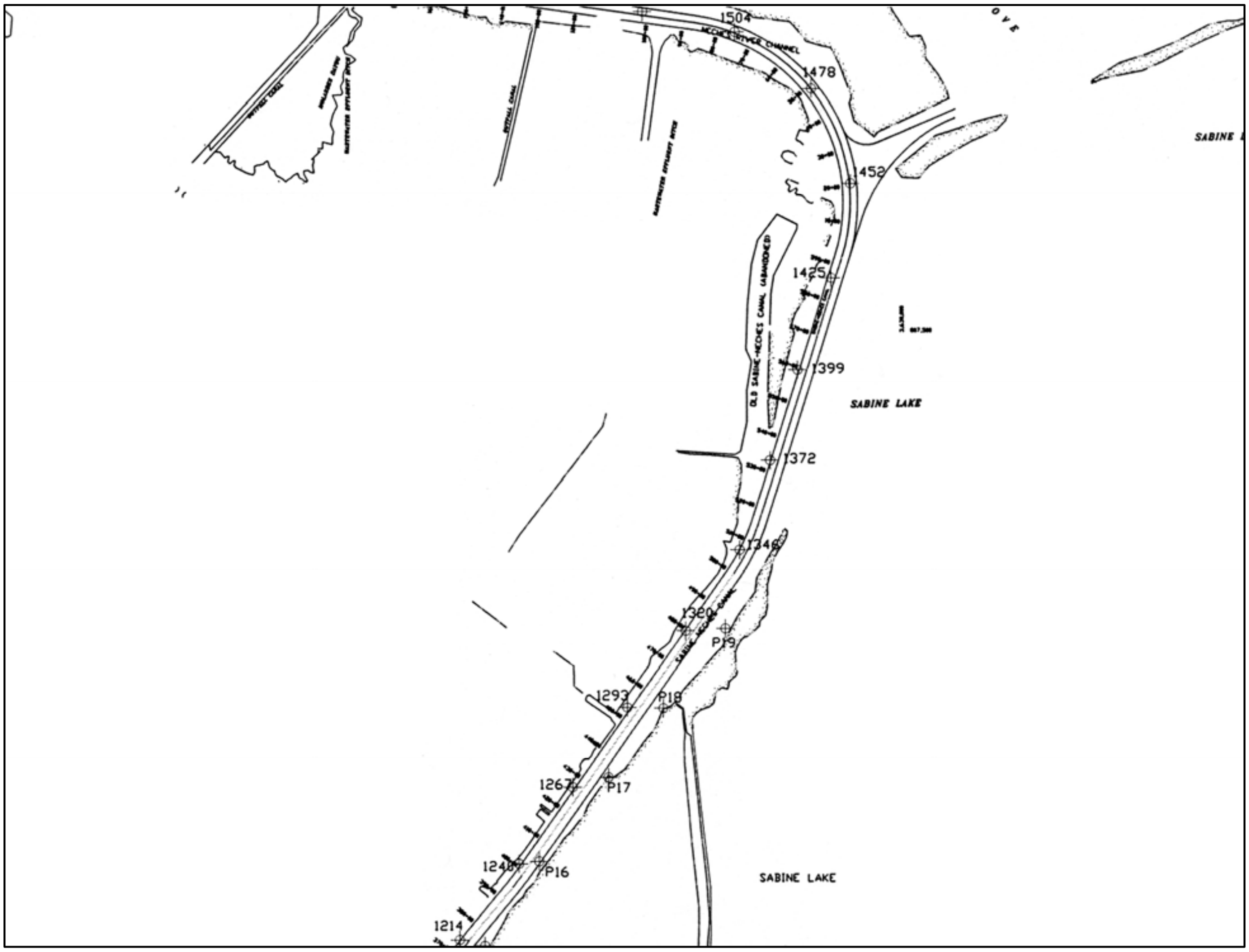


Figure 24. (Sheet 2 of 9)

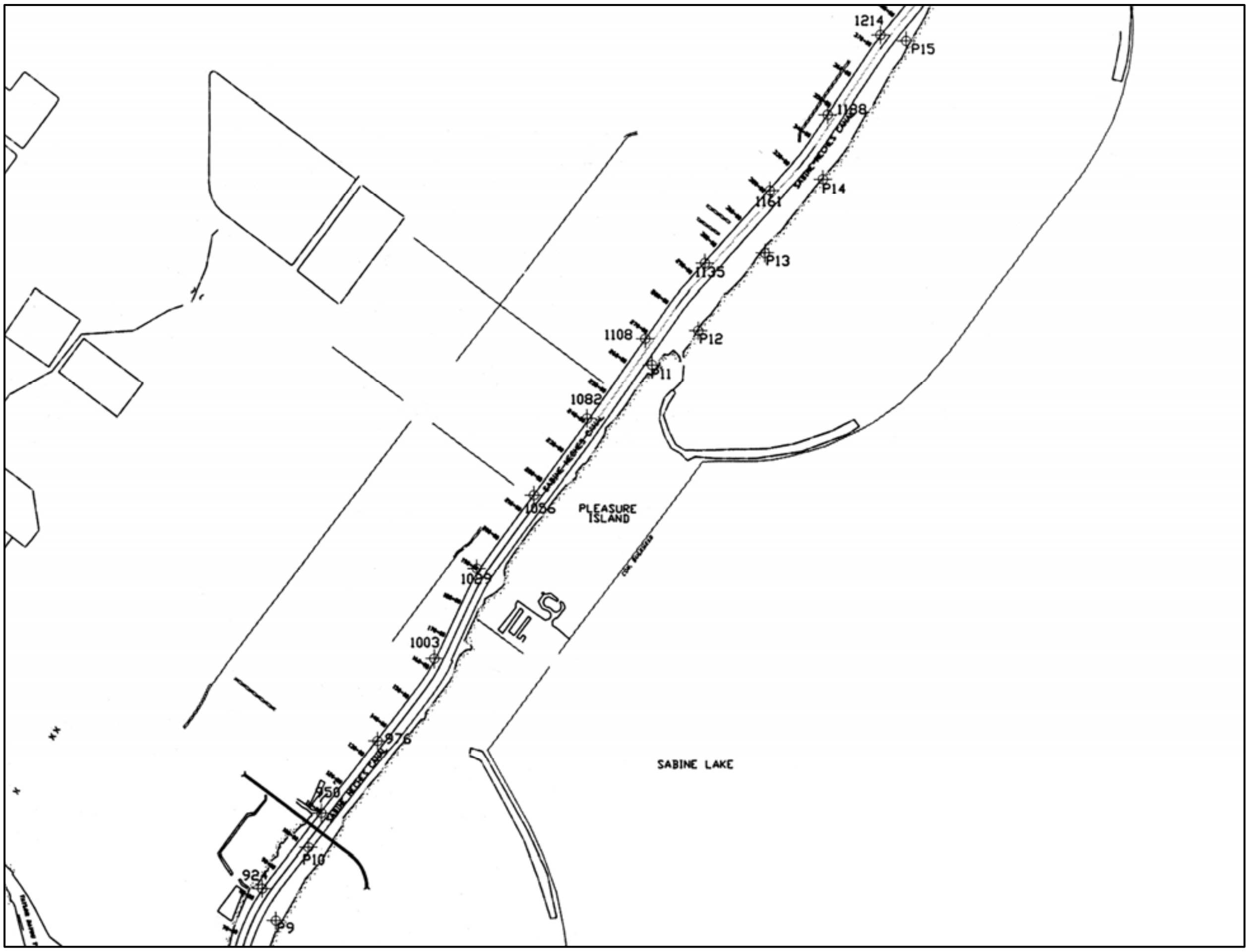
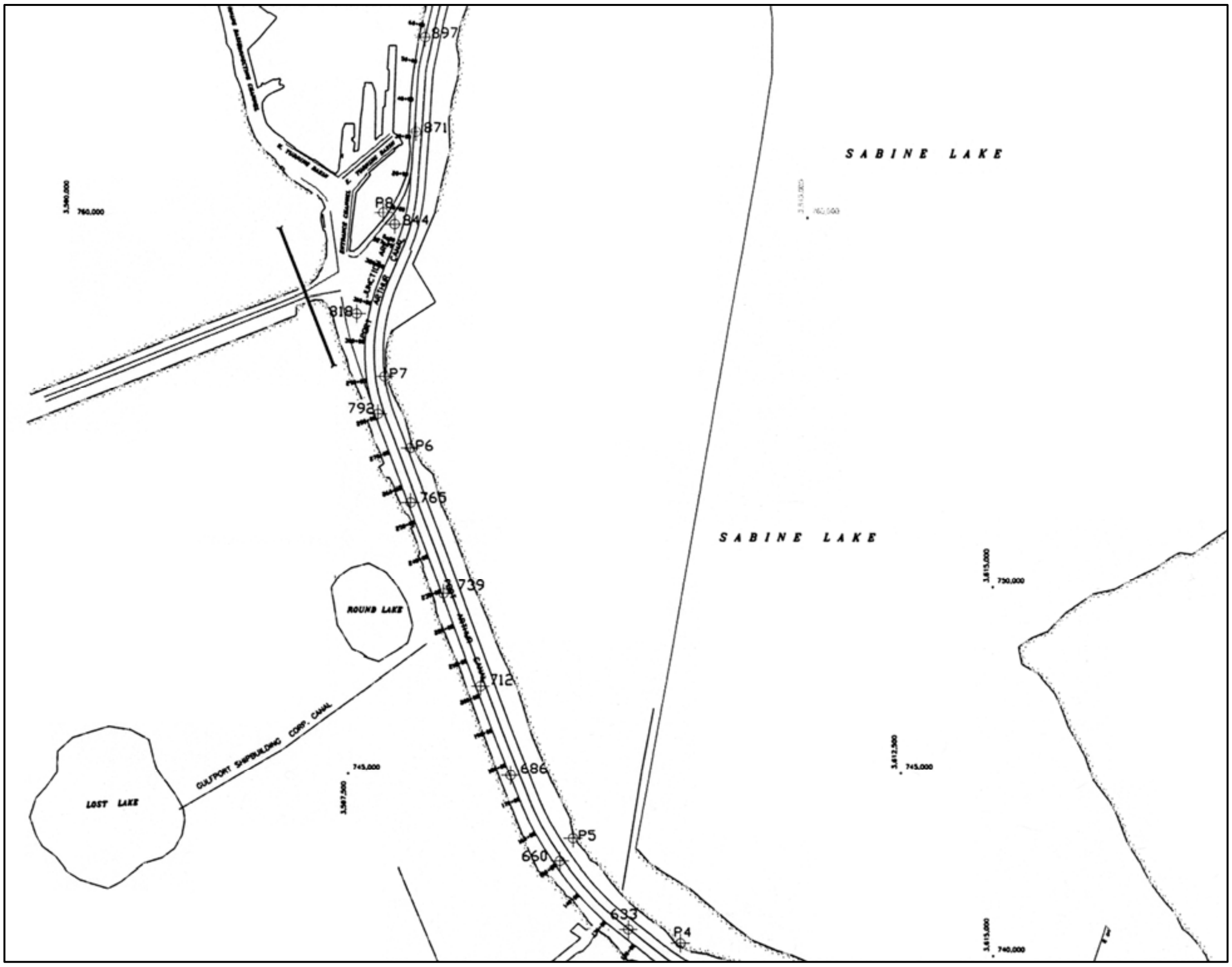


Figure 24. (Sheet 3 of 9)



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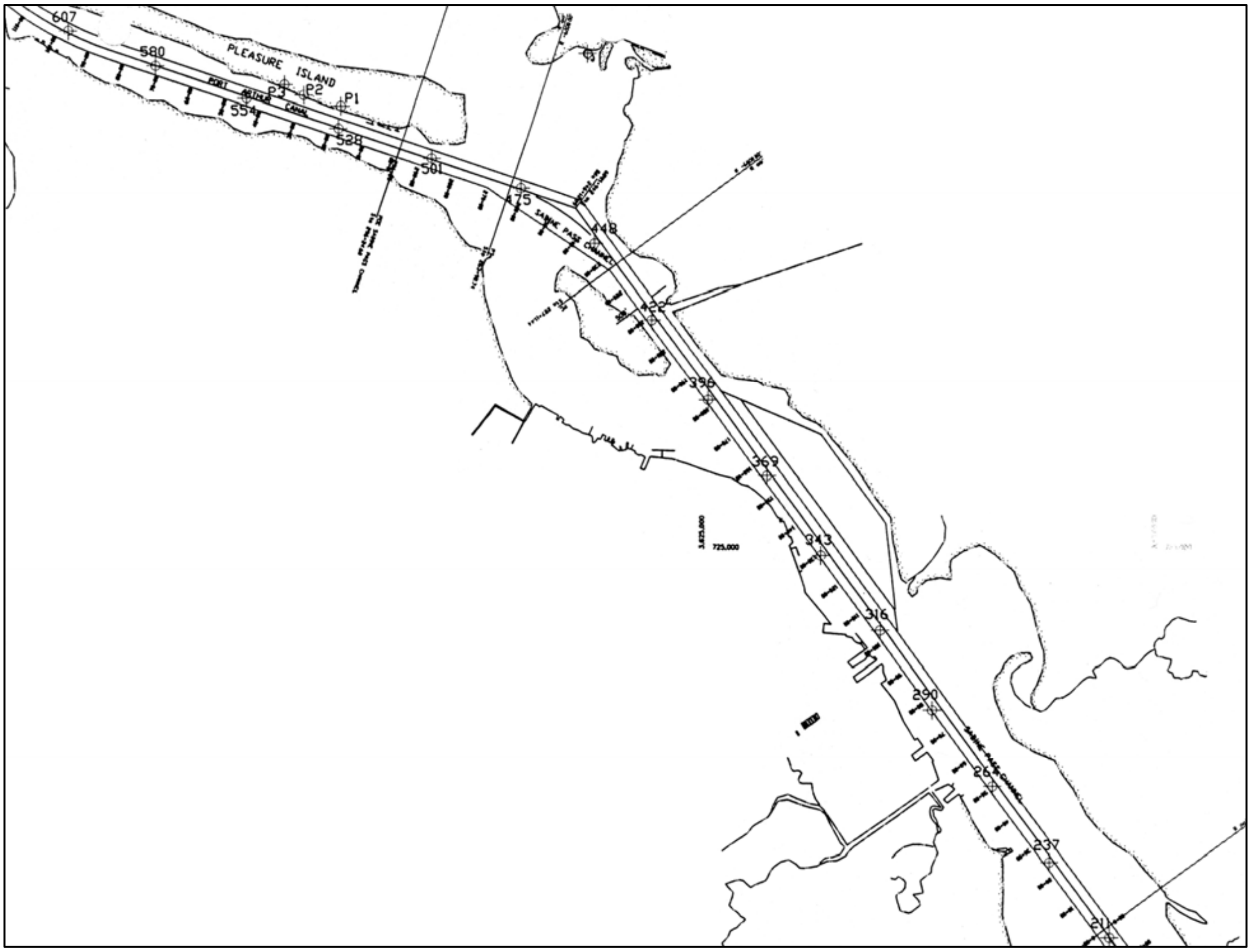
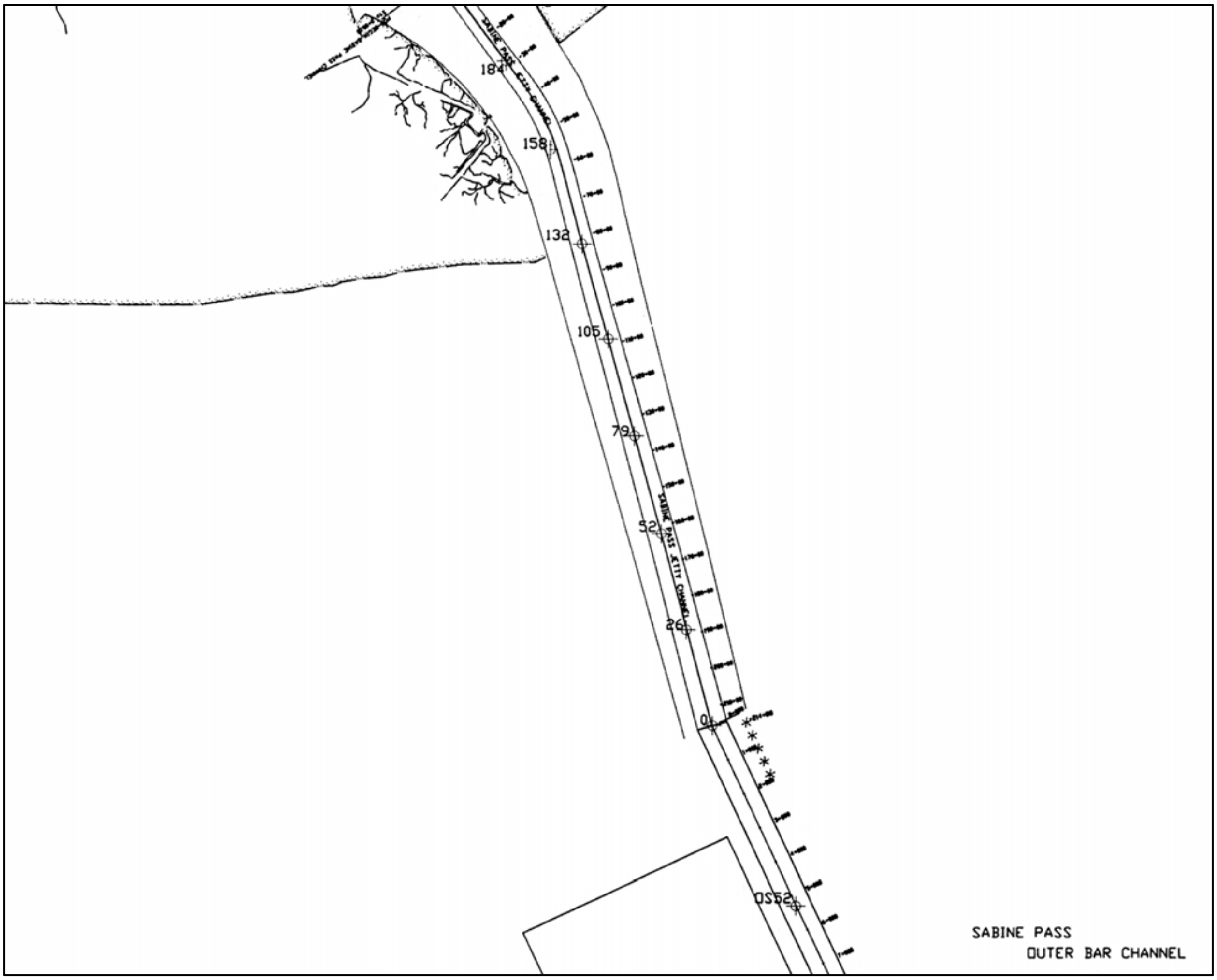


Figure 24. (Sheet 5 of 9)



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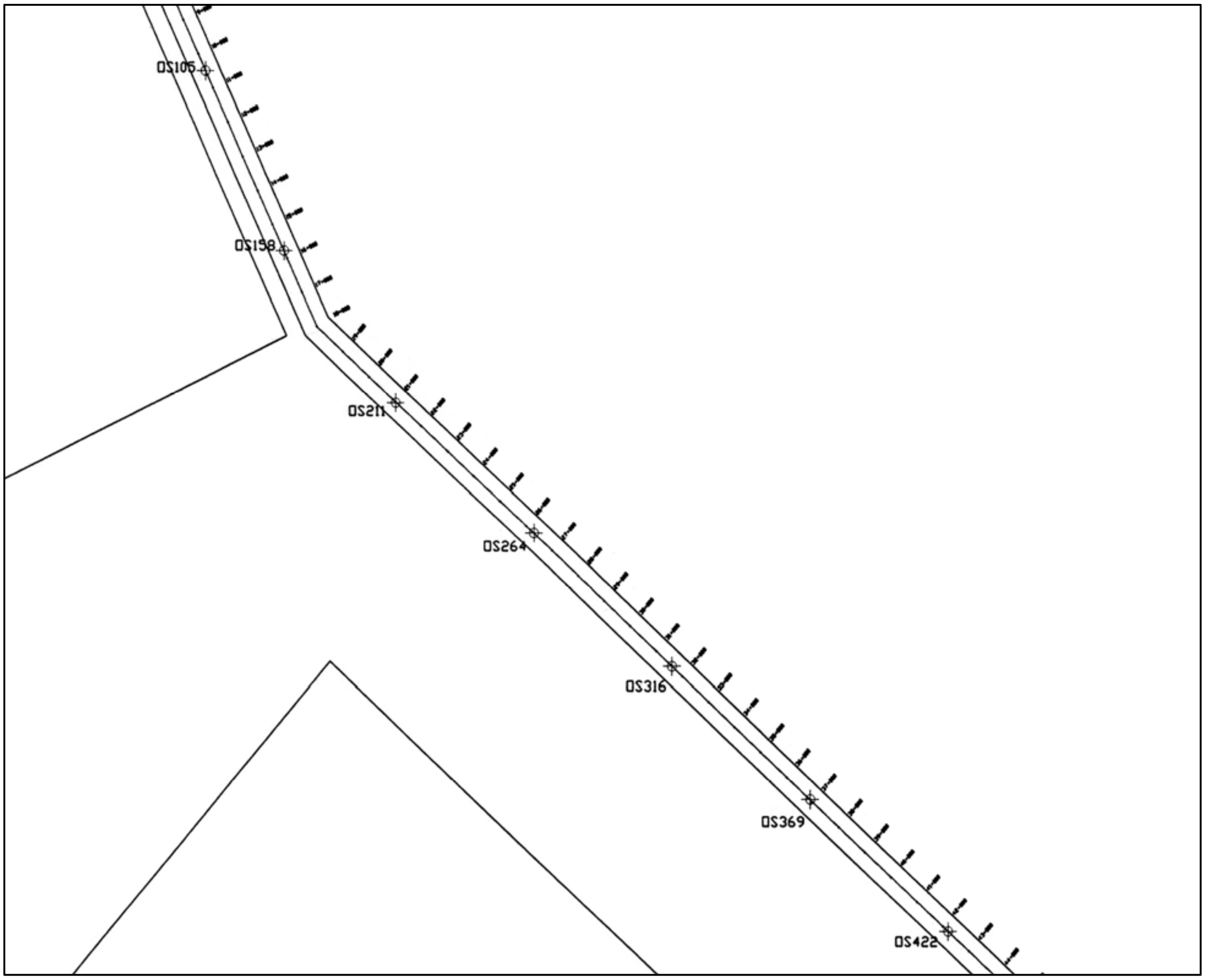


Figure 24. (Sheet 7 of 9)

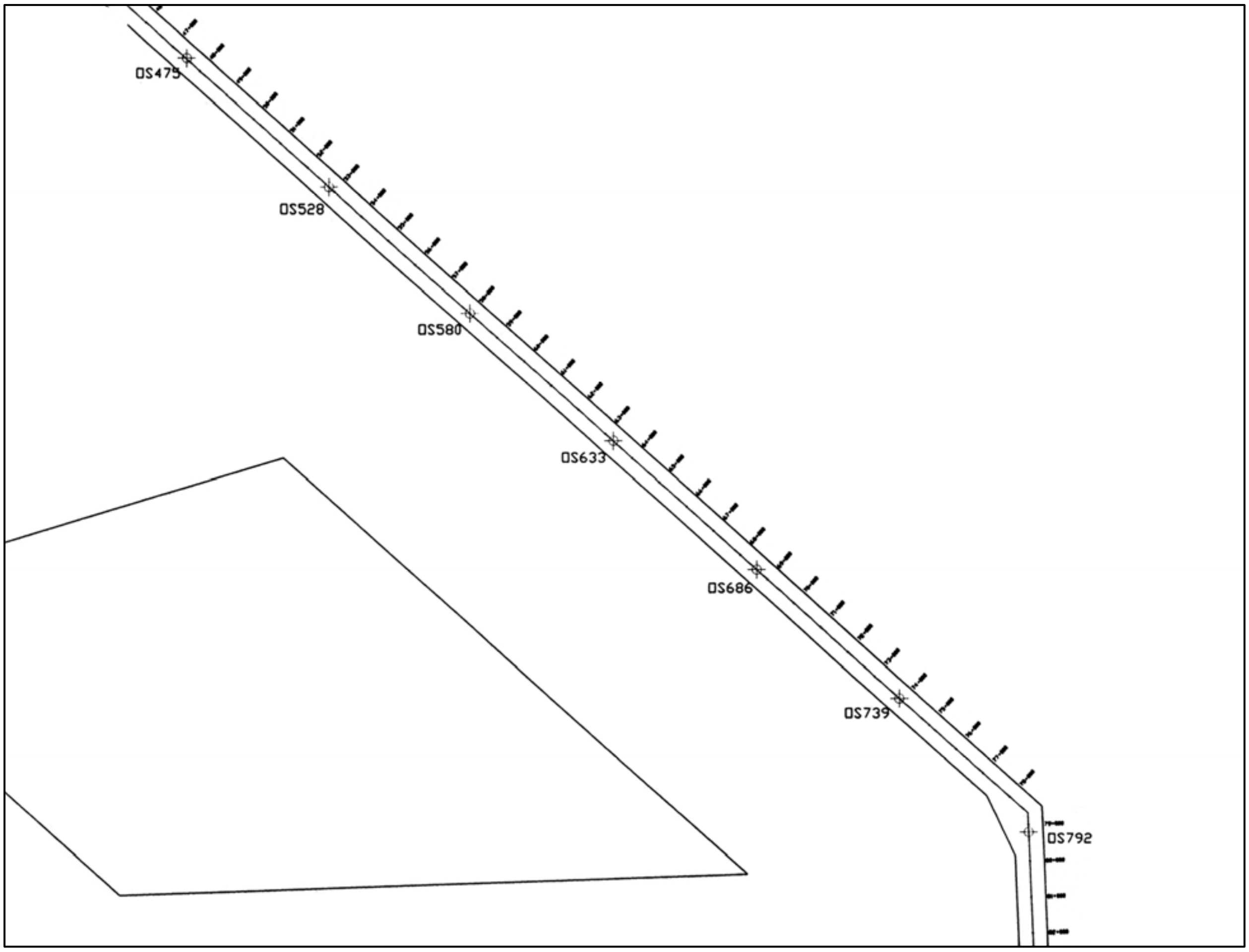


Figure 24. (Sheet 8 of 9)

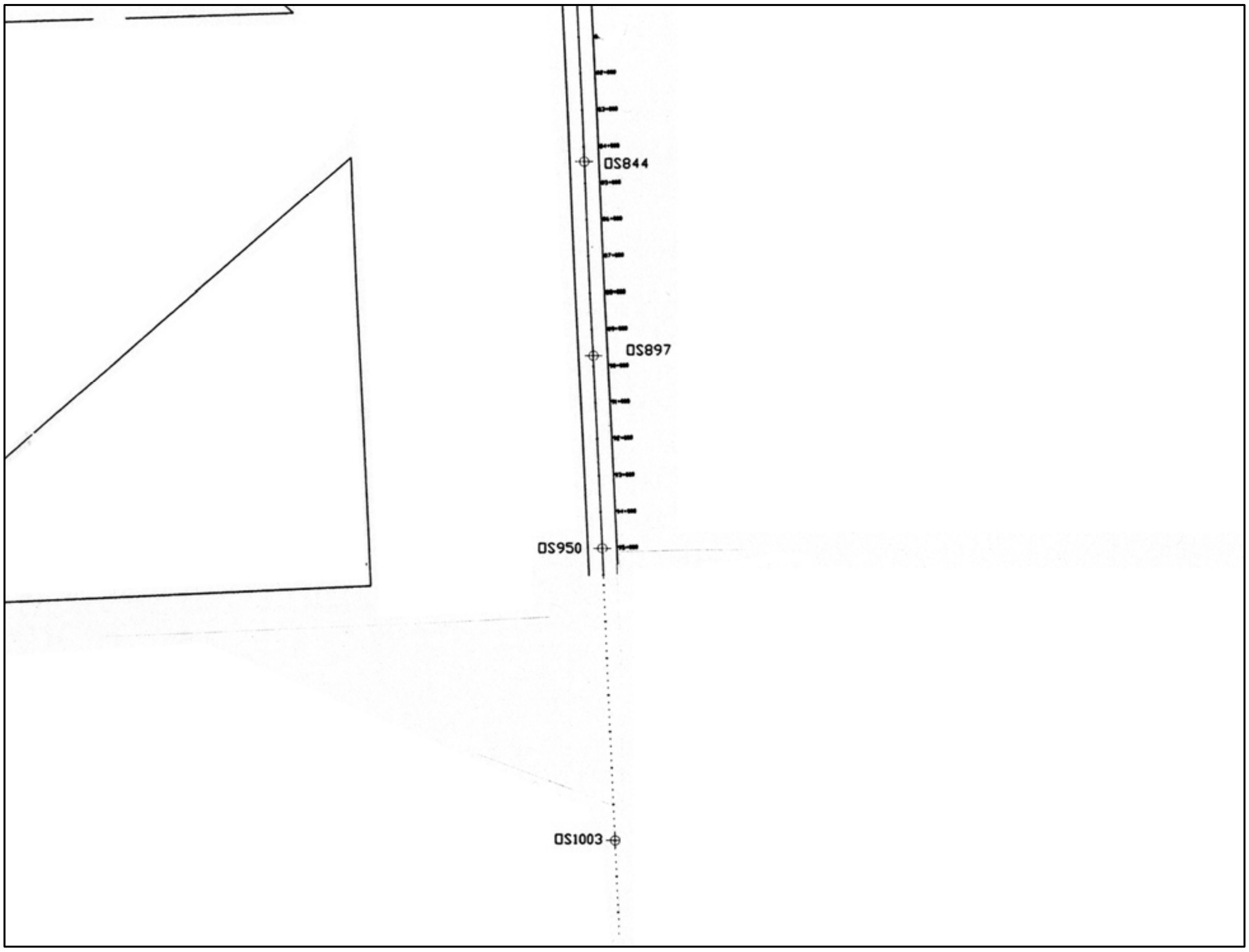


Figure 24. (Sheet 9 of 9)

Table 2
Bed Sample Analysis for Sabine Neches Project

Station Number	Sample	% Sand	% Silt + Clay	% Organic Matter
Reach 1				
1	1900	92.72	7.28	2.06
2	1874	82.36	17.64	3.15
3	1848	96.6	3.4	1.95
4	1821	95.02	4.98	0.97
5	1795	20.83	79.17	7.34
6	1768	3.2	96.8	9.61
7	1742	4.6	95.4	11.24
8	1716	26.02	73.98	8.56
9	1689	9.39	90.61	7.82
10	1663	88.22	11.78	0.61
11	1636	25.64	74.36	8.38
12	1610	9.03	90.97	8.74
13	1584	21.75	78.25	7.16
14	1557	49.57	50.43	7.80
15	1531	3.62	96.38	7.98
16	1504	10.74	89.26	7.96
17	1478	29.48	70.52	7.17
18	1452	20.59	79.41	7.05
Avg. =		**38.30**	**61.70**	**6.42**
Reach 2				
19	1425	16.38	83.62	6.81
20	1399	66.21	33.79	3.63
21	1372	29.05	70.95	5.30
22	1346	23.44	76.56	4.87
23	1320	17.14	82.86	4.50
24	1293	13.69	86.31	4.96
25	1267	45.16	54.84	5.06
26	1240	28.74	71.26	5.44
27	1214	12.58	87.42	6.80
28	1188	31.72	68.28	5.41
29	1161	20.02	79.98	7.46
30	1135	40.51	59.49	8.09
31	1108	8.32	91.68	7.53
32	1082	21.64	78.36	7.68
33	1056	13.15	86.85	5.46
34	1029	16.9	83.1	8.48
35	1003	13.13	86.87	7.80
36	976	11.65	88.35	14.64
37	950	16.78	83.22	7.54
38	924	8.85	91.15	9.49
39	897	37.53	62.47	5.37
40	871	7.51	92.49	7.71
41	844	9.42	90.58	8.66
Avg. =		**22.15**	**77.85**	**6.90**

(Continued)

Table 2 (Continued)				
Station Number	**Sample**	**% Sand**	**% Silt + Clay**	**% Organic Matter**
Reach 3				
42	818	7.29	92.71	9.23
43	792	7.57	92.43	8.99
44	765	7.9	92.1	6.91
45	739	22.26	77.74	6.27
46	712	33.86	66.14	6.07
47	686	13.83	86.17	7.82
48	660	4.1	95.9	8.25
49	633	16.82	83.18	8.63
50	607	25.15	74.85	6.08
51	580	8.68	91.32	7.26
52	554	26.3	73.7	4.19
53	528	20.53	79.47	5.93
Avg. =		**16.19**	**83.81**	**7.13**
Reach 4				
54	501	16.94	83.06	7.05
55	475	36.72	63.28	7.08
56	448	83.5	16.5	9.04
57	422	86.85	13.15	9.48
58	396	3.79	96.21	8.22
59	369	1.84	98.16	9.78
60	343	1.52	98.48	7.55
61	316	14.42	85.58	12.45
62	290	3.67	96.33	7.69
63	264	22.66	77.34	7.12
64	237	69.89	30.11	12.75
65	211	19.45	80.55	6.60
Avg. =		**30.10**	**69.90**	**8.73**
Reach 5				
66	184	4.02	95.98	11.12
67	158	10.79	89.21	7.27
68	132	Shells	Shells	Shells
69	105	12.13	87.87	3.28
70	79	Shells	Shells	Shells
71	52	Shells	Shells	Shells
72	26	Shells	Shells	Shells
73	0	16.81	83.19	2.30
Avg. =		**10.94**	**89.06**	**6.00**
Reach 6				
74	OS52	5.62	94.38	1.81
75	OS105	3.52	96.48	7.16
76	OS158	3.88	96.12	2.26
Avg. =		4.34	95.66	3.74
				(Continued)

Table 2 (Continued)

Station Number	Sample	% Sand	% Silt + Clay	% Organic Matter	
Reach 7					
77	OS211	1.89	98.11	5.02	
78	OS264	5.97	94.03	3.15	
79	OS316	32.88	67.12	2.65	
80	OS369	32.99	67.01	3.93	
81	OS422	20.66	79.34	4.14	
82	OS475	47	53	2.89	
83	OS528	8.06	91.94	4.28	
84	OS580	9.39	90.61	5.38	
85	OS633	20.28	79.72	9.58	
86	OS686	21.9	78.1	4.51	
87	OS739	3.45	96.55	7.16	
88	OS792	29.65	70.35	3.5499	
89	OS844	65.26	34.74	2.1731	
90	OS897	8.73	91.27		
91	OS950	34.46	65.54	3.60	
92	OS1003	46.15	53.85	4.083	
Avg. =		**24.29**	**75.71**	**4.13**	
Along Pleasure Island Shoreline					
Original Sample	**New Sample**	**% Sand**	**% Silt/Clay**	**% Moisture Content**	**% Organic Content**
P36T	P1T	29.23	70.77	0.37	3.03
P37B	P1B	76.64	23.36	0.35	1.79
P38T	P2T	7.66	92.34	0.44	3.8
P39B	P2B	3.82	96.18	0.64	4.2
P40T	P3T	2.79	97.21	0.45	3.61
P41B	P3B	4.04	95.96	0.60	5.18
P42T	P4T	0.45	99.55	0.57	6.7
P43B	P4B	6.21	93.79	0.40	4.92
P44T	P5T	12.78	87.22	0.62	6.1
P45B	P5B	28.17	71.83	0.47	5.8
P46T	P6T	7.32	92.68	0.47	4.82
P47B	P6B	21.82	78.18	0.55	4.24
P48B	P7B	25.79	74.21	0.46	3.77
P49T	P7T	4.37	95.63	0.55	5.6
P60T	P8T	4.55	95.45	0.46	21.92
P61B	P8B	0.66	99.34	0.65	5.75
P62B	P9B	52.28	47.72	0.43	3.19
P63T	P9T	0	100.00	0.60	6.44
P64T	P10T	0.06	99.94	0.55	5.65
P65B	P10B	18.89	81.11	0.44	4.13
P66T	P11T	12.58	87.42	0.37	3.46
P67B	P11B	0.44	99.56	0.36	2.45
P68T	P12T	13.79	86.21	0.25	2.2
P69B	P12B	49.07	50.93	0.34	1.64
P70T	P13T	60.68	39.32	0.42	5.27
P71B	P13B	60.07	39.93	0.38	2.07
P72B	P14B	5.17	94.83	0.32	1.89
P73T	P14T	5.24	94.76	0.34	3.80

(Continued)

Table 2 (Concluded)					
Original Sample	**New Sample**	**% Sand**	**% Silt/Clay**	**% Moisture Content**	**% Organic Content**
P74B	P15B	38.70	61.30	0.37	3.46
P75T	P15T	4.07	95.93	0.39	4.55
P76B	P16B	80.29	19.71	0.29	1.29
P77T	P16T	1.56	98.44	0.46	5.00
P78T	P17T	32.82	67.18	0.39	3.66
P79B	P17B	24.31	75.69	0.57	4.00
P80B	P18B	15.72	84.28	0.43	3.50
P81T	P18T	25.11	74.89	0.43	4.02
P82B	P19B	5.91	94.09	0.37	2.23
P83T	P19T	3.05	96.95	0.41	5.63

Table 3
Average Percentages of Sand; Silt Plus Clay and Percent Organic Matter in Bed Sediment at Sabine Neches Project

Reach	% Sand	% Silt + Clay	% Organic Matter
1	38.30	61.70	6.42
2	22.15	77.85	6.90
3	16.19	83.81	7.13
4	30.10	69.90	8.73
5	10.94	89.06	6.00
6	4.34	95.66	3.74
7	24.29	75.71	4.13

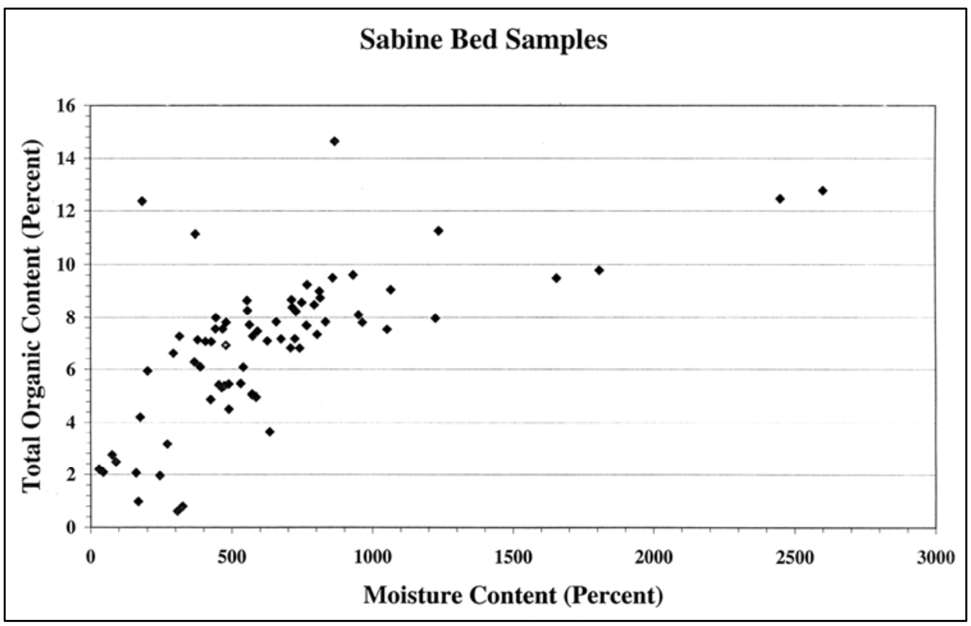


Figure 25. Total organic content correlated to moisture content for Sabine Neches sediment

Data on organic content in sediment samples were plotted against percentage sediment finer than 64 μ for each reach. The results for the seven reaches shown in Figure 23 are given in Figures 26 through 32. It is noted that the percentage of organic contents is higher when the percentage of sediment finer than 64 μ is higher. This is because the organic substances adsorb selectively to the clay particles and provide bonding material to them for aggregation and flock formation.

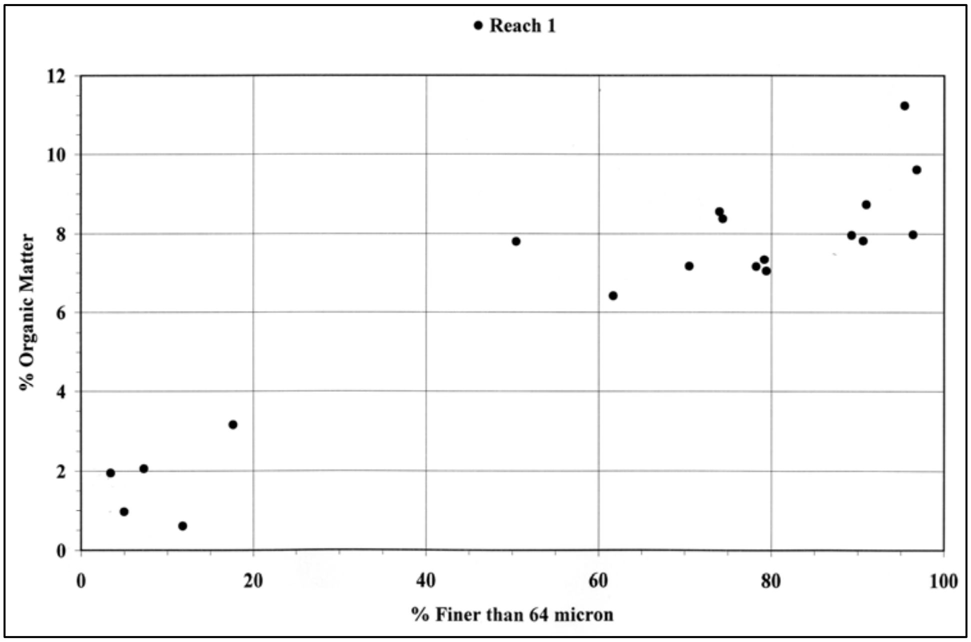


Figure 26. Reach 1, Sabine, organic content as a function of sediment finer than 64 μ

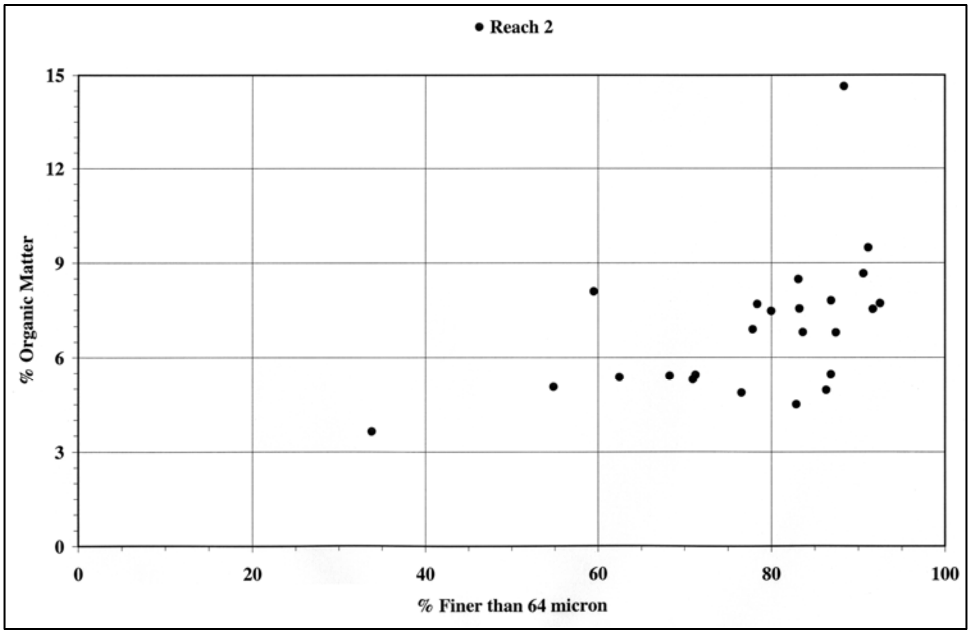


Figure 27. Reach 2, Sabine, organic content as a function of sediment finer than 64 µ

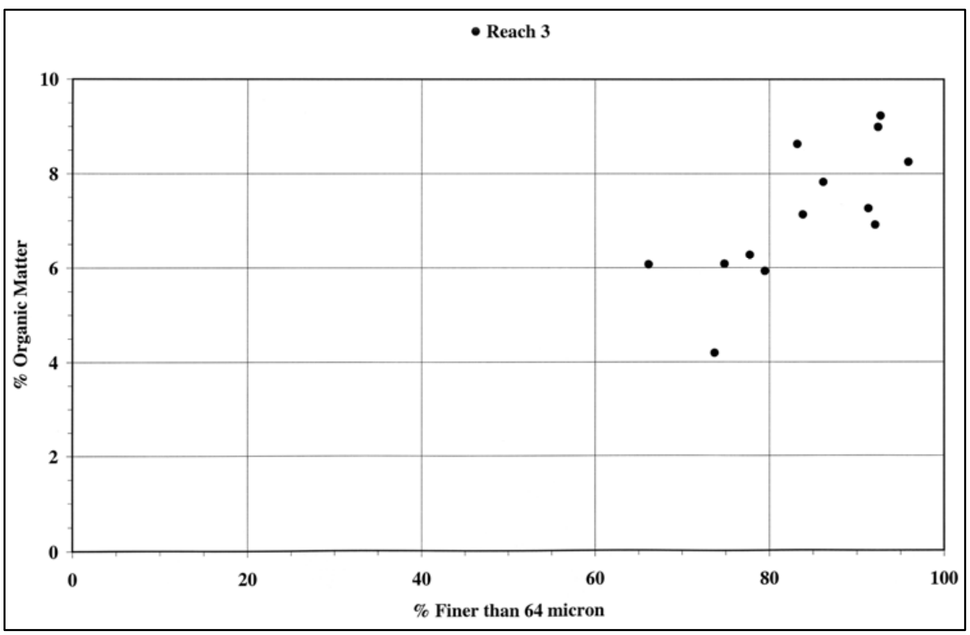


Figure 28. Reach 3, Sabine, organic content as a function of sediment finer than 64 µ

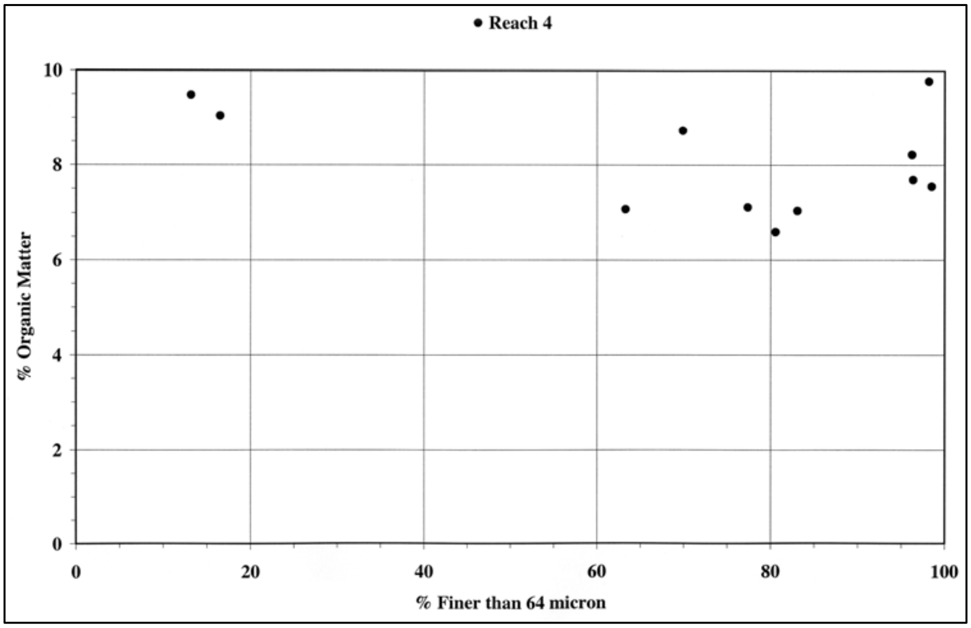


Figure 29. Reach 4, Sabine, organic content as a function of sediment finer than 64 µ

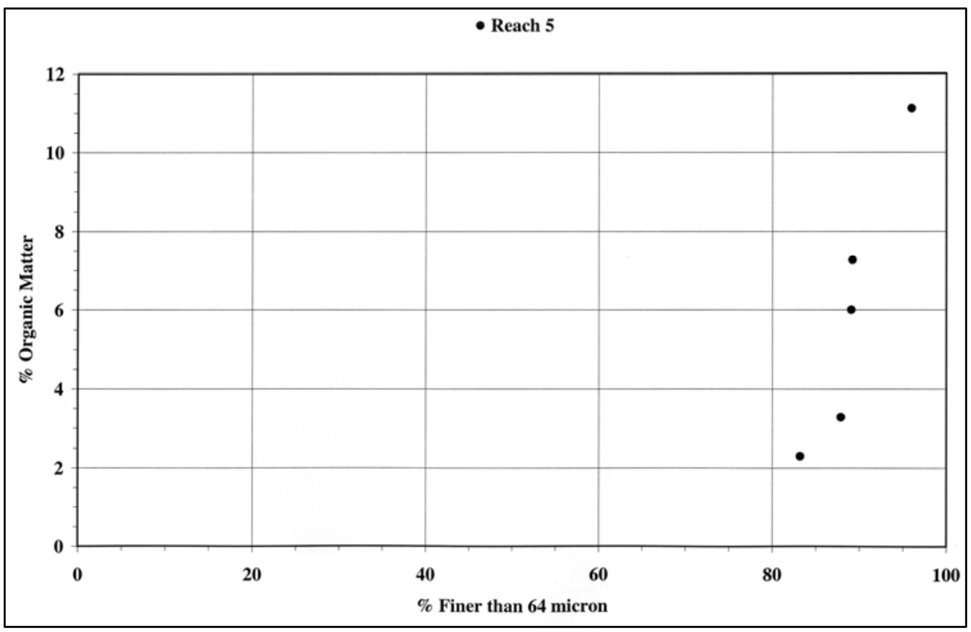


Figure 30. Reach 5, Sabine, organic content as a function of sediment finer than 64 µ

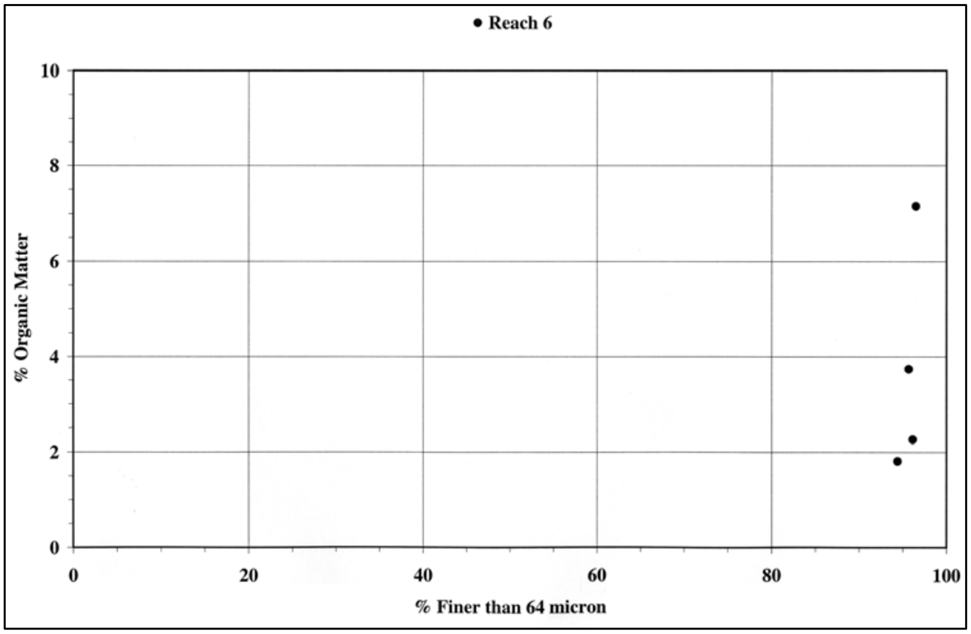


Figure 31. Reach 6, Sabine, organic content as a function of sediment finer than 64 µ

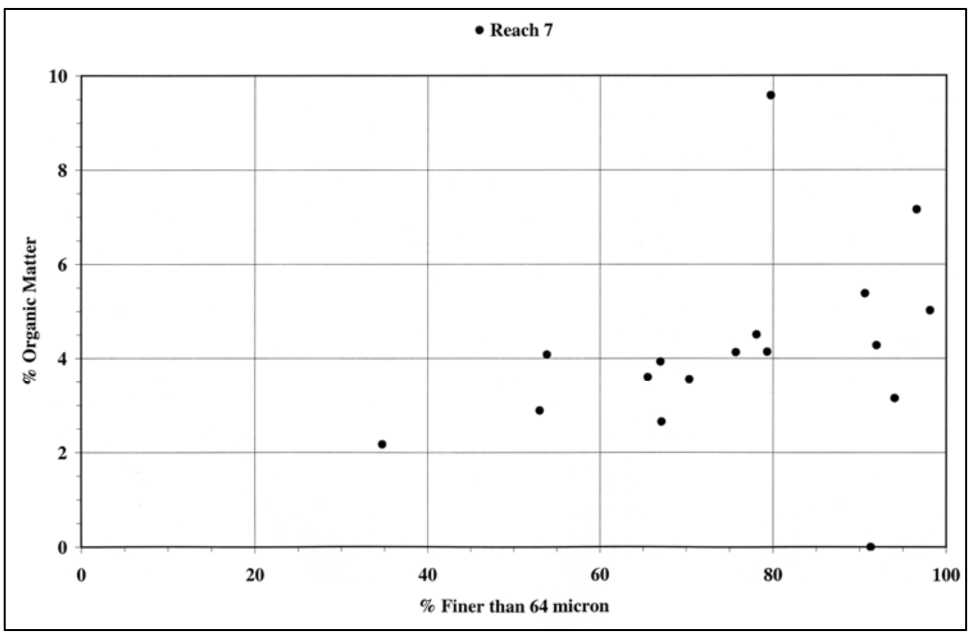
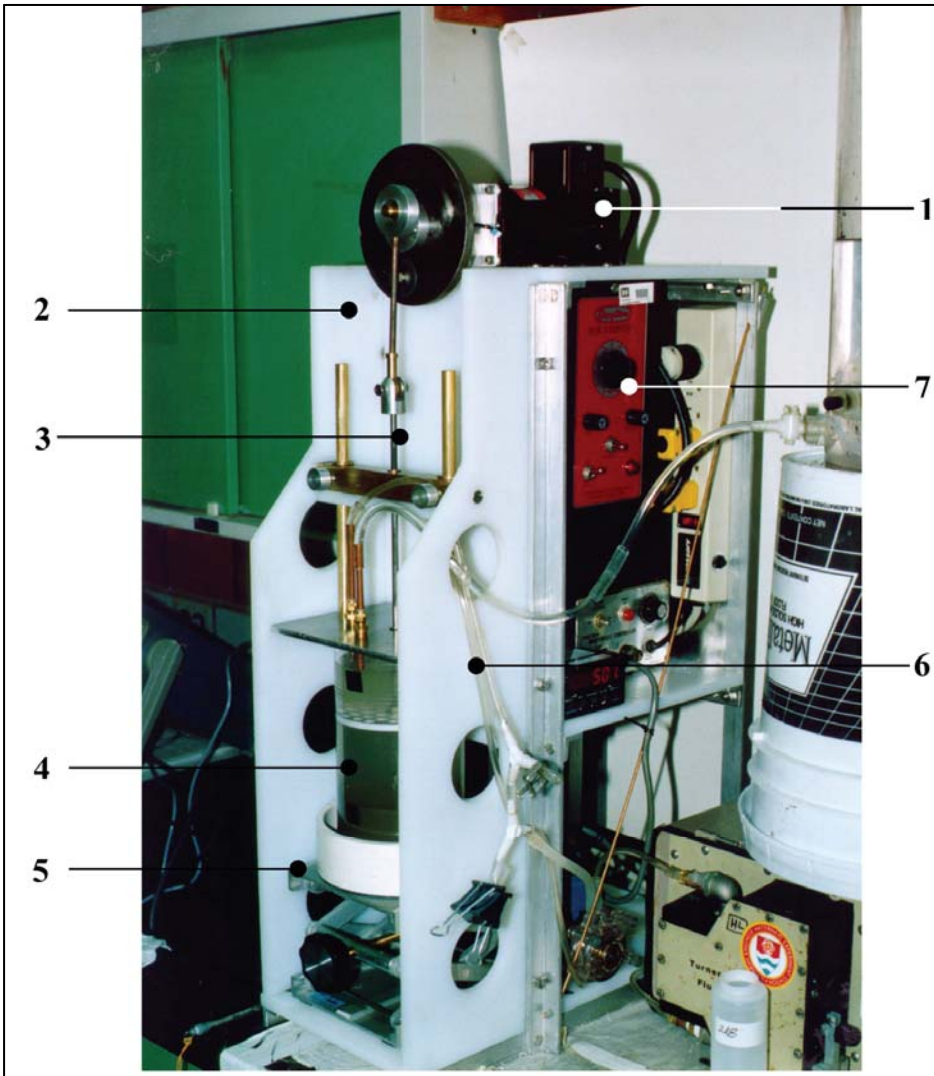


Figure 32. Reach 7, Sabine, organic content as a function of sediment finer than 64 µ

Erosion tests were conducted on three surface sediment samples collected at the Sabine Neches Project. These tests were conducted in a device called the particle entrainment simulator (PES), shown in Figure 33. CHL has extensively used this device over the past several years. Use of PES is a two-step process. First the sediment is eroded layer by layer under bed shear stress increased in small increments and suspension concentration is measured periodically as a function of time. This enables plotting the results as shown in Figures 34 and 35 for sample 1 and sample 2 respectively. These samples were selected because they had high percentages of fine sediments. Sample 1 had 4.67 percent sand, 95.34 percent silt plus clay, 36.5 percent moisture content and 4.17 percent organic content. Sample 2 had 1.62 percent sand, 98.38 percent silt plus clay, 51.0 percent moisture content, and 5.15 percent organic content. The data are used for computing the erosion rates under step 2 for the applied bed shear stresses.



1. Drive motor
2. Main frame
3. Grid oscillating rod
4. Sediment bed in cylinder
5. Adjustable platform
6. Suspension withdrawal tubes
7. Speed controller

Figure 33. Particle entrainment simulator (PES)

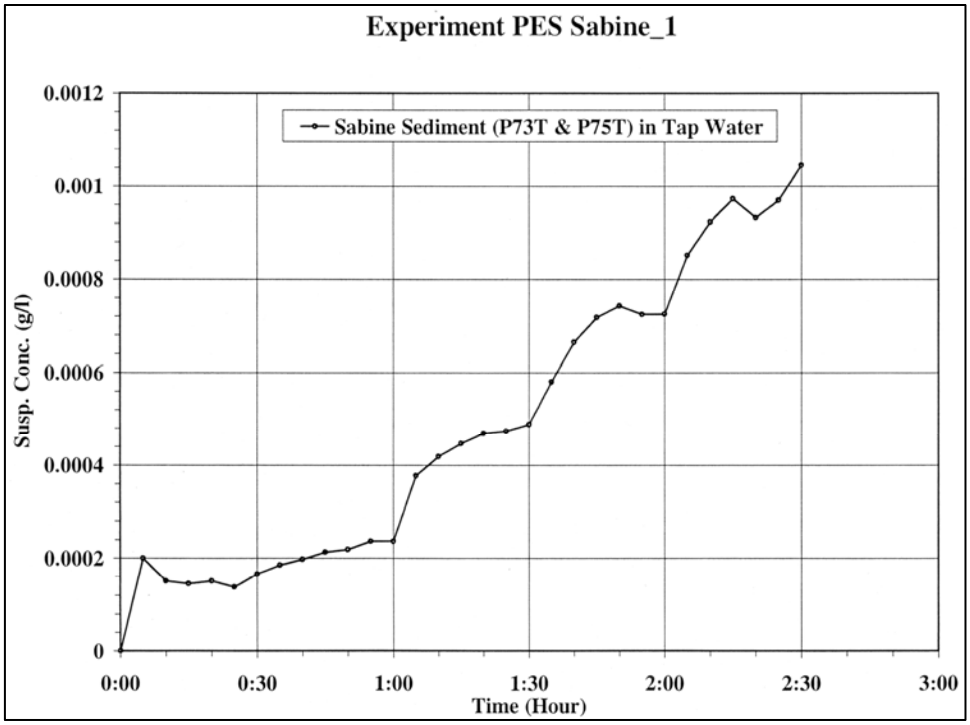


Figure 34. Results of erosion test on Sabine Neches sediment sample 1

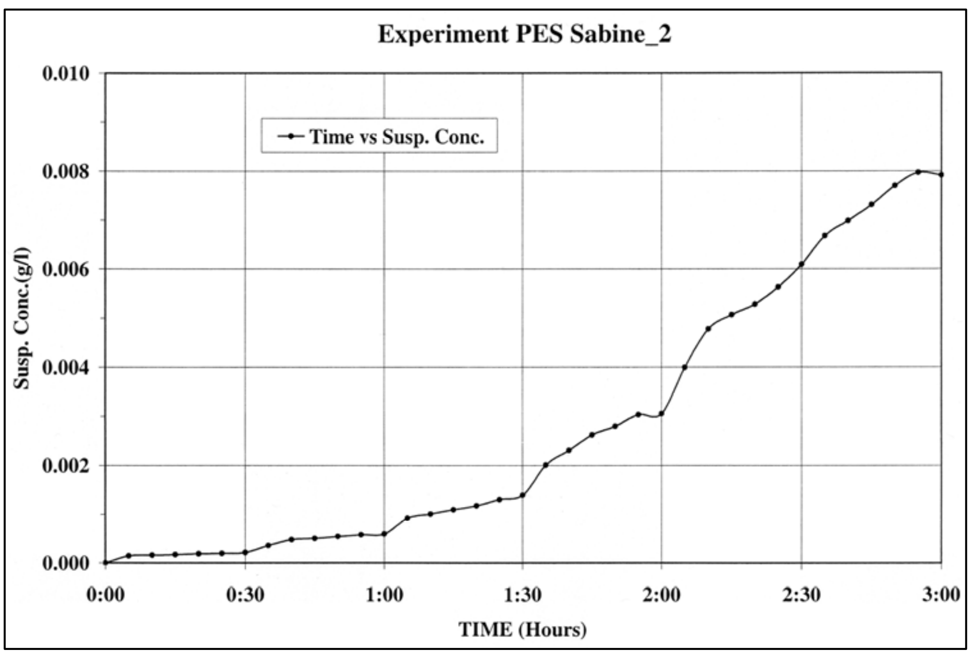


Figure 35. Results of erosion test on Sabine Neches sediment sample 2

Results are plotted in the form of rate of erosion versus bed shear stress as shown in Figure 36. The characteristics of samples are given as follows: Sample P15 had 21.39 percent sand, 78.61 percent silt plus clay, 38.0 percent moisture content and 4 percent organic content. Sample P19 had 4.48 percent sand, 95.52 percent silt plus clay, 39.0 percent moisture content, and 3.93 percent organic content.

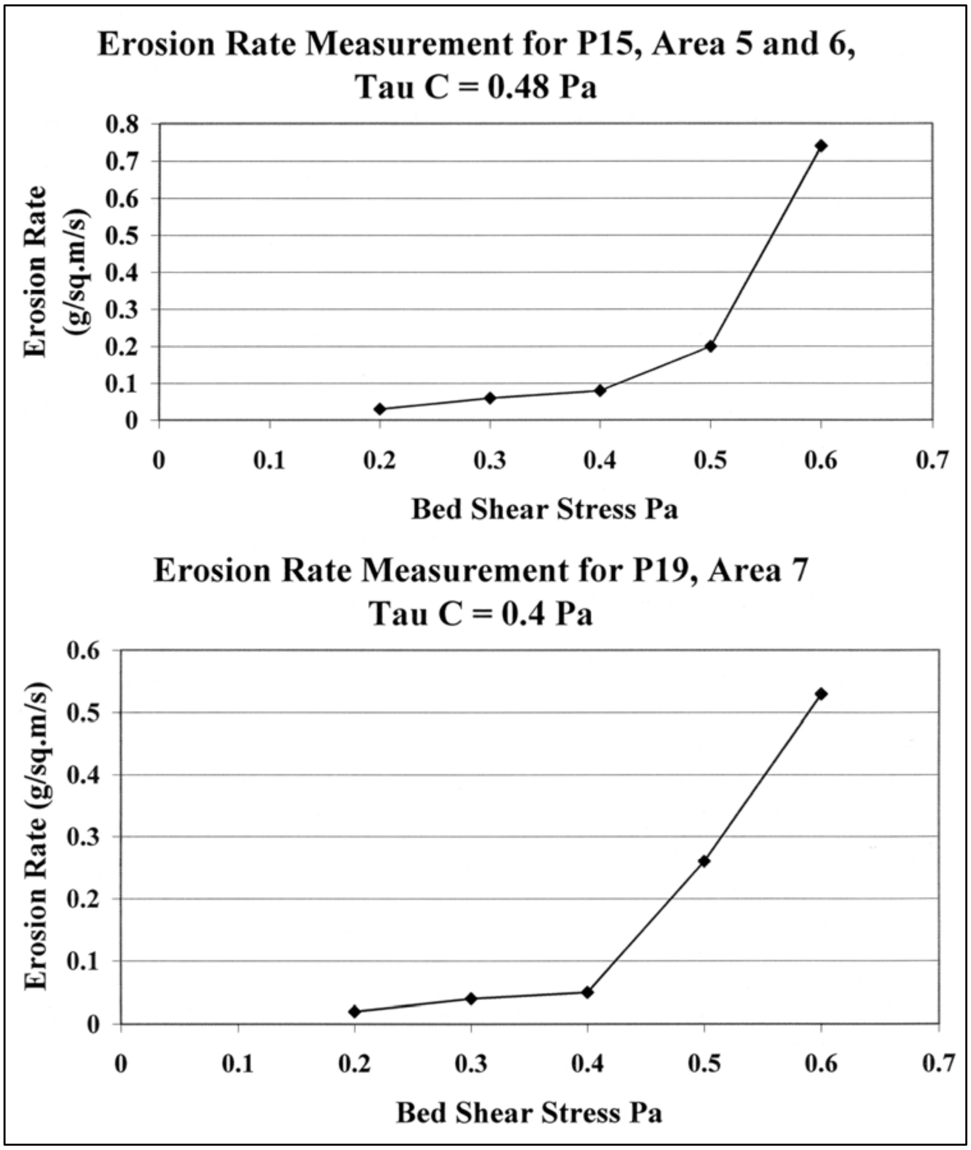


Figure 36. Critical bed shear stress for sediment sample at P15 and P19 at Pleasure Island

Project 3: Red Bank Creek, SC

The Red Bank Creek, SC, is located south of Lake Murray and the town of Lexington (Figure 37). The samples were collected at surface and at various depths below surface. The percentage of sand and silt plus clay was determined on these samples. The results are given in Table 4, and they are plotted in Figure 38. These show a wide variation from almost 100 percent sand to 99 percent fine sediment. This is significant because it demonstrates the importance of ascertaining spatial distribution of sediment types at any project under investigation. Making an assumption of uniformity of sediment based on a few samples is likely to lead to incorrect answers.

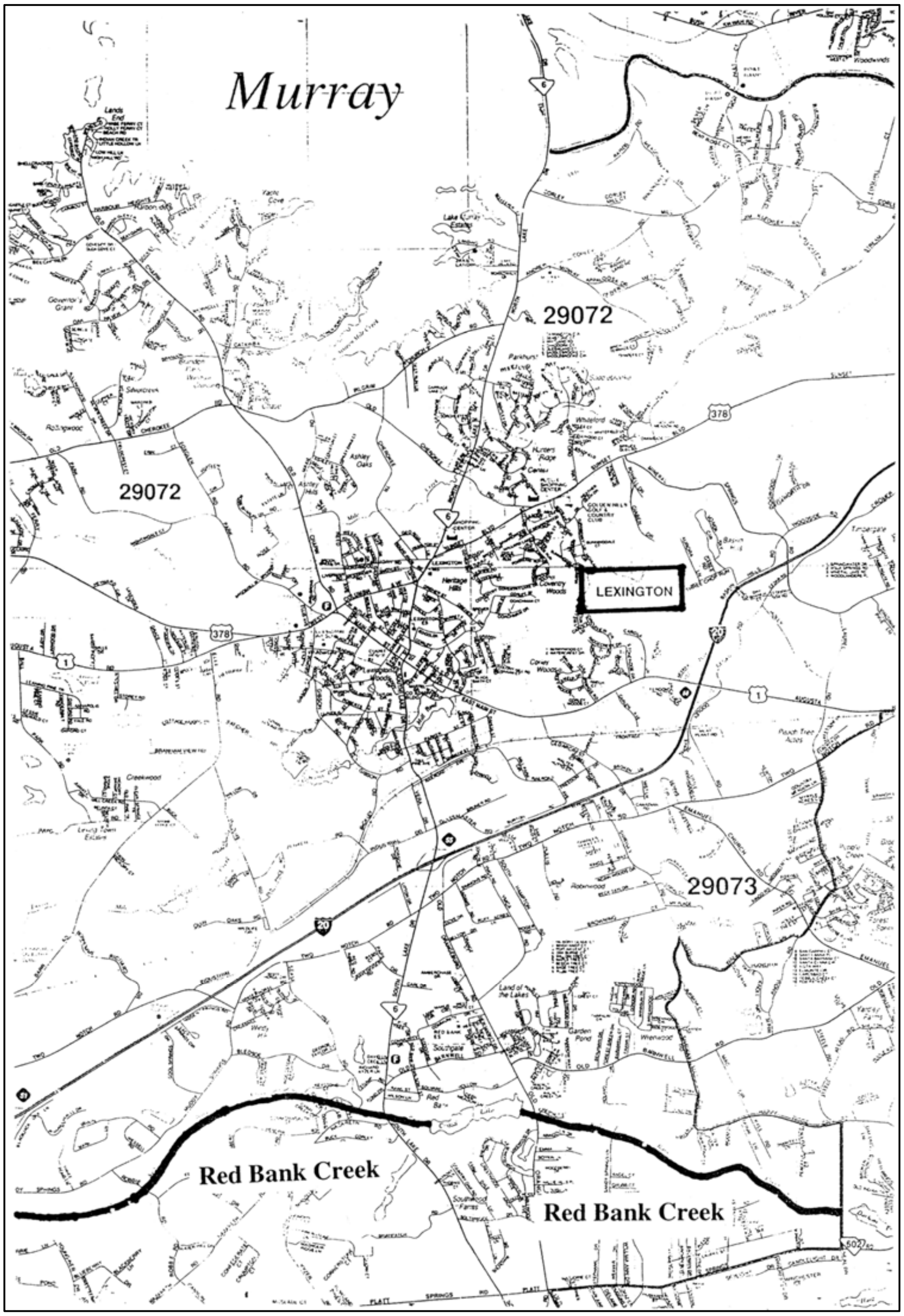


Figure 37. Location of Red Bank Creek

Table 4
Percentage of Sand and Silt Plus Clay in Bed Samples at Red Bank Channel

Sampling Date	Range Station	Depth, m (ft)	% Sand	% Silt plus Clay
4/3/01	D-1	1.2 (4.0)	19.50	80.50
4/3/01	D-4	1.2 (4.0)	39.13	60.87
4/3/01	D-3	1.2 (4.0)	14.42	85.58
4/3/01	D-2	1.1 (3.5)	94.93	5.07
4/3/01	CL1	3.7 (12.0)	38.26	61.74
4/3/01	CL1A		97.64	2.36
4/3/01	CL4	0.8 (2.5)	10.71	89.29
4/3/01	CL3	1.2 (4.0)	37.10	62.90
4/3/01	CL2	3.0 (10.0)	1.23	98.77
4/3/01	9	Surface	99.96	0.04
4/3/01	9A		99.91	0.09
4/3/01	11	Surface	98.88	1.12
4/3/01	12	Surface	99.99	0.01

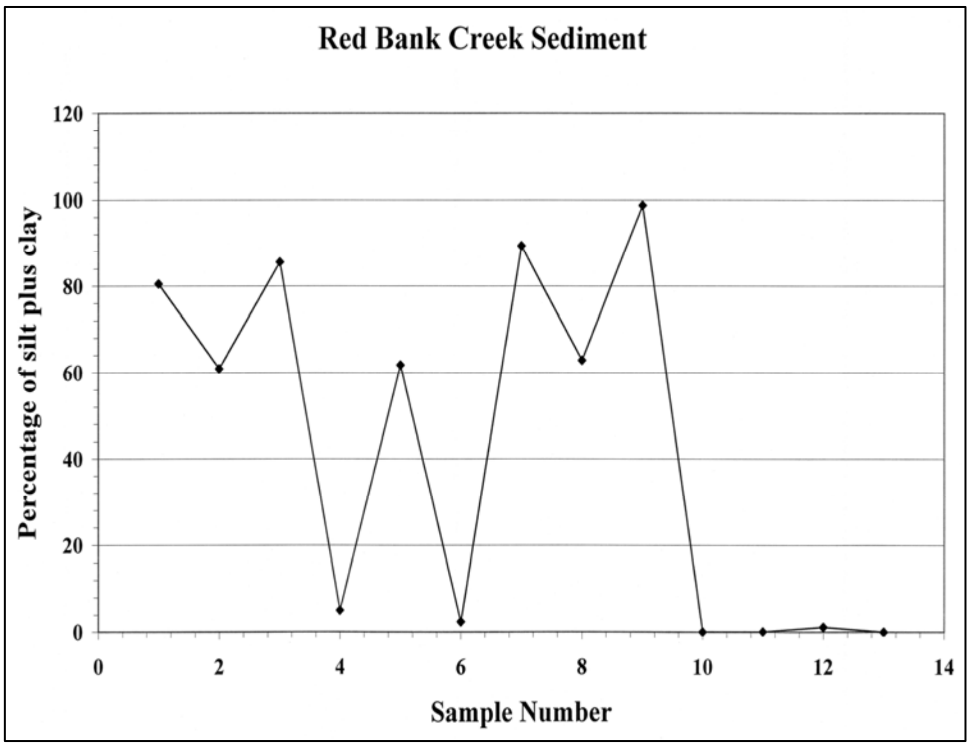


Figure 38. Results of analysis of bed samples collected at Red Bank Creek

Project 4: Charleston / Columbus Terminal, SC

Location of Charleston / Columbus Terminal is shown in Figure 39. Sample locations are shown in Figure 40. Total organic content by weight was determined from the percent loss on ignition (percent LOI) tests on sediment samples.

A large variation from 1 percent to 12 percent of organic matter was noticed. It has been established from laboratory tests that even a one percent organic matter by weight is sufficient for significantly changing the erosional and depositional properties of fine sediments. Higher percentages of organic matter influence the particle-size distribution and bulk density of the total sample. The results are given in Table 5. The observed large variation in percent organic matter at one site emphasizes the need for taking several samples for adequately determining the spatial variation in sediment properties.

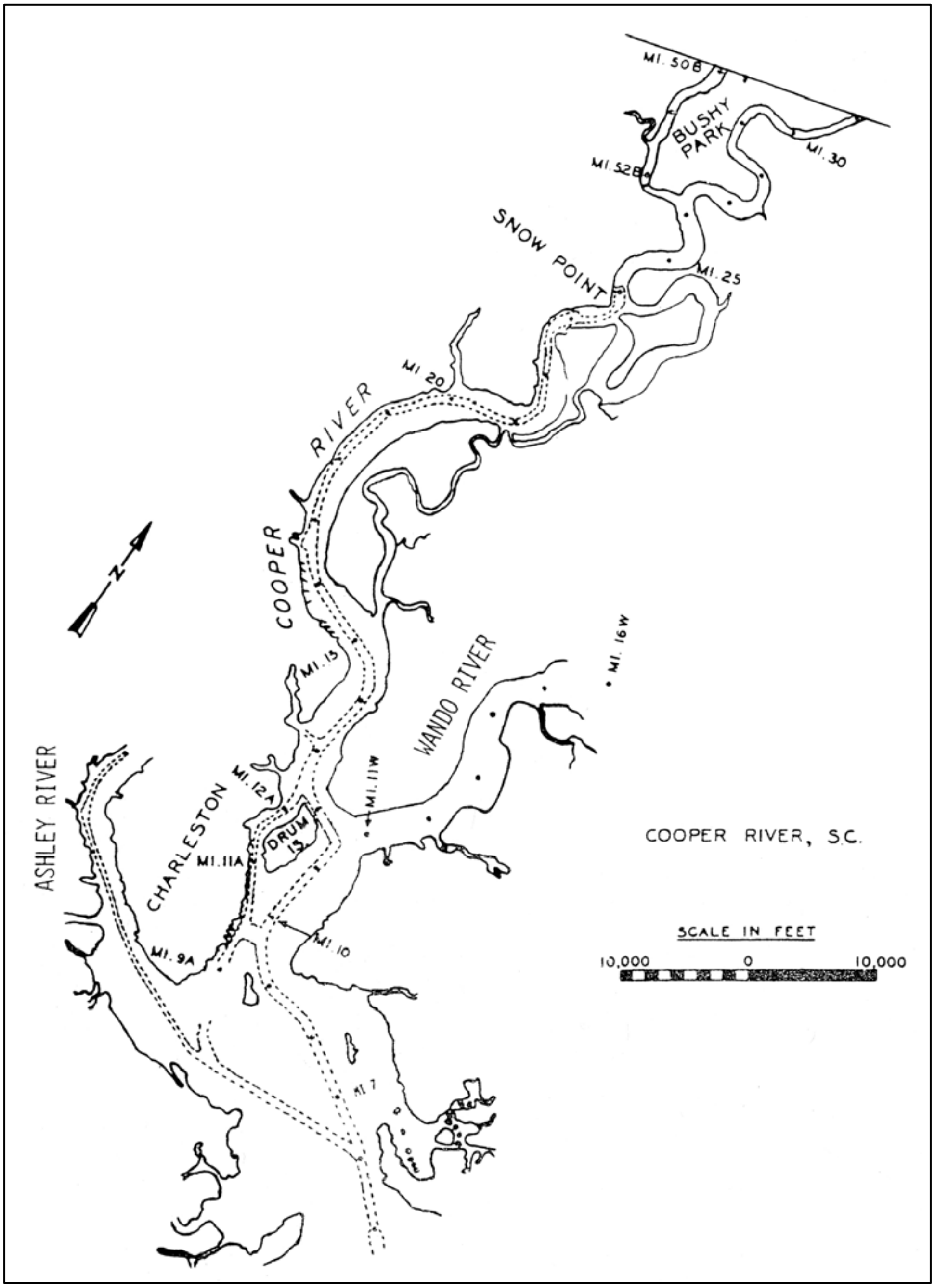


Figure 39. Location of Charleston/Columbus Terminal, SC

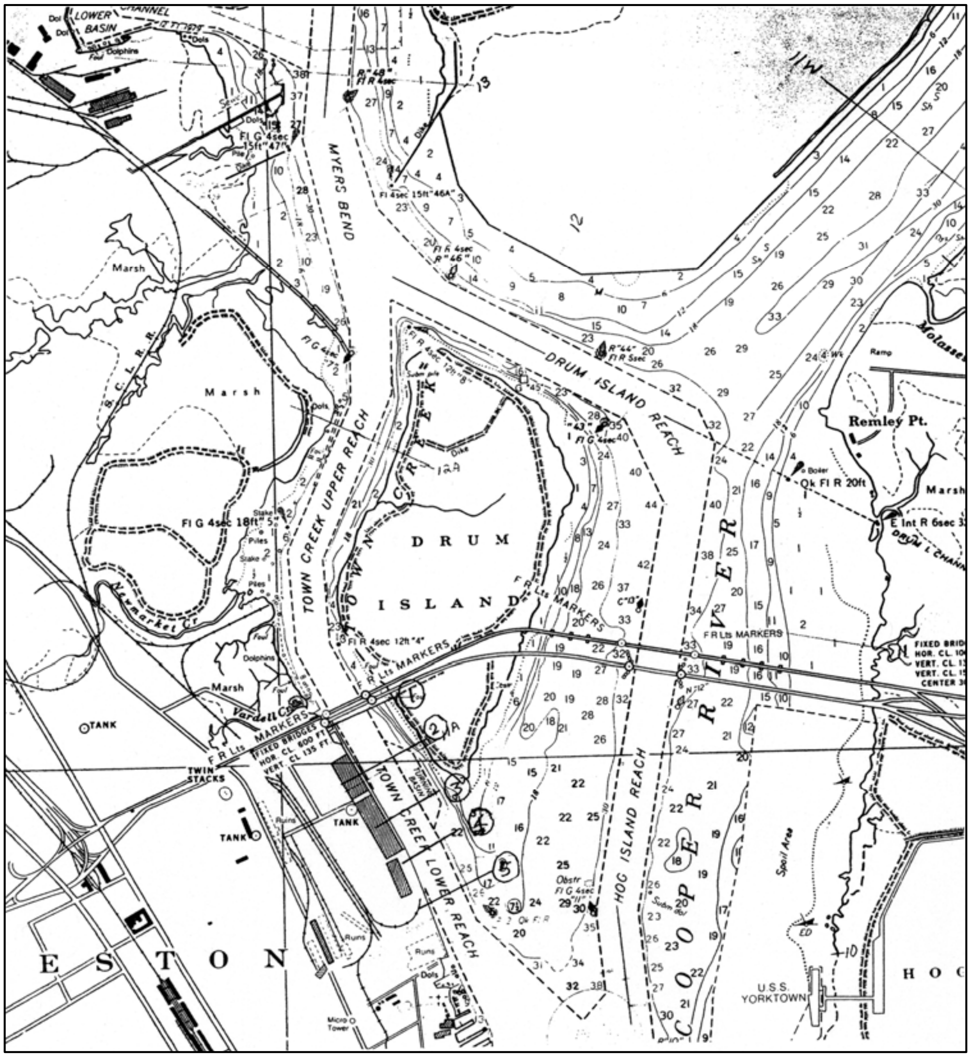


Figure 40. Location map of bed samples collected at Charleston/Columbus Terminal, SC

Table 5 Percentage of Organic Contents in Bed Samples at Charleston/Columbus Terminal	
Project Sampling Date: 10/14/99	
Sample	**% LOI**
L5-500 806 45.9 S	6.90
L5-500 806 45.9 B	9.57
L5-100 822 38.9 S	12.00
L5-100 822 38.9 B	11.81
L3-500 846 42.0 S	8.94
L3-500 846 42.0 B	9.87
L3-100 905 39.2 S	12.29
L3-100 905 39.2 B	12.24
3500 917 50.1 B	4.62
3000 922 46.1 S	0.95
1500 932 46.1 S	10.44
1500 932 46.1 B	11.91
500 940 44.6 S	11.94
500 940 44.6 B	12.44

Project 5: Inner Albemarle Sound, NC

Location of Inner Albemarle Sound is shown in Figure 41. Sample locations are shown in Figure 42. Bed samples collected at Albemarle Sound, NC, were analyzed to determine mean diameter, moisture content, and total organics. The results are given in Table 6. The percent organic content and moisture content are plotted in Figure 43 for the sediment samples collected at the Inner Albemarle Sound Project. It is noted that the moisture content generally increases with increasing percent of organic matter. The specific gravity of organic substances is lower than that of sediments. Therefore, it may also be stated that greater percentage of organic matter in natural sediments results in increased moisture content and decreased bulk density for natural sediments. A plot of total organic matter by weight versus mean diameter is shown in Figure 44, which shows a weak correlation between the total organic matter by weight and mean diameter.

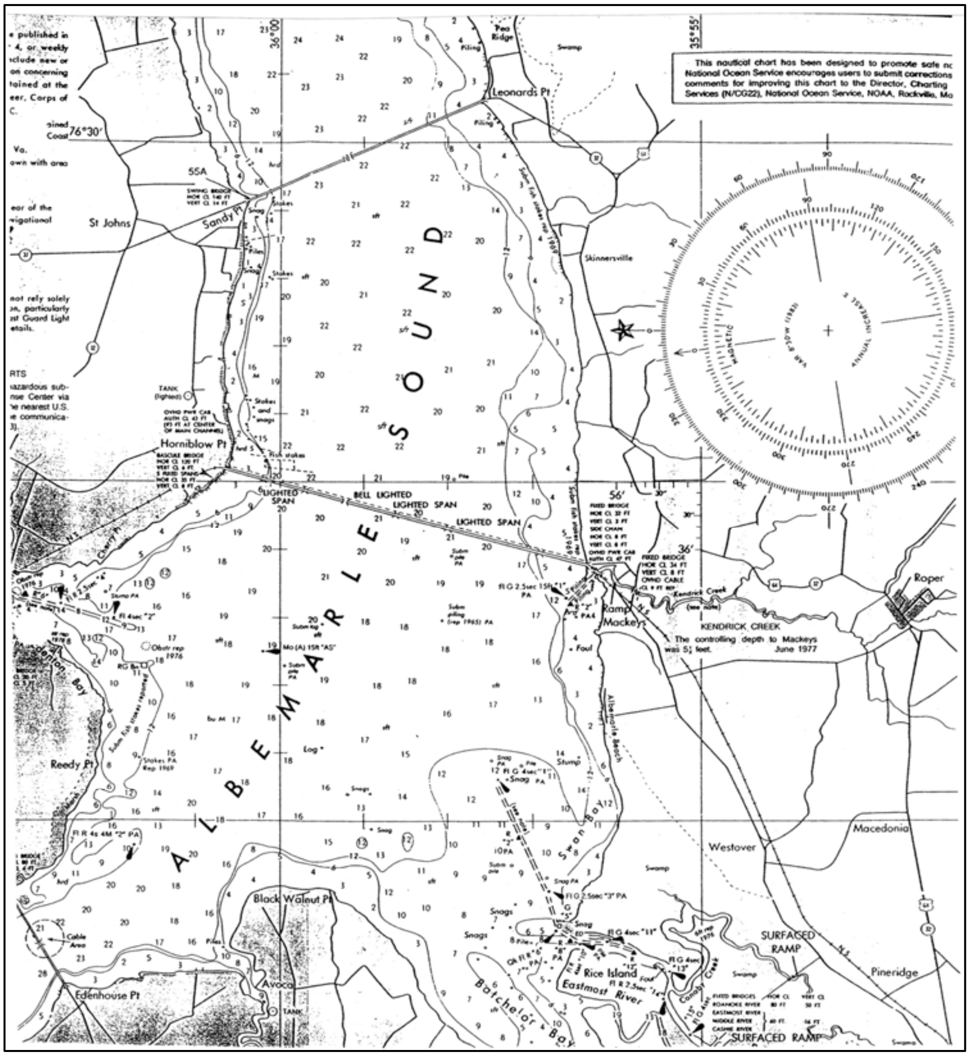


Figure 41. Location of Inner Albemarle Sound

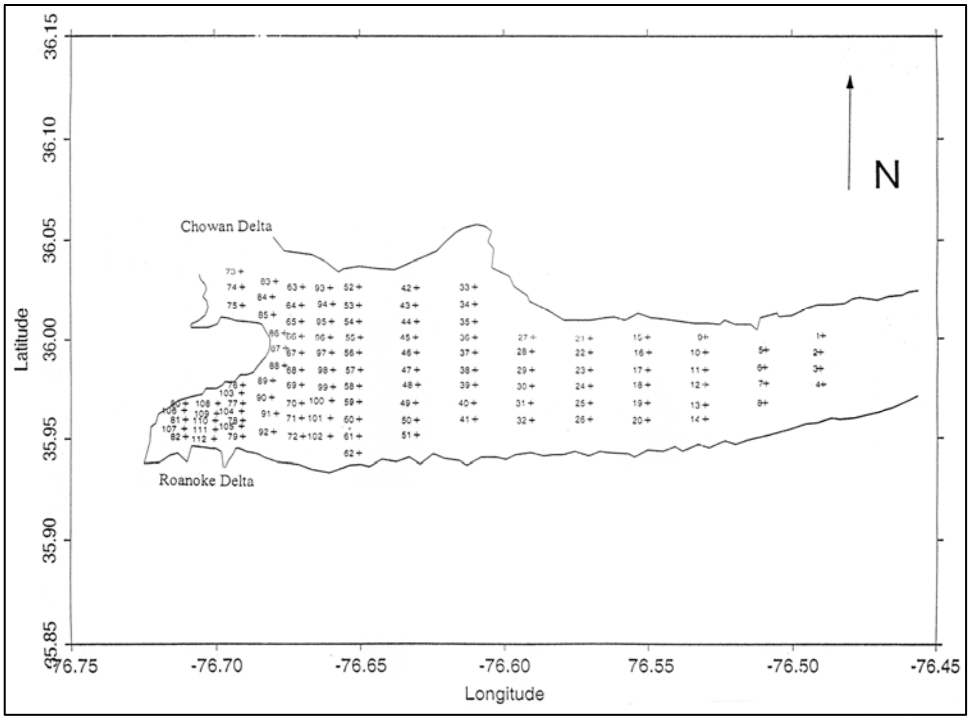


Figure 42. Location map of bed samples collected at Inner Albemarle Sound

Table 6
Mean Diameter, Percentage of Moisture Content and Total Organic Contents in Bed Samples at Albemarle Sound, NC

Station	Mean Diameter Microns	Moisture Content Percent	Total Organic Percent
1	5.96	169.77	11.34
2	5.89	187.56	12.83
3	7.96	220.54	13.31
4	11.56	232.57	13.89
5	5.5	200.51	12.61
6	6.47	203.75	13.12
7	8.29	239.89	13.79
8	13.71	218.85	13.7
9	8.94	215.15	13.47
10	4.96	179.92	12.39
11	4.84	150.27	11.59
12	5.58	198.62	12.32
13	9.31	228.65	13.53
14	9.02	194.08	13.61
15	7.91	244.17	15.49
16	5.88	178.2	13.12
17	4.67	158.91	12.29
18	7.17	265.42	13.89
19	9.71	272.49	13.85
20	11.95	234.16	12.79
21	13.2	286.54	15.84
22	6.53	239.07	13.28
23	6.89	237.16	13.66
24	7.21	224.48	13.21
25	8.73	213.06	12.61
26	12.92	238.21	12.68
27	9.77	228.66	15.91
28	7.14	227.64	14.41
29	7.21	287.53	13.64
30	8.02	243.97	13.03
31	8.55	204.5	12.78
32	14.75	198.66	11.77
33	59.82	182.45	11.92
34	23.85	273.35	18.71
35	7.52	292.43	15.96
36	6.68	280.98	14.72
37	6.94	233.62	15.09
38	7.12	228.41	14.13
39	7.32	240.53	13.71
40	8.42	233.42	12.98
41	13.01	209.92	11.68
42	9.01	0	0
43	7.85	277.57	16.02
44	6.87	285.3	15.25

(Continued)

Table 6 (Continued)			
Station	Mean Diameter Microns	Moisture Content Percent	Total Organic Percent
45	6.29	260.14	14.73
46	6.84	253.98	13.85
47	6.84	250.04	13.29
48	7.05	223.44	13.02
49	7.55	200.7	12.25
50	9.47	191.09	12.31
51	20.1	171.08	10.42
52	16.68	304.98	15.86
53	4.74	185.7	11
54	7.78	197.24	14.06
55	7.58	195.84	13.72
56	7.84	295.69	13.8
57	8.61	204.5	12.63
58	6.35	130.75	10.88
59	6.89	125.76	10.54
60	8.91	187.6	12.19
61	15.8	165.59	11.14
62	9.64	141.86	11.35
63	11.52	35.19	0.48
64	7.66	272.24	14.74
65	9.1	219.74	12.42
66	8.48	228.99	12.71
67	9.59	219.42	12.28
68	6.23	146.97	11.63
69	7.8	137.72	11.31
70	9.67	160.22	12.03
71	16.22	166.71	11.06
72	18.6	181.56	11.37
73	7.43	298.38	15.47
74	7.67	265.6	14.3
75	7.48	225.68	13.61
76	33.56	120.03	7.34
77	24.13	144.85	10.84
78	24.97	96.76	8.96
79	47.47	79.33	3.18
80	31.19	135.85	9.17
81	37.17	99.71	7.79
82	30.85	192.38	18.96
83	13.72	264.59	16.28
84	8.4	248.64	14.73
85	10	246.01	13.36
86	220.5	0	0
87	20.87	131.01	8.38
88	20.88	156.11	10.52
89	17.44	187.02	11.78
90	19.74	163.52	11.18

(Continued)

Table 6 (Concluded)			
Station	Mean Diameter Microns	Moisture Content Percent	Total Organic Percent
91	11.45	111.58	9.94
92	29.9	132.7	9.28
93	19.05	267.85	16.65
94	10.36	303.97	16.4
95	7.74	263.2	14.26
96	6.61	236.23	13.37
97	7.01	199.2	12.88
98	8.14	182.06	12.83
99	6.44	124.36	10.69
100	7.63	152.22	11.1
101	8.86	175.77	11.97
102	16.03	183.3	11.74
103	22.79	140.56	10.2
104	34.36	200.68	12.36
105	29.51	88.1	6.68
106	35.33	124.92	9.04
107	34.61	133.33	10.72
108	18.95	133.66	9.87
109	29.07	114.91	9.34
110	27.4	67.95	6.41
111	22.35	93.72	7.59
112	70.32	0	0

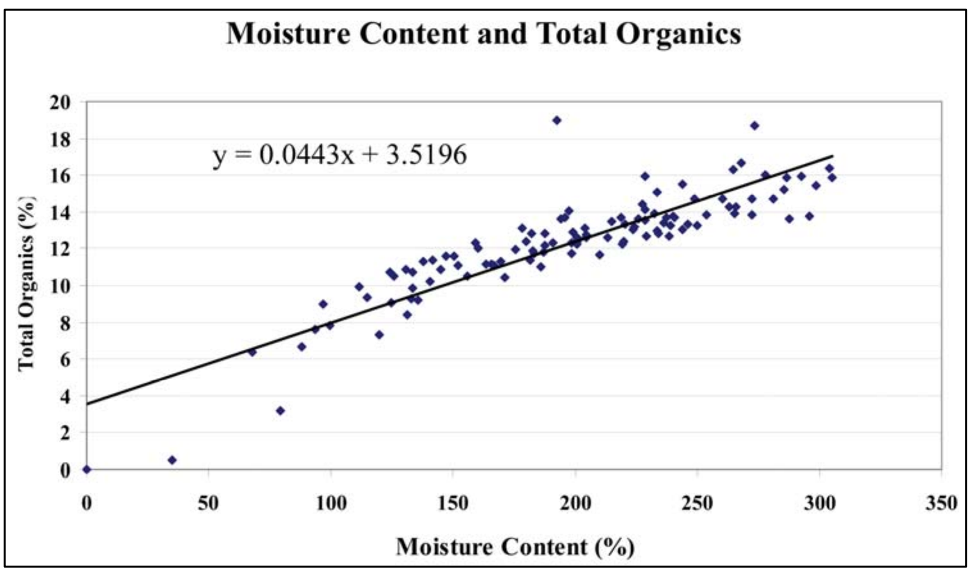


Figure 43. Total organics correlated to moisture content for Inner Albermarle Sound sediment

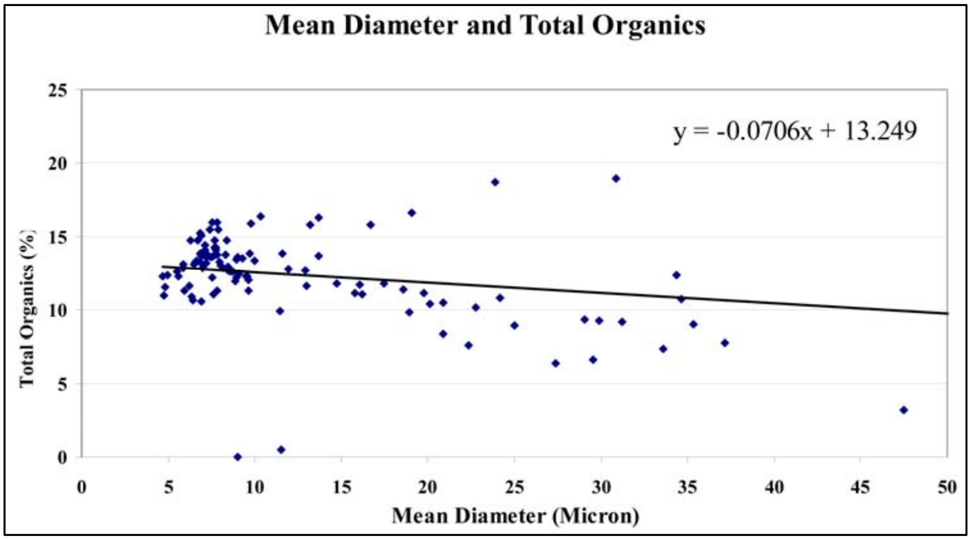


Figure 44. Total organics correlated to mean diameter for Inner Albemarle Sound sediment

Project 6: Upper Mississippi River (UMR)

Bed sediment samples were collected along the Mississippi River at the following stations: Wood Slough, Sugar Creek Island, Treadway Lake, Bath Chute, Bach Slough, Turkey Island, Coon Hollow Island, Big Soupbone Island North, Big Soupbone Island South, Open Impounded Area, Cook Slough South, Goetz Slough, Cassville Slough Complex, Cassville Slough North, Island 189, Frenchtown Lake North, Frenchtown Lake South, Broken Arrow Slough, Battle Slough, and Lost Channel Light.

The locations of sample collection are shown in Figures 45a through 45m. The number of samples collected at each location varied. The samples were analyzed to determine the following:

a. Percent silt plus clay

b. Total organic matter

c. Moisture content

d. Bed density

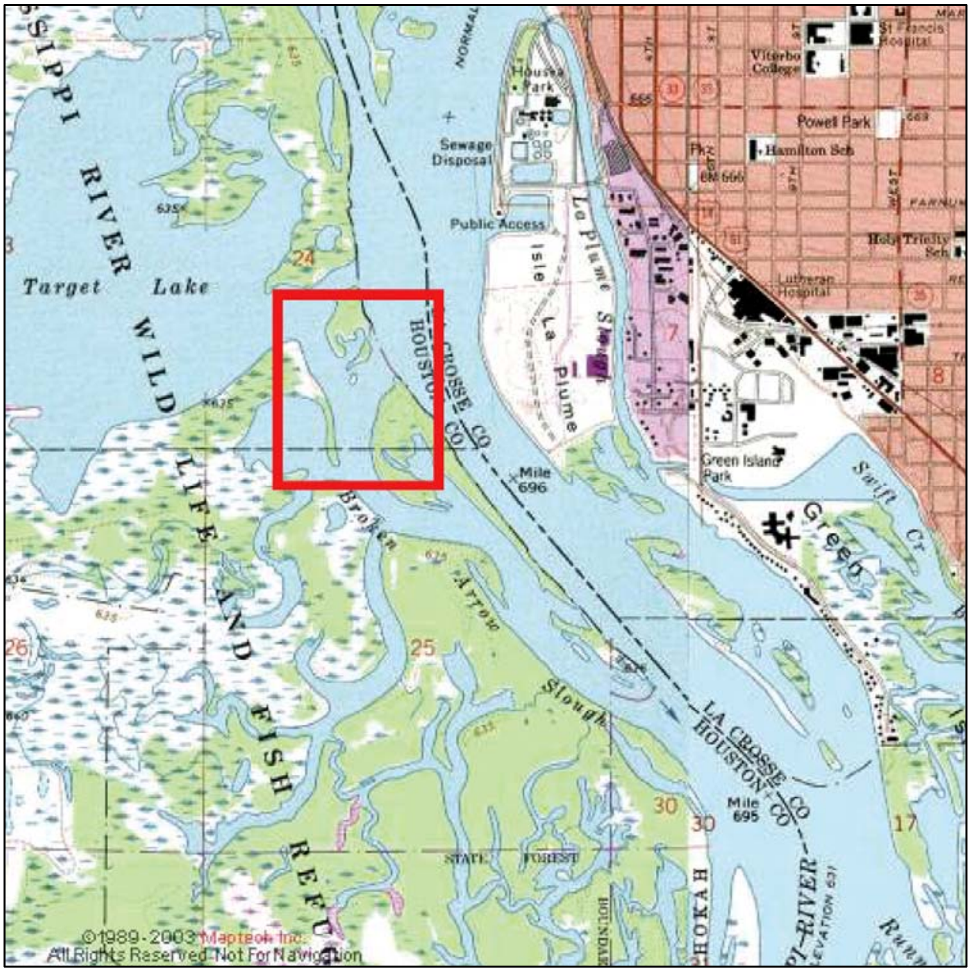


Figure 45a. Sediment sampling site, Broken Arrow Slough, in Pool 8, LaCrosse, WI

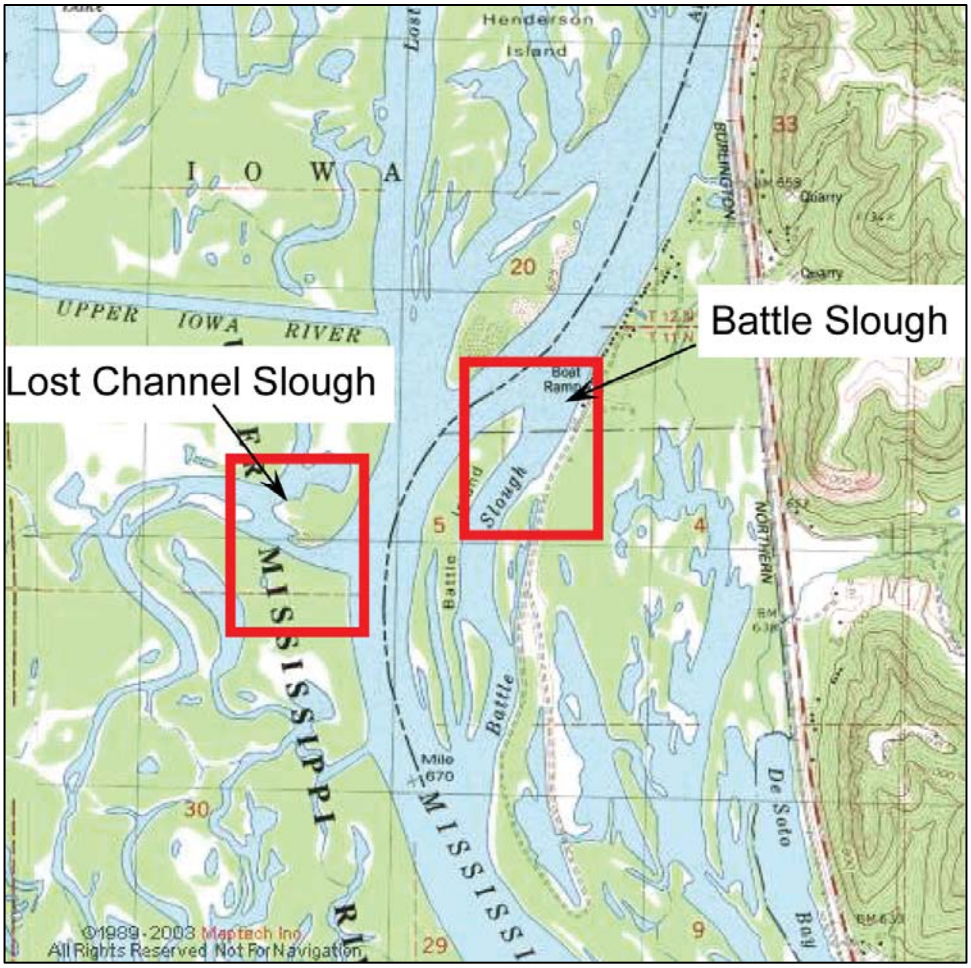


Figure 45b. Sediment sampling site, Battle Slough and Lost Channel Slough, in Pool 9

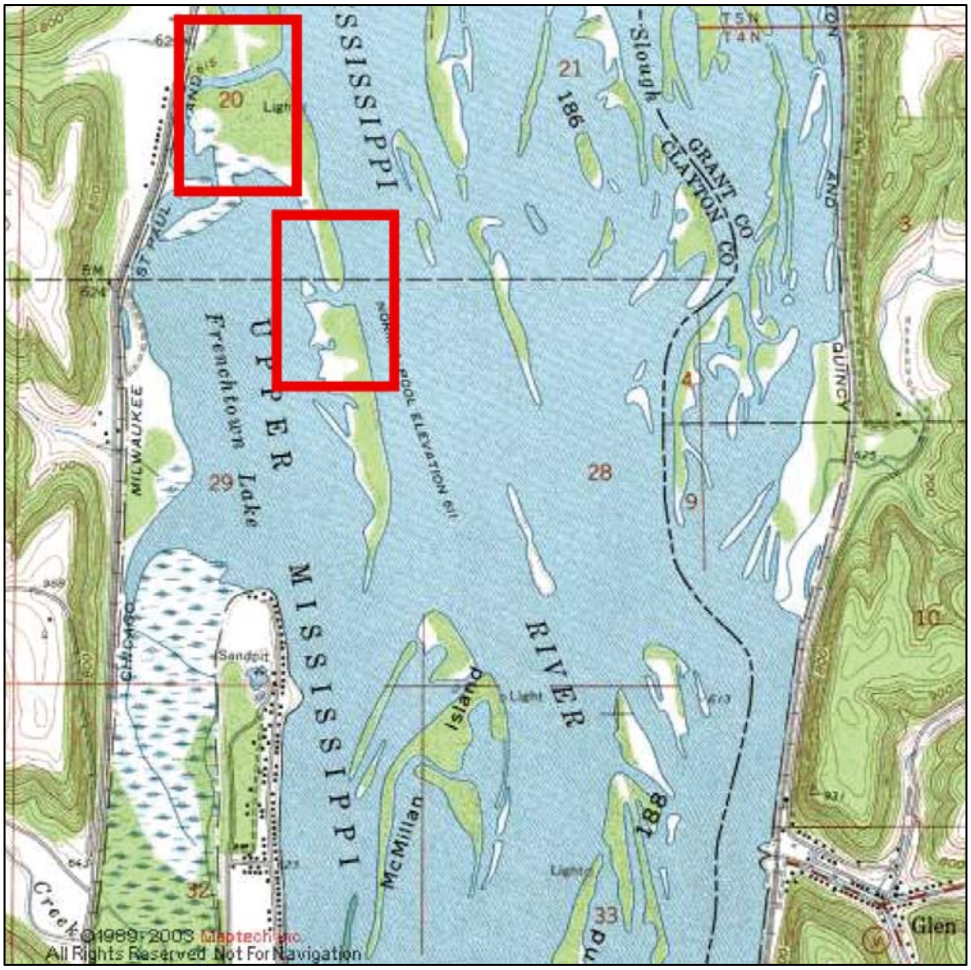


Figure 45c.   Sediment sampling site, Frechtown Lake north and south, in Pool 10

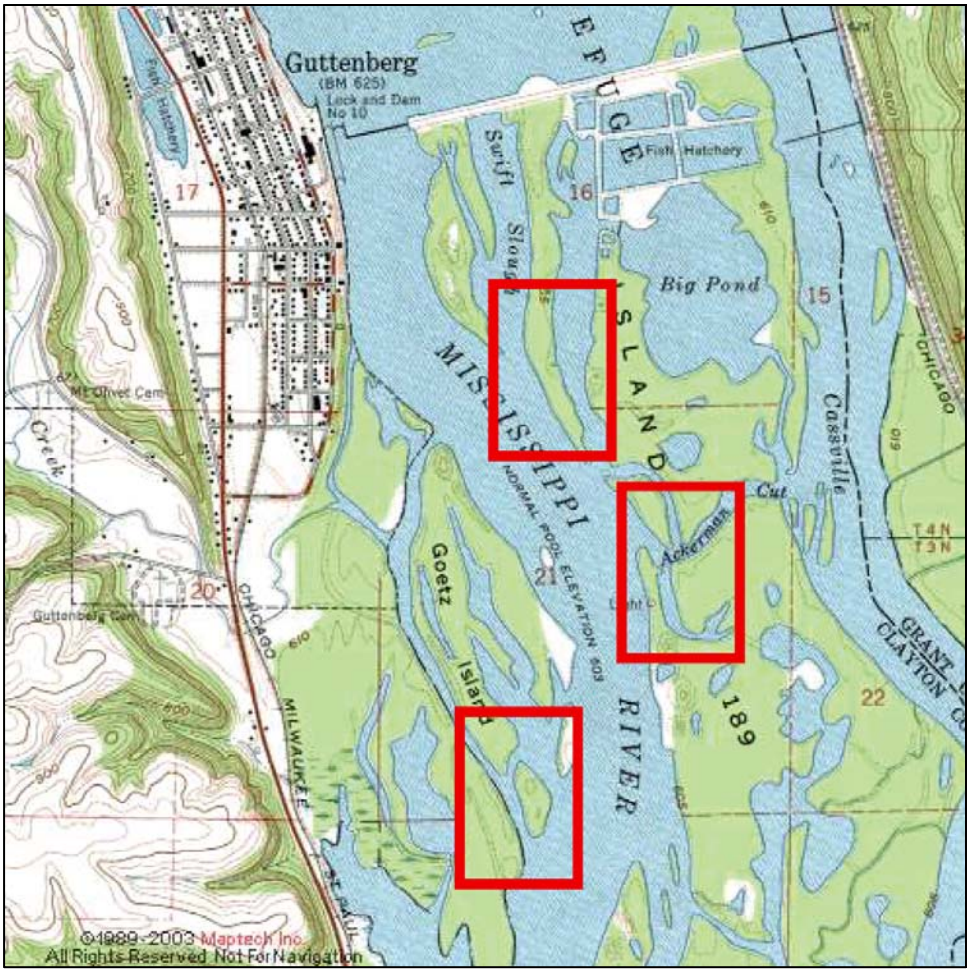


Figure 45d. Sediment sampling sites, Goetz Slough, Island 189 and Cassville Slough, in Pool 11

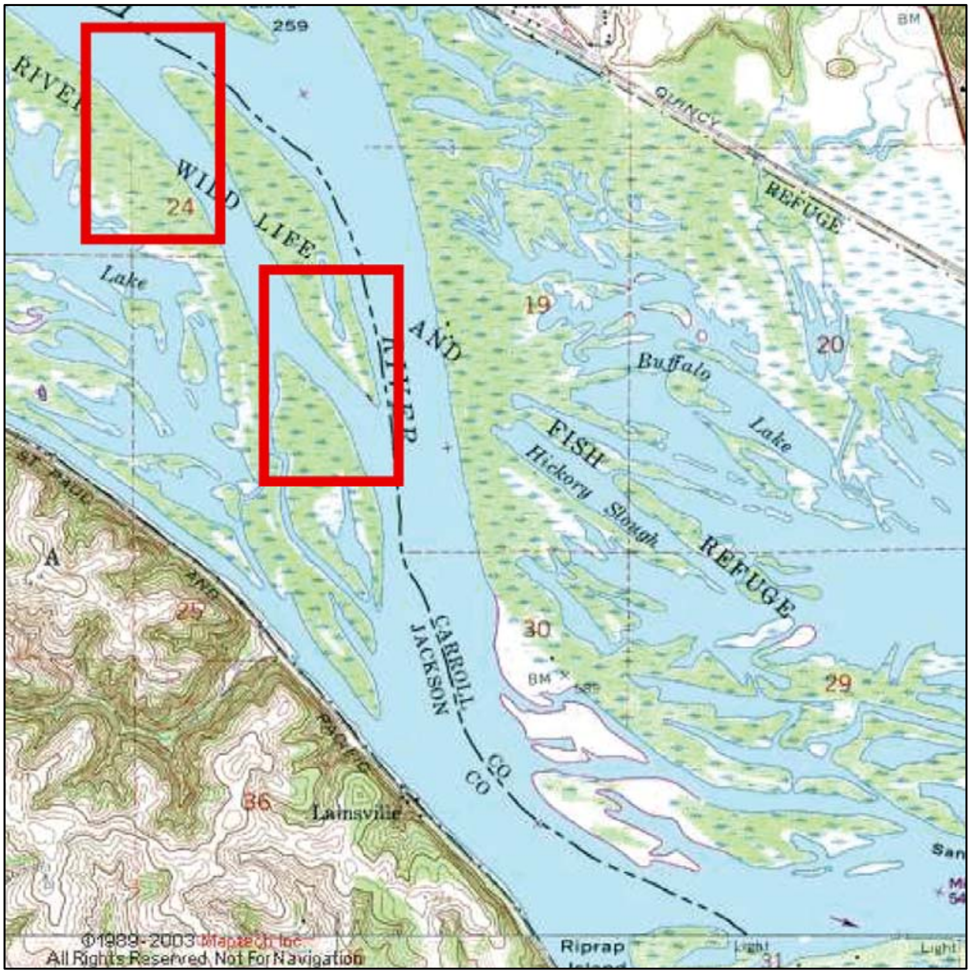


Figure 45e. Sediment sampling site, Big Soupbone Island, in Pool 13

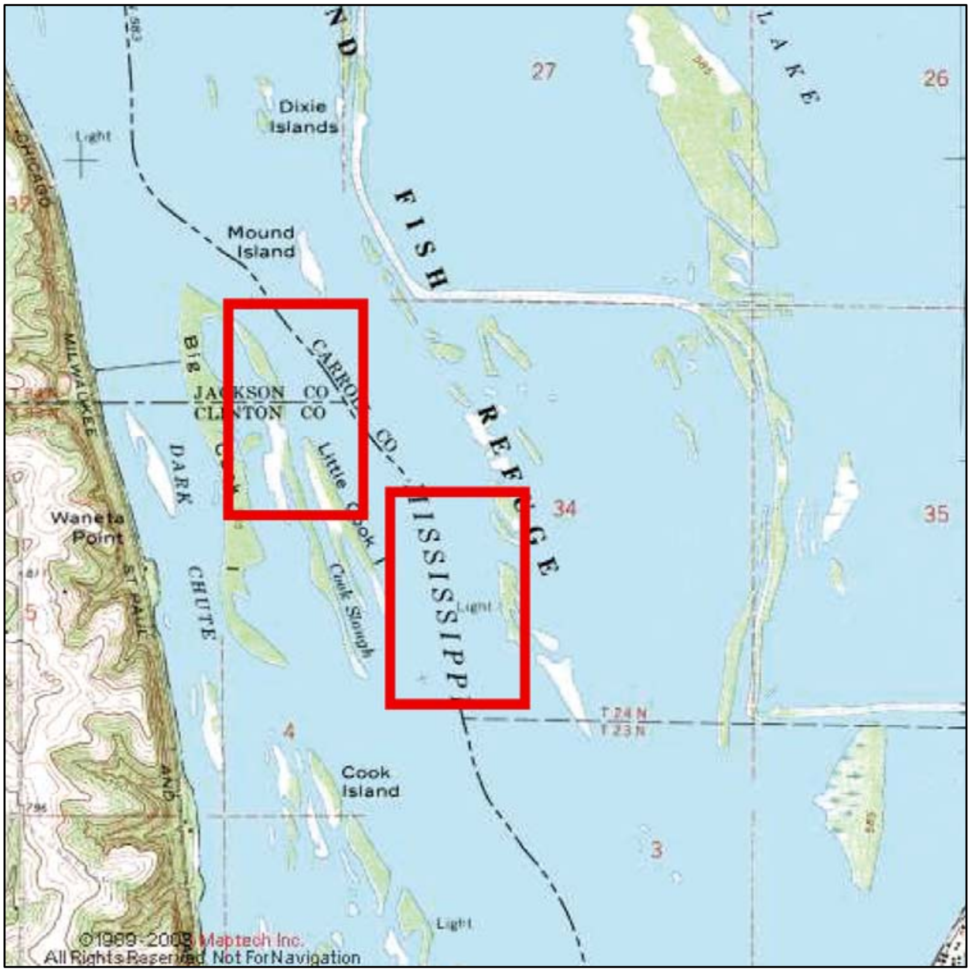


Figure 45f. Sediment sampling site, Cook Slough north and south, in Pool 13

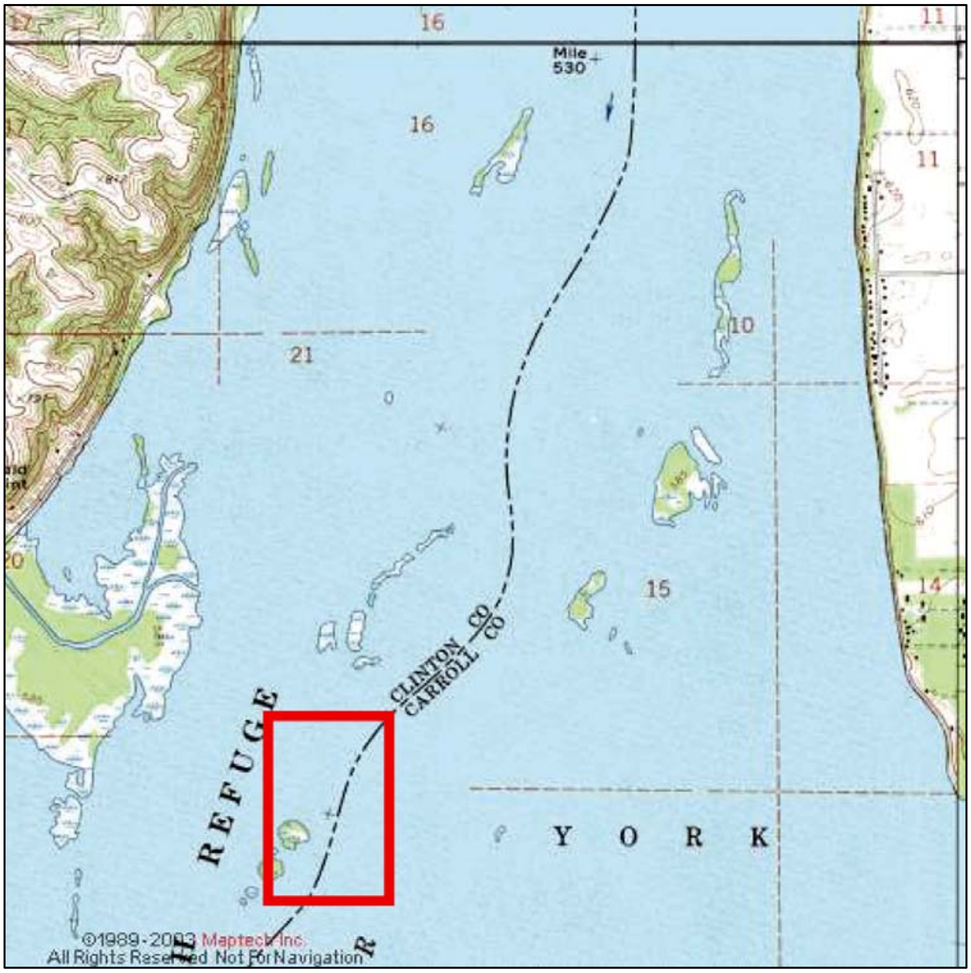


Figure 45g. Sediment sampling site, UMR river mile 528.0, in Pool 13

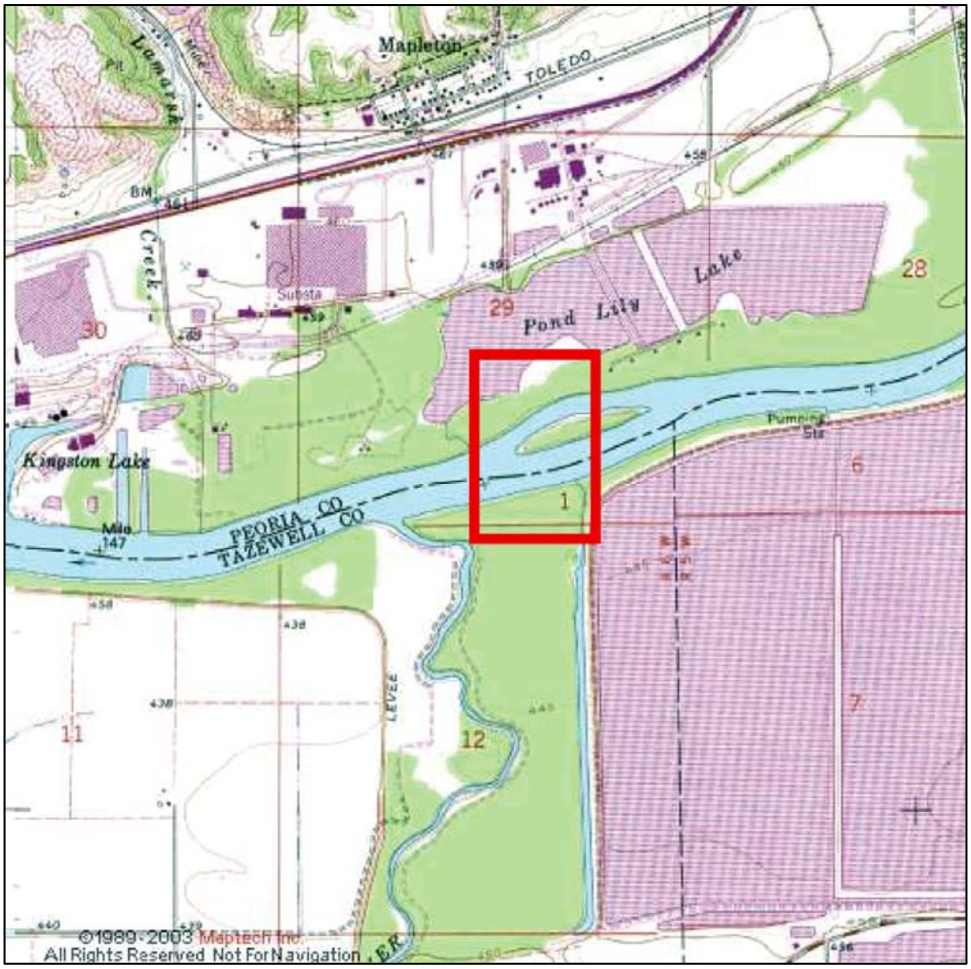


Figure 45h. Sediment sampling site, Turkey Island at Illinois River, mile 148.4, in La Grange Pool

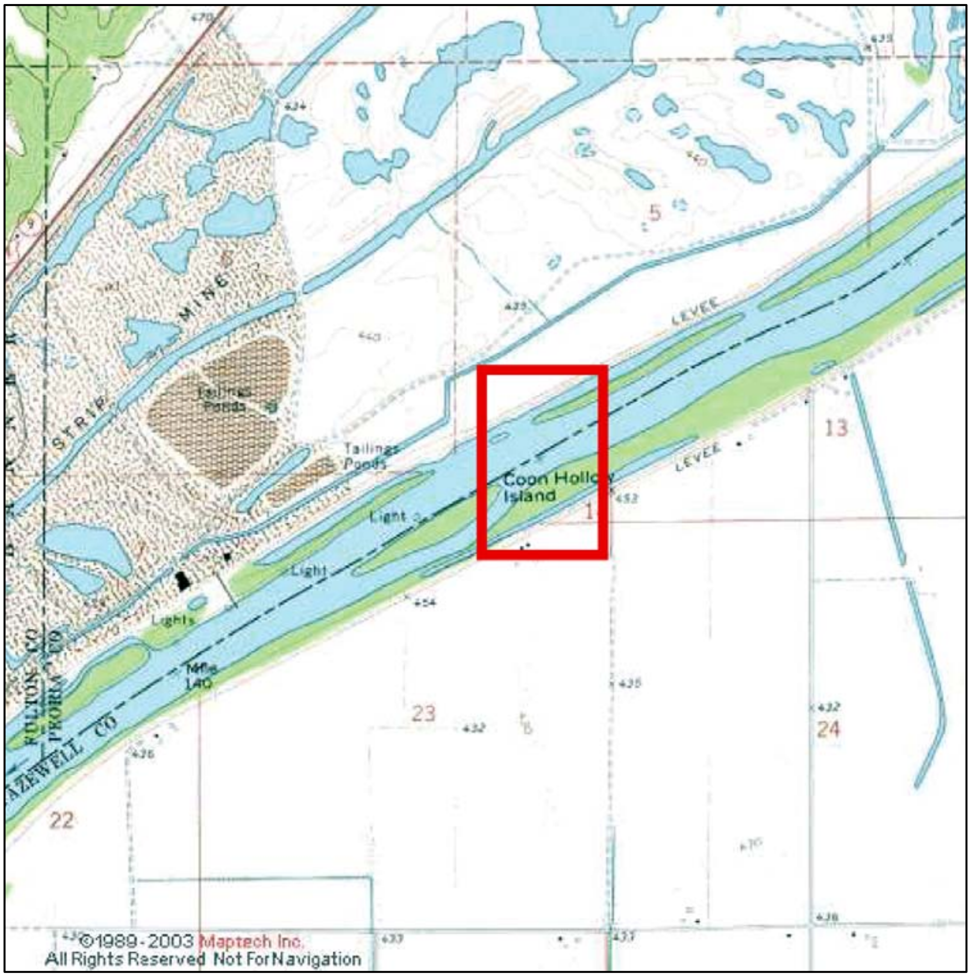


Figure 45i. Sediment sampling site, Coon Hollow Island at Illinois River, mile 140.9, in La Grange Pool

Figure 45j. Sediment sampling site, Bath Chute at Illinois River, mile 113.4, in La Grange Pool

Figure 45k. Sediment sampling site, Bach Slough at Illinois River, mile 98.0, in La Grange Pool

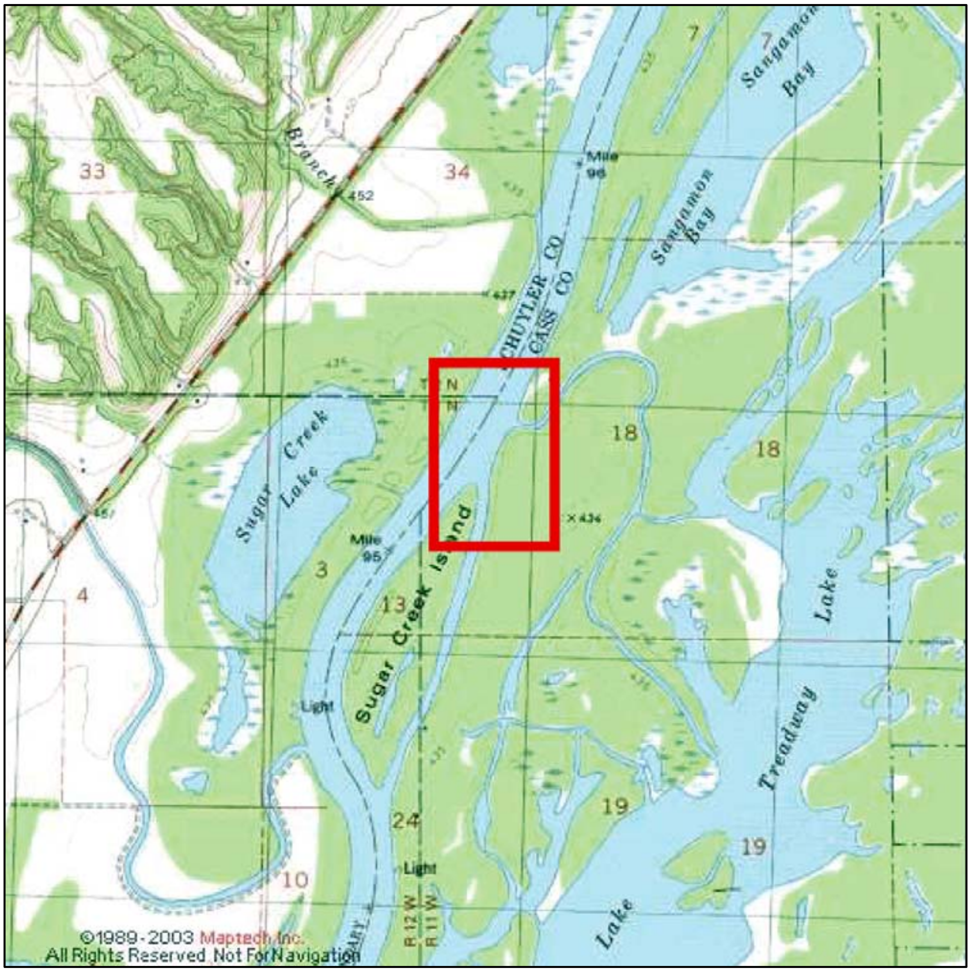


Figure 45l. Sediment sampling site, Sugar Creek Island and Treadway Lake at Illinois River, mile 95.3, in the La Grange Pool

Figure 45m. Sediment sampling site, Wood Slough at Illinois River mile 91.9, in La Grange Pool

The results of analysis for sediment collected at the listed 20 station locations are presented in Tables 7 and 8 and also through plots of data. Appendix 2 gives plots of bed density as a function of percent organic matter. Appendix 3 gives plots of bed density as function of percent moisture content. Appendix 4 gives plots of percent organic matter as a function of percentage of sediment finer than 64 μ. Appendix 5 gives plots of bed density as a function of percent finer than 64 μ. Appendix 5 gives plots of percent moisture content as a function of percent finer than 64 μ.

Table 7
Upper Mississippi River Sediment Analysis

Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64μ	% Silt/Clay <64μ
Wood Slough						
91.9/1	3.0	1.3165	1365	5.59	3.47	95.53
91.9/2	0.0	0.3671	1834	2.45	38.56	61.44
91.9/3	0.5	0.4474	1753	3.88	24.45	75.55
91.9/4	1.0	0.5636	1659	3.54	29.3	70.7
91.9/5	1.5	0.5025	1705	3.16	28.8	71.2
91.9/6	0.0	0.4501	1750	3.13	42.2	57.8
91.9/7	0.5	0.5875	1643	3.73	33.14	66.86
91.9/8	1.0	0.4679	1735	3.80	24.64	75.36
91.9/9	1.5	0.5079	1701	3.03	29.09	70.91
91.9/10	0.5	0.4468	1753	3.22	15.53	84.47
91.9/11	0.5	0.5024	1706	2.78	35.59	64.41
91.9/12	0.5	0.2589	1977	1.33	6.77	93.23
91.9/13	0.5	0.7676	1542	3.26	4.76	95.24
91.9/14	0.5	0.6537	1602	3.50	34.06	65.94
Average		0.5600	1695	3.31	25.03	74.97
Sugar Creek Island						
95.3/1	1.5	0.5881	1643	3.41	35.63	64.37
95.3/2	0.0	0.4203	1779	4.35	28.43	71.57
95.3/3	0.5	1.8527	1277	4.73	17.04	82.96
95.3/4	1.0	0.6582	1599	4.09	20.02	79.98
95.3/5	1.5	0.5729	1653	2.42	37.7	62.3
95.3/6	0.0	0.7277	1561	3.42	21.09	78.91
95.3/7	0.5	0.8302	1514	4.75	18.4	81.6
95.3/8	1.0	0.3906	1809	2.89	39.25	60.75
95.3/9	1.5	0.5319	1683	3.91	24.85	75.15
95.3/10	0.5	0.8636	1500	4.48	28.36	71.64
Average		0.7436	1601	3.84	27.08	72.92
Treadway Lake						
95.4/1	0.6	0.4271	1772	3.38	27.91	72.09
95.4/2	0.0	0.8991	1486	7.34	8.06	91.94
95.4/3	0.5	0.8641	1499	5.48	13.6	86.4
95.4/4	1.0	0.4651	1737	4.41	11.71	88.29
95.4/5	1.5	0.5330	1682	5.96	16.65	83.35
95.4/6	0.0	0.6808	1586	4.98	10.43	89.57
95.4/7	0.5	0.7422	1554	4.35	10.09	89.91
95.4/8	1.0	0.4558	1745	2.88	15.92	84.08
95.4/9	1.5	0.4521	1749	3.27	14.83	85.17
95.4/10	0.5	0.6247	1619	4.29	12.63	87.37
95.4/11	0.5	1.0346	1439	5.58	10.89	89.11
95.4/12	0.5	0.7071	1572	5.15	15.84	84.16
95.4/13	0.5	0.7109	1570	6.87	4.21	95.79
95.4/14	0.5	0.8318	1513	5.55	6.13	93.87
Average		0.6734	1609	4.96	12.78	87.22

(Continued)

Table 7 (Continued)						
Station	**Depth, m**	**Moisture Content**	**Bed Density, kg/m^3**	**% Total Organic Matter**	**% Sand >64µ**	**% Silt/Clay <64µ**
			Bath Chute			
113.4/1	1.7	0.2197	2041	1.54	81.69	18.31
113.4/2	0.0	0.5569	1664	3.47	34.04	65.96
113.4/3	0.5	0.5220	1690	1.87	38.94	61.06
113.4/4	1.0	0.4987	1709	2.61	41.36	58.64
113.4/5	1.5	0.4510	1750	1.43	69.31	30.69
113.4/6	0.3	0.6588	1599	4.06	11.19	88.81
113.4/7	0.5	0.4879	1718	2.44	57.42	42.58
113.4/8	1.0	0.4313	1768	2.28	63.95	36.05
113.4/9	1.5	0.5137	1697	2.59	42.81	57.19
113.4/10	0.5	0.5369	1679	4.59	49.61	50.39
113.4/11	0.5	0.6228	1620	4.55	49.84	50.16
113.4/12	0.5	0.5584	1663	4.45	49.66	50.34
113.4/13	0.5	0.5782	1650	4.34	49.2	50.8
113.4/14	0.5	0.5862	1644	4.39	23.4	76.6
Average		0.5159	1706	3.18	47.32	52.68
			Bach Slough			
98.0/1	0.5	0.8389	1510	5.18	15.66	84.34
98.0/2	0.0	0.8447	1507	5.86	6.82	93.18
98.0/3	0.5	0.7556	1547	4.65	11.06	88.94
98.0/4	1.0	0.6653	1595	4.89	4.39	95.61
98.0/5	1.5	0.9155	1479	6.16	1.02	98.98
98.0/6	0.0	0.7446	1553	6.22	2.19	97.81
98.0/7	0.5	0.5258	1687	4.86	2.44	97.56
98.0/8	1.0	0.5146	1696	5.03	3.94	96.06
98.0/9	1.5	0.5946	1639	5.01	6.17	93.83
98.0/10	0.5	0.5333	1682	3.88	19.04	80.96
98.0/11	0.5	0.8308	1513	5.17	3.51	96.49
98.0/12	0.5	0.5205	1692	4.64	5.46	94.54
98.0/13	0.5	0.5743	1652	5.61	1.49	98.51
98.0/14	0.5	0.6282	1617	4.26	6.6	93.4
Average		0.6776	1598	5.10	6.41	93.59
			Turkey Island			
148.4/1	1.0	0.2841	1940	1.10	96.14	3.86
148.4/2	0.0	0.4051	1794	3.28	34.66	65.34
148.4/3	0.5	0.3993	1800	1.70	80.13	19.87
148.4/4	1.0	0.3742	1827	1.28	93.09	6.91
148.4/5	0.0	0.2739	1954	1.73	91.31	8.69
148.4/6	0.5	0.3424	1863	1.16	91.88	8.12
148.4/7	1.0	0.3350	1872	0.68	92.2	7.8
148.4/8	1.5	0.2888	1933	2.38	38.07	61.93
148.4/9	0.5	0.2771	1950	0.85	97.35	2.65
148.4/10	0.5	0.4397	1760	1.36	23.21	76.79
148.4/11	0.5	0.4409	1759	3.77	81.61	18.39
148.4/12	0.5	0.8068	1524	4.25	29.65	70.35
						(Continued)

Table 7 (Continued)						
Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64µ	% Silt/Clay <64µ
148.4/13	0.5	0.5820	1647	2.52	79.5	20.5
Average		0.4037	1817	2.00	71.45	28.55
Coon Hollow Island						
140.9/1	1.5	0.2671	1965	0.59	95.29	4.71
140.9/2	0.0	0.3639	1838	1.31	90.84	9.16
140.9/3	0.5	0.5147	1696	2.59	60.06	39.94
140.9/4	1.0	0.3098	1904	0.80	81.1	18.9
140.9/5	0.0	0.4318	1768	2.51	81.63	18.37
140.9/6	0.5	0.4156	1783	2.91	59.63	40.37
140.9/7	1.0	0.4788	1725	3.59	23.12	76.88
140.9/8	1.5	0.2888	1933	0.53	98.62	1.38
140.9/9	0.5	0.5694	1656	3.37	31.49	68.51
140.9/10	0.5	0.6153	1625	2.41	64.3	35.7
140.9/11	0.5	0.4337	1766	1.90	78.88	21.12
140.9/12	0.5	0.6889	1582	2.61	52.95	47.05
140.9/13	0.5	0.5170	1694	5.34	20.38	79.62
Average		0.4534	1764	2.34	64.48	35.52
Big Soupbone Island North						
543.3/1	4.2	0.2501	1991	0.20	99.98	0.02
543.3/2	0.0	0.3105	1903	1.92	51.92	48.08
543.3/3	0.5	0.4382	1762	2.89	33.57	66.43
543.3/4	1.0	0.3278	1881	2.29	13.73	86.27
543.3/5	1.5	0.5393	1677	3.80	23.44	76.56
543.3/6	0.0	0.4259	1773	2.03	72.45	27.55
543.3/7	0.5	0.5180	1693	2.92	20.64	79.36
543.3/8	1.0	0.3540	1850	3.62	14.43	85.57
543.3/9	1.5	0.5034	1705	2.70	41.87	58.13
543.3/10	0.5	0.6538	1602	4.07	7.47	92.53
543.3/11	0.5	0.5911	1641	3.03	35.02	64.98
543.3/12	0.5	0.4705	1732	3.17	33.59	66.41
543.3/13	0.5	0.4805	1724	2.52	50.04	49.96
543.3/14	0.5	0.3791	1821	1.48	55.21	44.79
Average		0.4459	1768	2.62	39.53	60.47
Big Soupbone Island South						
542.0/1	6.1	0.2687	1962	0.18	100	0
542.0/2	0.0	0.4493	1751	3.81	6.74	93.26
542.0/3	0.5	0.4463	1754	3.90	4.74	95.26
542.0/4	1.0	0.3901	1809	3.52	18.03	81.97
542.0/5	1.5	0.4528	1748	5.09	0.07	99.93
542.0/6	0.0	0.3007	1917	0.64	95.85	4.15
542.0/7	0.5	0.4732	1730	4.14	10.92	89.08
542.0/8	1.0	0.4305	1769	3.27	15.46	84.54
542.0/9	1.5	0.6742	1590	5.93	6.27	93.73
542.0/10	0.5	0.6693	1593	4.52	14.63	85.37
542.0/11	0.5	0.4975	1710	3.65	22.58	77.42
						(Continued)

Table 7 (Continued)						
Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64μ	% Silt/Clay <64μ
542.0/12	0.5	0.6202	1622	4.19	1.87	98.13
542.0/13	0.5	0.5370	1679	3.13	32.21	67.79
542.0/14	0.5	0.5607	1662	2.62	30.61	69.39
Average		0.4836	1735	3.47	25.71	74.29
Open Impounded Area						
528.0/1	0.5	0.2593	1976	0.51	97.12	2.88
528.0/2	1.0	0.6000	1635	3.19	10.43	89.57
528.0/3	1.5	0.2454	1998	0.46	92.31	7.69
528.0/4	1.5	0.2529	1986	0.51	90.49	9.51
528.0/5	1.0	0.4665	1736	4.08	13.32	86.68
528.0/6	0.5	0.2694	1961	0.39	98.42	1.58
Average		0.3489	1882	1.52	67.01	32.99
Cook Slough South						
532.0/1	1.0	0.2947	1925	0.31	99.68	0.32
532.0/2	0.0	0.4230	1776	1.90	68.32	31.68
532.0/3	0.5	0.4600	1742	1.63	50.83	49.17
532.0/4	1.0	0.6973	1577	8.06	30.98	69.02
532.0/5	1.5	0.7288	1561	5.48	26.6	73.4
532.0/6	0.0	0.3514	1853	1.67	72.17	27.83
532.0/7	0.5	0.4705	1732	2.83	28.87	71.13
532.0/8	1.0	0.4505	1750	4.24	63.99	36.01
532.0/9	1.5	0.5004	1707	4.53	9.38	90.62
532.0/10	0.5	0.4041	1795	3.93	35.93	64.07
532.0/11	0.5	0.5095	1700	2.57	50.1	49.9
532.0/12	0.5	0.3343	1873	1.06	81.58	18.42
532.0/13	0.5	0.3745	1826	1.50	69.76	30.24
532.0/14	0.5	0.6810	1586	4.56	29.95	70.75
532.7/1	1.3	0.4343	1765	1.66	77.72	22.28
532.7/2	0.5	0.6755	1589	3.78	15.74	84.26
532.7/3	1.0	0.4980	1709	1.91	33.9	66.1
532.7/4	1.5	0.5935	1639	3.20	50.61	49.39
532.7/5	0.5	0.3966	1803	2.69	22.01	77.99
532.7/6	1.0	0.3461	1859	2.84	26.35	73.65
532.7/7	1.5	0.3015	1915	1.52	70.75	29.25
532.7/8	0.5	0.5113	1699	3.90	49.73	50.27
Average		0.4744	1745	2.99	48.41	51.59
Goetz Slough						
612.6/1	1.3	0.5249	1688	3.31	42.96	57.04
612.6/2	0.0	0.2499	1991	0.37	97.78	2.22
612.6/3	0.5	0.6552	1601	4.23	16.83	83.17
612.6/4	1.0	0.2654	1967	0.63	94.85	5.15
612.6/5	1.5	0.2669	1965	0.34	98.02	1.98
612.6/6	0.0	0.1868	2102	0.66	97.17	2.83
612.6/7	0.5	0.2499	1991	0.39	95.95	4.05
612.6/8	1.0	0.7328	1559	4.69	15.9	84.1
						(Continued)

Table 7 (Continued)						
Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64μ	% Silt/Clay <64μ
612.6/9	1.5	0.4000	1799	3.15	30.94	69.06
612.6/10	0.5	0.2656	1967	0.52	94.77	5.23
612.6/11	0.5	0.5382	1678	3.64	17.64	82.36
612.6/12	0.5	0.4878	1718	3.47	24.11	75.89
612.6/13	0.5	0.3179	1894	1.07	79.95	20.05
612.6/14	0.5	0.2832	1941	0.37	99.07	0.93
Average		0.3874	1847	1.92	64.71	35.29
Cassville Slough Complex						
613.1/1	1.8	0.2520	1988	0.30	99.87	0.13
613.1/2	0.0	0.3848	1815	2.70	61.64	38.36
613.1/3	0.5	0.5166	1695	3.87	32.94	67.06
613.1/4	1.0	0.3402	1866	1.77	59.2	40.8
613.1/5	1.5	0.2831	1941	0.82	88.27	11.73
613.1/6	0.0	0.3533	1850	3.16	36.31	63.69
613.1/7	0.5	0.4159	1783	3.97	21.95	78.05
613.1/8	1.0	0.3424	1863	3.18	45.43	54.57
613.1/9	1.5	0.3708	1830	3.60	77.38	22.62
613.1/10	0.5	0.3896	1810	2.84	45.22	54.78
613.1/11	0.5	0.4309	1768	2.96	36.51	63.49
613.1/12	0.5	0.3100	1904	1.09	96.18	3.82
613.1/13	0.5	0.4437	1756	3.54	71.41	28.59
613.1/14	0.5	0.6052	1632	5.29	44.97	55.03
Average		0.3884	1821	2.79	58.38	41.62
Cassville Slough North						
613.9/1	9.1	0.3000	1917	1.01	94.97	5.03
613.9/2	0.0	0.9602	1463	6.86	21.25	78.75
613.9/3	0.5	0.6347	1613	3.99	41.79	58.21
613.9/4	1.0	0.3662	1836	1.82	67.6	32.4
613.9/5	1.5	0.3324	1876	0.81	82.88	17.12
613.9/6	0.0	0.4253	1774	3.01	47.28	52.72
613.9/7	0.5	0.3071	1908	1.15	88.66	11.34
613.9/8	1.0	0.2981	1920	0.66	88.5	11.5
613.9/9	1.5	0.3044	1912	0.47	93.95	6.05
613.9/10	0.5	0.2843	1939	0.26	98.89	1.11
613.9/11	0.5	0.2559	1982	0.21	99.11	0.89
Average		0.3191	1438	1.45	58.92	19.65
Island 189						
614.0/1	1.8	0.5488	1670	2.43	40.33	59.67
614.0/2	0.0	0.6904	1581	4.75	4.42	95.58
614.0/3	0.5	0.5635	1660	4.04	16.9	83.1
614.0/4	1.0	0.5455	1673	3.87	5.7	94.3
614.0/5	1.5	0.5815	1647	3.63	43.63	56.37
614.0/6	0.0	0.4291	1770	3.84	69.11	30.89
614.0/7	0.5	0.4339	1766	2.53	51.21	48.79
614.0/8	1.0	0.4947	1712	4.03	53.68	46.32

(Continued)

Table 7 (Continued)						
Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64µ	% Silt/Clay <64µ
614.0/9	1.5	0.5071	1702	4.68	35.19	64.81
614.0/10	0.5	0.2598	1976	0.71	76.05	23.95
614.0/11	0.5	0.2740	1954	0.78	92.56	7.44
614.0/12	0.5	0.2795	1946	0.68	90.17	9.83
614.0/13	1.4	0.2806	1945	0.49	98.53	1.47
614.0/14	0.5	0.2961	1923	0.57	93.05	6.95
614.0/15	1.0	0.3110	1903	0.35	98.18	1.82
614.0/16	0.5	0.4269	1772	3.26	19	81
614.0/17	1.0	0.4035	1796	3.27	28.02	71.98
Average		0.4309	1788	2.58	53.87	46.13
Frenchtown Lake North						
620.3/1	1.5	2.3007	1230	5.41	24.06	75.94
620.3/2	0.0	0.5560	1665	2.29	61.03	38.97
620.3/3	0.5	0.5395	1677	2.83	77.14	22.86
620.3/4	1.0	0.9441	1469	3.63	55.42	44.58
620.3/5	1.5	1.4561	1337	2.65	65.59	34.41
620.3/6	0.0	0.5926	1640	3.51	59.34	40.66
620.3/7	0.5	0.7760	1538	2.47	79.23	20.77
620.3/8	1.0	0.6189	1623	3.33	40.13	59.87
620.3/9	1.5	0.5984	1636	2.99	30.67	69.33
620.3/10	0.5	0.9823	1456	4.13	49.32	50.68
620.3/11	0.5	0.4928	1714	1.45	81.34	18.66
620.3/12	0.5	0.4836	1721	2.28	55.56	44.44
620.3/13	0.5	0.7982	1528	3.13	63.9	36.1
620.3/14	0.5	0.7328	1559	2.60	33.31	66.69
Average		0.8480	1556	3.05	55.43	44.57
Frenchtown Lake South						
619.8/1	2.7	0.5287	1685	3.04	10.84	89.16
619.8/2	0.0	0.4599	1742	2.30	71.23	28.77
619.8/3	0.5	0.7073	1572	3.09	49.33	50.67
619.8/4	1.0	1.0076	1447	3.28	56.50	43.50
619.8/5	1.5	0.5384	1678	1.59	74.14	25.86
619.8/6	0.0	0.5409	1676	3.38	31.89	68.11
619.8/7	0.5	0.6972	1577	4.41	11.61	88.39
619.8/8	1.0	0.5330	1682	3.25	20.16	79.84
619.8/9	1.5	0.6411	1609	3.52	27.37	72.63
619.8/10	0.0	0.5750	1652	4.51	26.68	73.32
619.8/11	0.5	0.4541	1747	1.83	57.04	42.96
619.8/12	1.0	0.4572	1744	3.45	32.30	67.70
619.8/13	1.5	0.6224	1621	3.13	25.86	74.14
619.8/14	0.5	0.5200	1693	3.24	43.26	56.74
619.8/15	0.5	0.6210	1622	3.48	32.44	67.56
619.8/16	0.5	0.5015	1707	2.79	34.13	65.87
619.8/17	0.5	0.4708	1732	2.10	62.06	37.94
Average		0.5808	1658	3.08	39.23	60.77
						(Continued)

Table 7 (Concluded)						
Station	Depth, m	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64µ	% Silt/Clay <64µ
Broken Arrow Slough						
696.3/2	0.0	0.3090	1905	0.64	94.95	5.05
696.3/3	0.5	0.2965	1922	1.30	89.42	10.58
696.3/4	1.0	0.3660	1836	0.90	89.18	10.82
696.3/5	1.5	0.3394	1867	0.65	93.17	6.83
696.3/6	0.0	0.3133	1900	0.69	92.98	7.02
696.3/7	0.5	0.3245	1885	0.63	93.05	6.95
696.3/8	1.0	0.3086	1906	0.52	93.57	6.43
696.3/9	1.5	0.3982	1801	0.85	89.60	10.40
696.3/10	0.5	0.5048	1704	2.62	66.26	33.74
696.3/11	0.5	0.4091	1790	1.80	79.56	20.44
696.3/12	0.5	0.4448	1755	1.40	72.06	27.94
696.3/13	0.5	0.2794	1946	0.37	99.24	0.76
696.3/14	0.5	0.3600	1843	0.71	94.81	5.19
696.3/1	2.8	0.2510	1990	0.29	99.97	0.03
696.3/15	4.9	0.2304	2023	0.47	92.36	7.64
Average		0.3368	2005	0.98	95.73	11.41
Battle Slough						
671.1/1	2.1	0.2470	1996	0.30	100	0
671.1/2	3.0	0.2470	1996	0.49	99.99	0.01
671.1/3	3.0	0.2450	1999	0.35	99.57	0.43
671.1/4	0.5	0.3183	1893	0.79	92.06	7.94
671.1/5	0.5	0.5964	1637	2.93	69.32	30.68
Average		0.3306	1904	0.97	92.19	7.81
Lost Channel Light						
670.1/1	3.0	0.3272	1882	0.89	92.09	7.91
670.1/2	0.0	0.7096	1571	5.46	12.43	87.57
670.1/3	0.5	0.4790	1725	4.94	10.26	89.74
670.1/4	1.0	0.4979	1709	3.86	61.01	38.99
670.1/5	1.5	0.4858	1719	3.86	49.69	50.31
670.1/6	0.0	0.3394	1867	4.04	37.73	62.27
670.1/7	0.5	0.6002	1635	4.20	64.34	35.66
670.1/8	1.0	0.6434	1608	4.40	37.90	62.10
670.1/9	1.5	0.5777	1650	4.33	36.70	63.30
670.1/10	0.5	0.5702	1655	3.77	68.61	31.39
670.1/11	0.5	0.4694	1733	2.56	65.88	34.12
670.1/12	0.5	0.3954	1804	1.26	87.46	12.54
670.1/13	0.5	0.6701	1592	4.70	26.11	73.89
670.1/14	0.5	0.6899	1581	6.62	10.50	89.50
Average		0.5325	1695	3.92	47.19	52.81

Table 8
Sediment Samples from Upper Mississippi River — Results of Average Values of Parameters for Each Station

Station Number	Station Name	Moisture Content	Bed Density, kg/m^3	% Total Organic Matter	% Sand >64μ	% Silt/Clay <64μ
1	Wood Slough	0.5600	1695	3.31	25.03	74.97
2	Sugar Creek Island	0.7436	1601	3.84	27.08	72.92
3	Treadway Lake	0.6734	1609	4.96	12.78	87.22
4	Bath Chute	0.5159	1706	3.18	47.32	52.68
5	Bach Slough	0.6776	1598	5.10	6.41	93.59
6	Turkey Island	0.4037	1817	2.00	71.45	28.55
7	Coon Hollow Island	0.4534	1764	2.34	64.48	35.52
8	Big Soupbone Island North	0.4459	1768	2.62	39.53	60.47
9	Big Soupbone Island South	0.4836	1735	3.47	25.71	74.29
10	Open Impounded Area	0.3489	1882	1.52	67.01	32.99
11	Cook Slough South	0.4744	1745	2.99	48.41	51.59
12	Goetz Slough	0.3874	1847	1.92	64.71	35.29
13	Cassville Slough Complex	0.3884	1821	2.79	58.38	41.62
14	Cassville Slough North	0.3191	1438	1.45	58.92	19.65
15	Island 189	0.4309	1788	2.58	53.87	46.13
16	Frenchtown Lake North	0.8480	1556	3.05	55.43	44.57
17	Frenchtown Lake South	0.5808	1658	3.08	39.23	60.77
18	Broken Arrow Slough	0.3368	2005	0.98	95.73	11.41
19	Battle Slough	0.3306	1904	0.97	92.19	7.81
20	Lost Channel Light	0.5325	1695	3.92	47.19	52.81

All the bed samples were analyzed to determine the following correlations:

a. Percent moisture content as a function of percent sand.

b. Percent moisture content as a function of percent finer than 64 μ.

c. Bed density as a function of percent sand.

d. Bed density as a function of percent finer than 64 μ.

e. Percent organic matter as a function of percent sand.

f. Percent organic matter as a function of percent finer than 64 μ.

Results of analysis of all the samples are plotted in Figures 46 through 51.

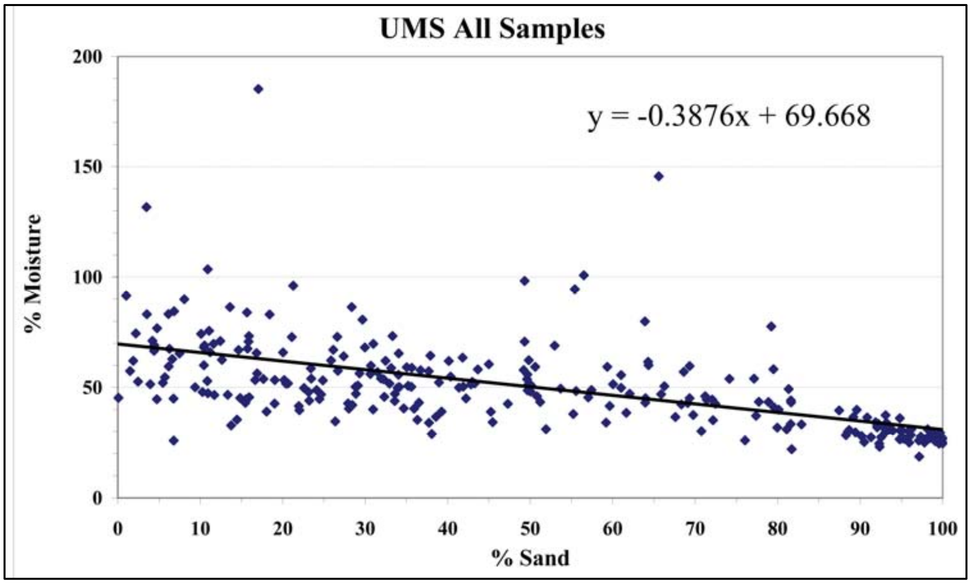


Figure 46. Percent moisture content as a function of percent sand

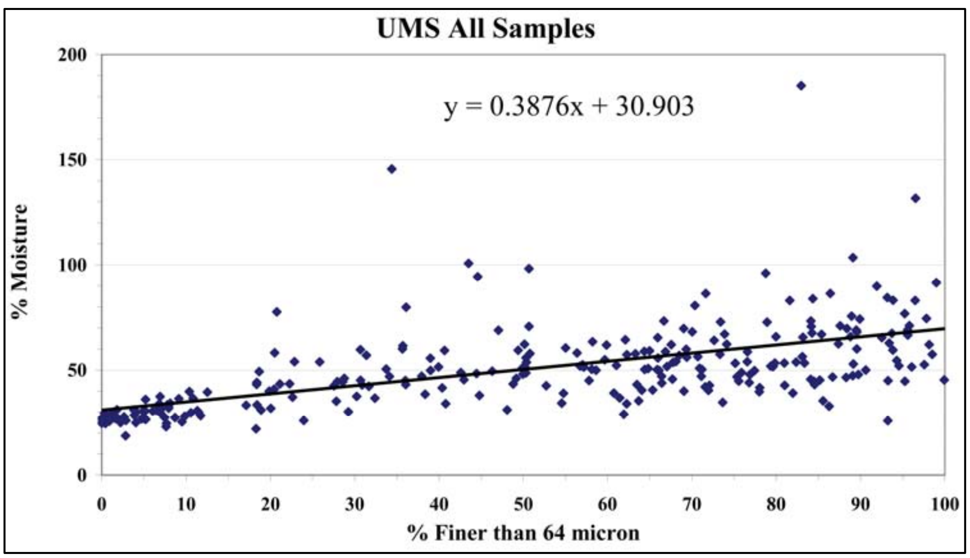


Figure 47. Percent moisture content as a function of percent finer than 64 μ

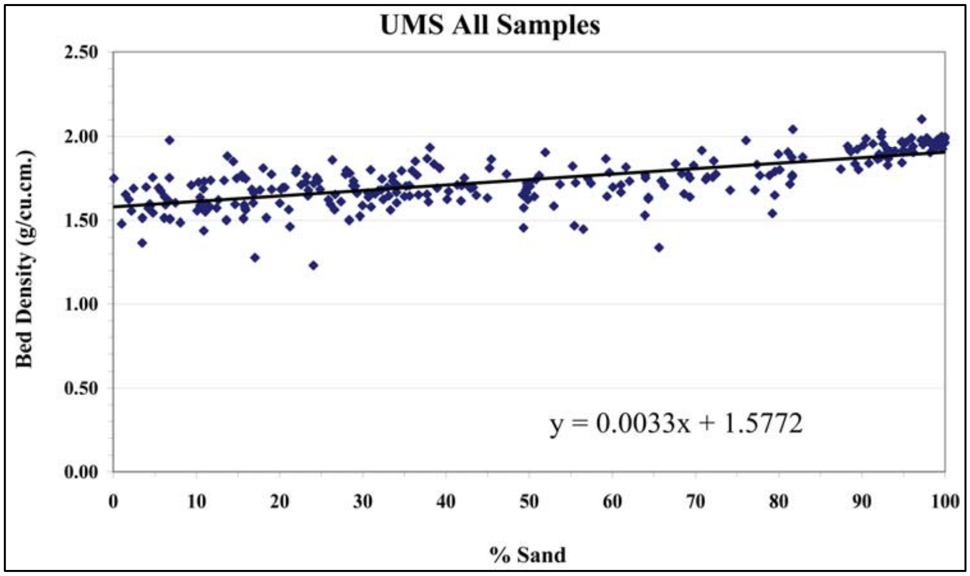


Figure 48. Bed density as a function of percent sand

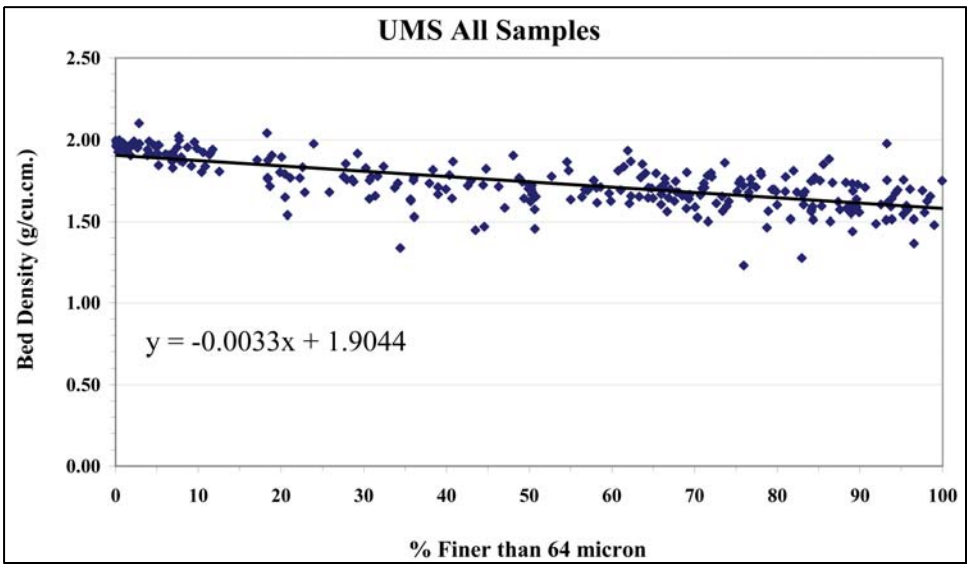


Figure 49. Bed density as a function of percent finer than 64 μ

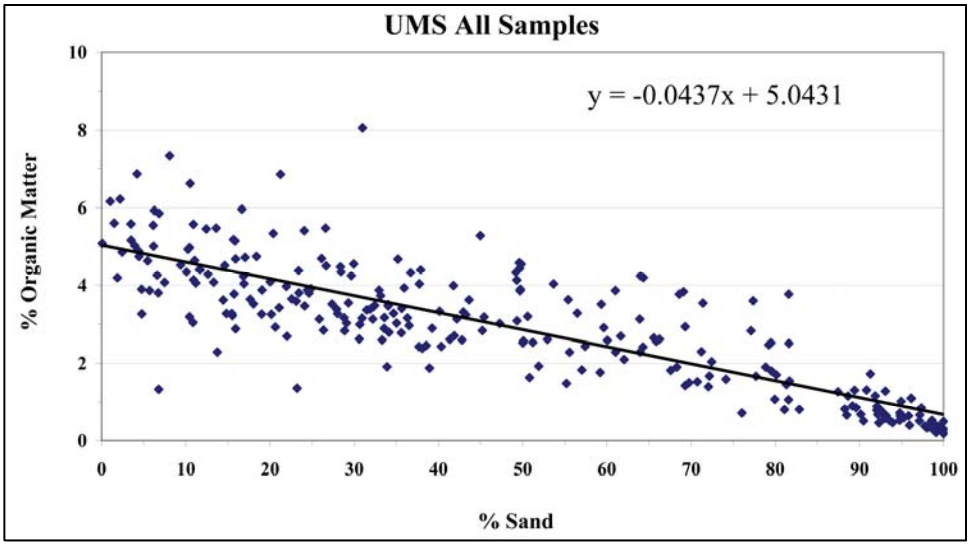


Figure 50. Percent organic matter as a function of percent sand

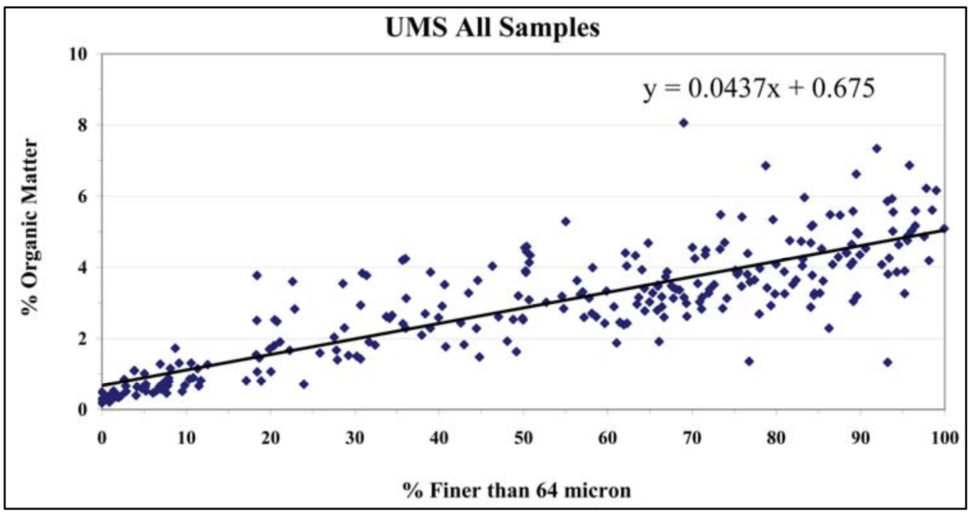


Figure 51. Percent organic matter as a function of percent finer than 64 μ

The general conclusions are as follows:

a. Bed density remains the same or slightly decreases with increasing percentage of organic content when the organic contents are less than 6 percent by weight.

b. Bed density decreases with increasing amount of moisture content. A typical decrease was from 2 g/cm^3 to 1.5 g/cm^3 with moisture content increasing from 20 percent to 70 percent.

c. The amount of organic matter generally increases with increasing percent of fines (silt plus clay). This is because organic matter selectively attaches to clay particles.

Project 7: Loxahatchee River, FL

The Loxahatchee River estuary is contained between Palm Beach and Martin counties in southeast Florida. The river empties into the Atlantic Ocean through the Jupiter Inlet. Shoaling has been occurring in the estuary at several spots, mainly at the confluence of major tributaries in the central embayment of the estuary. Ganju (2001) investigated feasibility of a sediment trap in the area of interest. Bed samples were collected from the tributaries. Percentage of fines smaller than 74 μ ranged from 59 to 87 and the percentage of organics by weight ranged from 13 to 19. Bulk density varied between 1,218 and 1,336 kg/m^3 the dry density varied from 336 to 562 kg/m^3. Erosional and depositional characteristics of sediment were determined in the laboratory. Erosion rate versus shear stress relationship is shown in Figure 52 and settling velocity as a function of suspension concentration is shown in Figure 53.

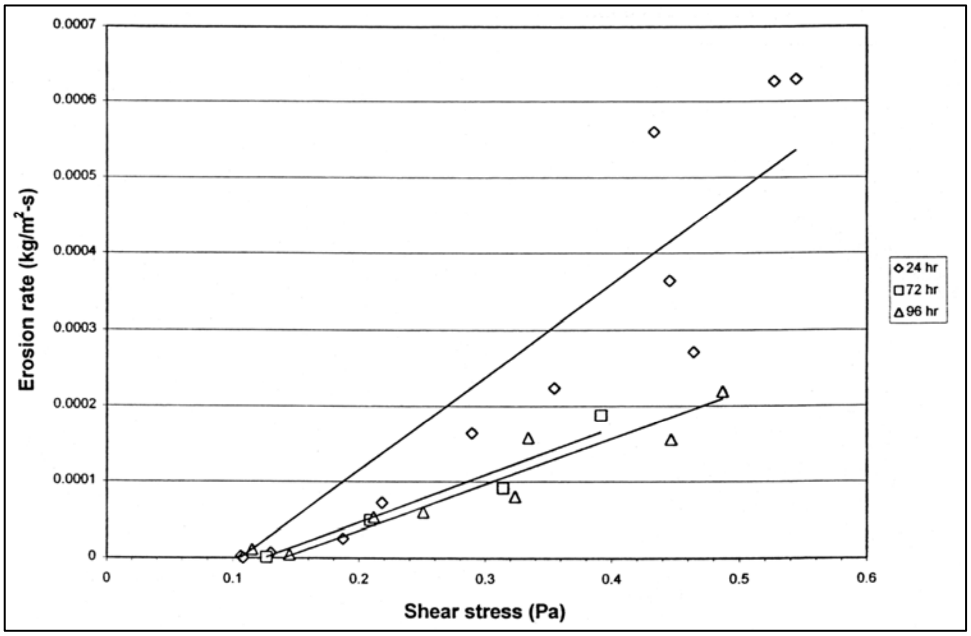


Figure 52. Erosion rate versus shear stress relationship for Loxahatchee estuary sediments

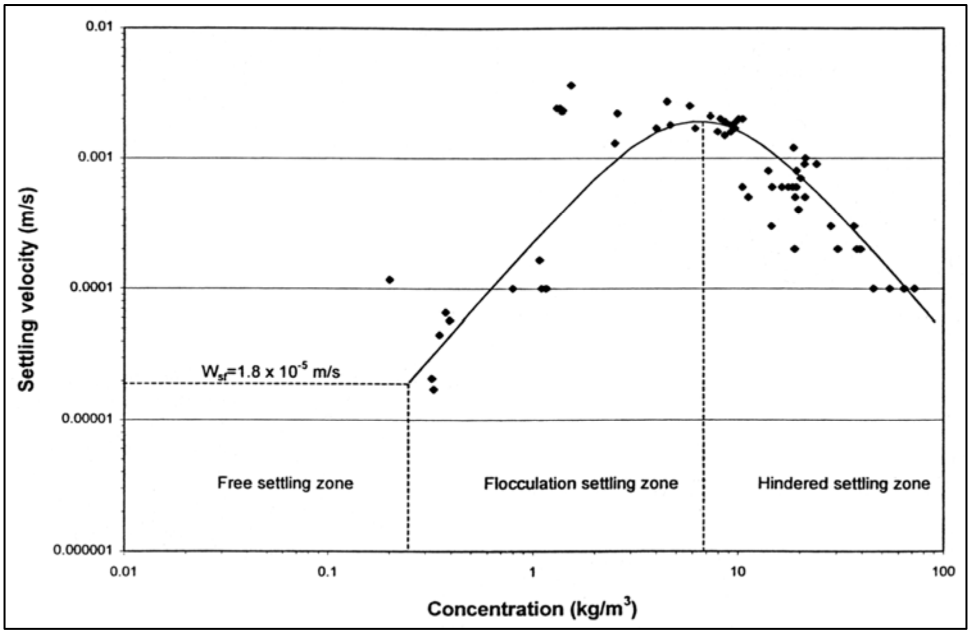


Figure 53. Settling velocity as a function of suspension concentration for Loxahatchee estuary sediments

Ganju (2001) concluded from laboratory experiments that varying organic content led to changes in density and settling velocity, which altered the depositional characteristics of the sediment. An increase in organic content led to a decrease in settling velocity, which resulted in a lower removal of suspended sediment.

Project 8: Newnans Lake, FL

Gowland and Mehta (2002) have reported laboratory results of analysis of 45 organic-rich sediment samples collected from Newnans Lake, FL. The results are given as follows:

a. The extracted pore fluid was acidic with pH varying between 4.7 and 6.4.

b. The organic content varied between 13 and 58 percent.

c. Bulk density varied from 1,005 to 1,242 kg/m^3.
Dry density varied from 19 to 407 kg/m^3.
Particle density varied from 1,150 to 1,597 kg/m^3.

d. Erosion rate ranged from 0.0 g/m^2/s at 0.06 Pa shear stress to 1.6 g/m^2/s at 0.3 Pa shear stress.

e. Settling velocities ranged from 1.7 x 10^{-6} m/s to 8.7 x 10^{-6} m/s.

6 Concluding Remarks

The characteristics of organic-rich sediments are likely to be site-specific. Further research is needed to evolve relationships that may be universally applicable. The following conclusions are given for specific projects.

Newnan's Lake, FL

The particle density, bulk density, and dry density of sediment mixtures changed significantly with the percent (by weight) of organic contents. The value of all the three densities at zero organic matter is about 2,600 kg/m^3. A small amount such as 5 percent by weight of organic content, the bulk density reduced to 1,700 kg/m^3 and dry density reduced to 1,200 kg/m^3. With 30 percent organic matter, the values drop down to 2,200, 1,100, and 200 kg/m^3 respectively for the particle, bulk, and dry density.

Both the erosion rate and the erosion rate constant are significantly affected by the amount of organic content. It is reported that for a shear stress of 0.2 Pa, the erosion rate changed from 0.04 g/m^2/s to 0.3 g/m^2/s and the erosion rate constant changed from 0.45 g/N-s to 2.06 g/N-s when the organic contents changed from 10 percent to 60 percent.

Settling velocities ranged from 1.7×10^{-6} to 8.7×10^{-4} m/s. Settling column tests showed dependence of settling velocity on the organic content and suspension concentration.

Rodman Reservoir, FL

Higher percentages of organics resulted in lower particle density. At zero organic contents, the particle density is 2,700 kg/m^3 corresponding to sand whereas it dropped to 1,400 kg/m^3 when organic content increased to 75 percent.

Cedar / Ortega River, FL

Sediment accumulation rates changed as a function of organic contents, which varied from 10 percent to 45 percent by weight.

Upper Mississippi River

Moisture content by weight increased from about 25 to about 75 percent with sediment finer than 64 μ increasing from zero to 100 percent.

Organic matter by weight increased from zero to about 6 percent when sediment finer than 64 μ increased from zero to 100 percent.

Bulk bed density decreased from 2.0 g/cu cm to 1.5 g/cu cm with sediment finer than 64 μ decreased from zero to 100 percent.

Sabine Neches Project

Moisture content generally increases with increasing percent of organic matter. Lower specific gravity together with increased moisture content resulted in decreased bulk density with increased percentage of organic matter in natural sediments.

Percentage of organic contents was higher when the percentage of sediment finer than 64 μ was higher. This is because the organic substances adsorb selectively to the clay particles and provide bonding material to them for aggregation and flock formation.

Red Bank Creek, SC

Laboratory analysis showed a wide variation from almost 100 percent sand to 99 percent fine sediment. This is significant because it demonstrates the importance of ascertaining spatial distribution of sediment types at any project under investigation. Making an assumption of uniformity of sediment based on a few samples is likely to lead to incorrect answers.

Charleston/Columbus Terminal, SC

A large variation from 1 percent to 12 percent of organic matter was noticed. Higher percentages of organic matter influenced the particle-size distribution and bulk density of the total sample. The observed large variation in percent organic matter at one site emphasizes the need for taking several samples for adequately determining the spatial variation in sediment properties.

Inner Albemarle Sound, NC

It is noted that the moisture content generally increases with increasing percent of organic matter. The specific gravity of organic substances is lower than that of sediments. Therefore, it may also be stated that a greater percentage of organic matter in natural sediments results in increased moisture content and decreased bulk density for natural sediments. A weak correlation was seen between the total organic matter by weight and mean diameter.

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Appendix A
Procedure Demonstration for Sediment Bed Classification

The sediment classification and procedures described in this appendix were developed specifically for the Upper Mississippi River project where preliminary estimates of wave-induced sediment resuspension were urgently needed in spite of limitations on the size and analysis of field and laboratory database relative to the total project area. The results were expected to be used for (a) assessment of relative impact of increased barge traffic in the river and (b) identification of potential areas along the riverbanks that are likely to be sensitive from the point of view of environmental considerations, and may need further evaluations. Use of these procedures outside the Upper Mississippi River project will require a separate evaluation of applicability.

Part 1. Classification of Bed Sediment Sample Based on its Relative Erodibility

Step 1. Classification Based on Particle-Size Distribution

Need measured values of the following three bed sample parameters:

a. Particle-size distribution curve, particularly percentage of sediment finer than 4 μ and percentage of sediment finer than 62 μ, or values of D_{70} and D_{16}.

b. Percentage of total organic matter.

c. Wet bulk density.

If the sample contains 70 percent or more particles finer than 4 μ (i.e., $D_{70} < 4$ μ), it is classified as Group1-Cohesive. Such samples contain 70 percent or more clay and less than 30 percent silt plus sand. Follow steps in Figure A1 for labeling.

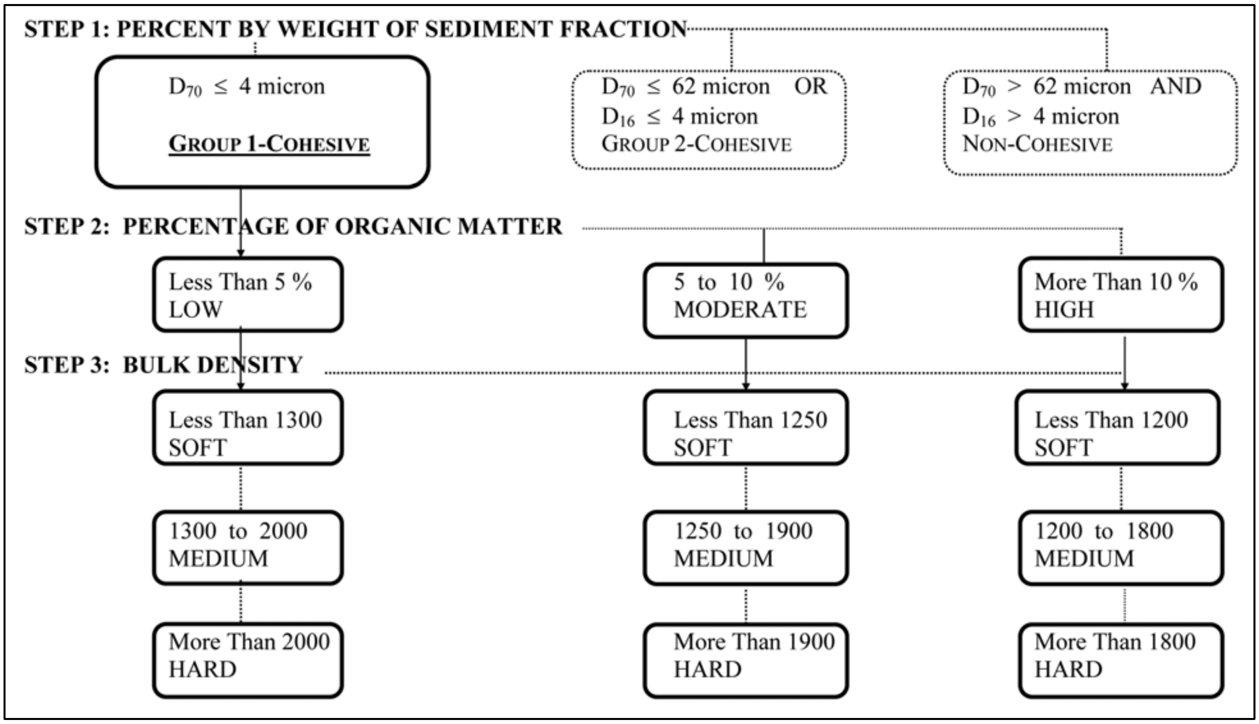


Figure A1. Protocol for classification of sediments under Group 1 – Cohesive

If the sample does not fall in Group1-Cohesive and contains more than 70 percent sediment finer than 62 μ (i.e., $D_{70} < 62$ μ), or if it contains more than 16 percent sediment finer than 4 μ (i.e., $D_{16} > 4$ μ), it is classified as Group2-Cohesive. Such samples contain 70 percent or more silt plus clay. Follow steps in Figure A2 for labeling.

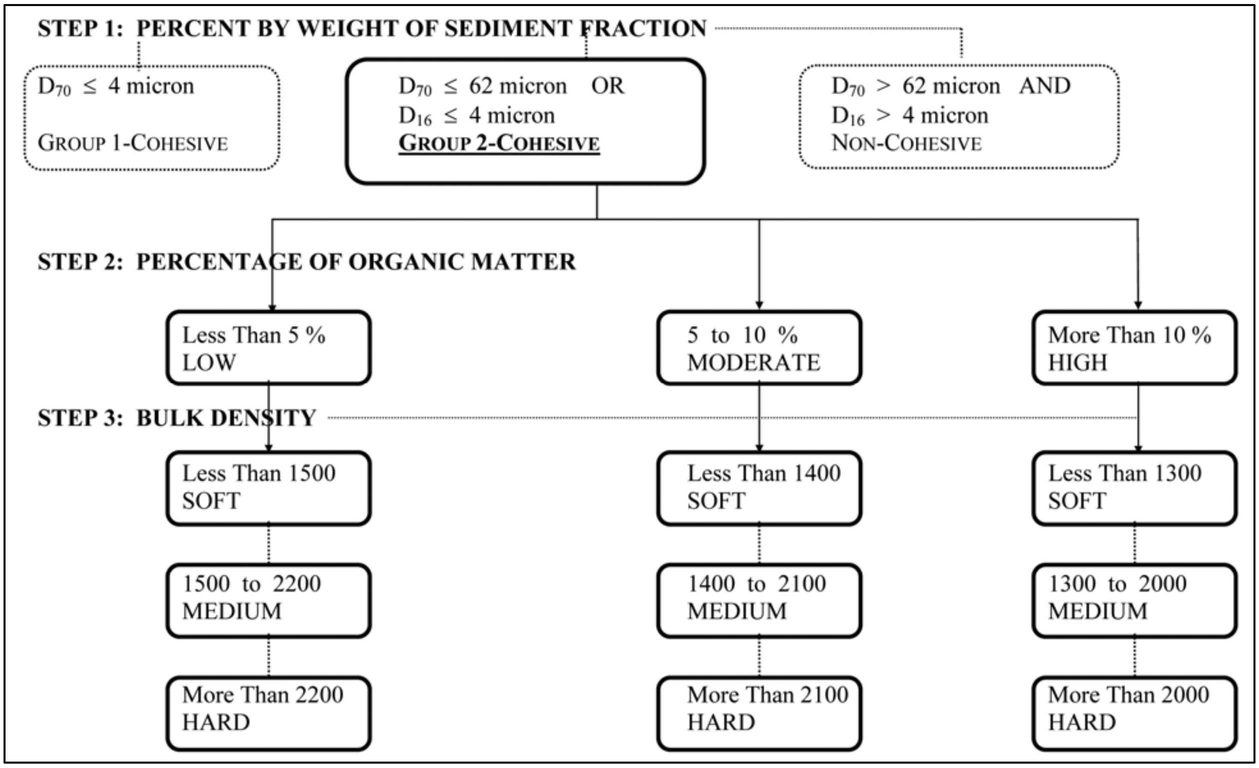
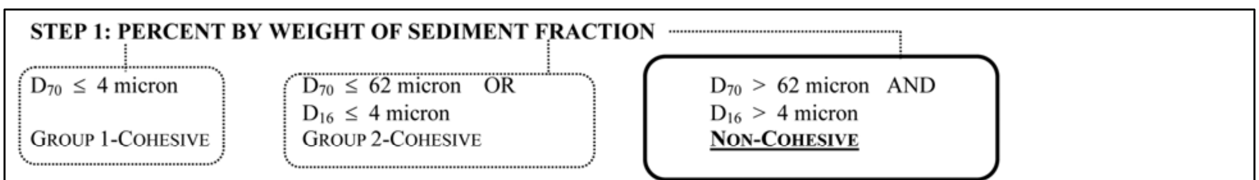


Figure A2. Protocol for classification of sediments under Group 2 – Cohesive sediments

If the sample contains 30 percent or more sediment coarser than 62 μ, and less than 16 percent of sediment finer than 4 μ (i.e., D70 > 62 μ and D16 > 4 μ), it is classified as noncohesive. Follow steps in Figure A3 for labeling.



The only parameter that needs to be considered for treatment of noncohesive sediments is the particle size. The other two parameters, namely, percentage of total organic matter and wet bulk density may not be significant unless the sand mixture contains more than 10 percent of organic matter.

STEP 1: PARTICLE SIZE SELECTION

Select a representative single value of grain diameter for a bed sample, e.g. D50 from the particle size distribution graph. If necessary, several sizes may be selected to represent different size classes.

STEP 2: ENTRAINMENT AND DEPOSITION

Follow procedure described by Parchure (2001b) for further treatment.

Figure A3. Protocol for classification of noncohesive sediments

Use format suggested in Figure A4 to record the classification based on Step 1. Samples under Group1-Cohesive and Group2-Cohesive are given further *Erodibility Labels* to indicate their relative resistance to erosion.

Upper Mississippi River Project								
Sample	% Weight finer than 4 microns	% Weight finer than 62 microns	% Weight coarser than 62 microns	Step 1 Classification	Organic Content %	Step 2 Classification	Bulk Density Kg / m^3	Step 3 Classification
6001	21.0 %	80.0 %	20.0 %	Silt Mixture	3.18	Low	1873	Medium

Figure A4. Sediment classification based on three measured parameters of bed samples

Step 2. Classification Based on Percentage of Total Organic Matter

Determine the value of percentage of total organic matter.

a. If it is less than 5 percent, classify it as low.

b. If it is between 5 and 10 percent, classify it as moderate.

c. If it is more than 10 percent, classify it as high.

Use format suggested in Figure A1 to record the classification based on step 2.

Step 3: Classification Based on Wet Bulk Density

Determine the value of wet bulk density.

a. If the sample is classified as Group1-Cohesive, look up step 3 under Figure A1.

b. If the sample is classified as Group2-Cohesive, look up step 3 under Figure A2.

Use format suggested in Figure A1 to record the erodibility label of soft, medium, or hard assigned under the column labeled step 3.

Note: After following these three steps, each bed sample initially classified as Group1-Cohesive or Group2-Cohesive will ultimately be classified in Figures A1 and A2 under three erodibility labels, soft, medium, or hard. These labels refer only to the relative erosional resistance of the sediment sample.

Appendix B
Bed Density as a Function of Percent Organic Matter (Upper Mississippi River Data)

List of stations for bed sediment sample collection along the Mississippi River:

1. Wood Slough
2. Sugar Creek Island
3. Treadway Lake
4. Bath Chute
5. Bach Slough
6. Turkey Island
7. Coon Hollow Island
8. Big Soupbone Island North
9. Big Soupbone Island South
10. Open Impounded Area (River Mile 528)
11. Cook Slough South
12. Goetz Slough
13. Cassville Slough Complex
14. Cassville Slough North
15. Island 189
16. Frenchtown Lake North
17. Frenchtown Lake South
18. Broken Arrow Slough
19. Battle Slough
20. Lost Channel Light

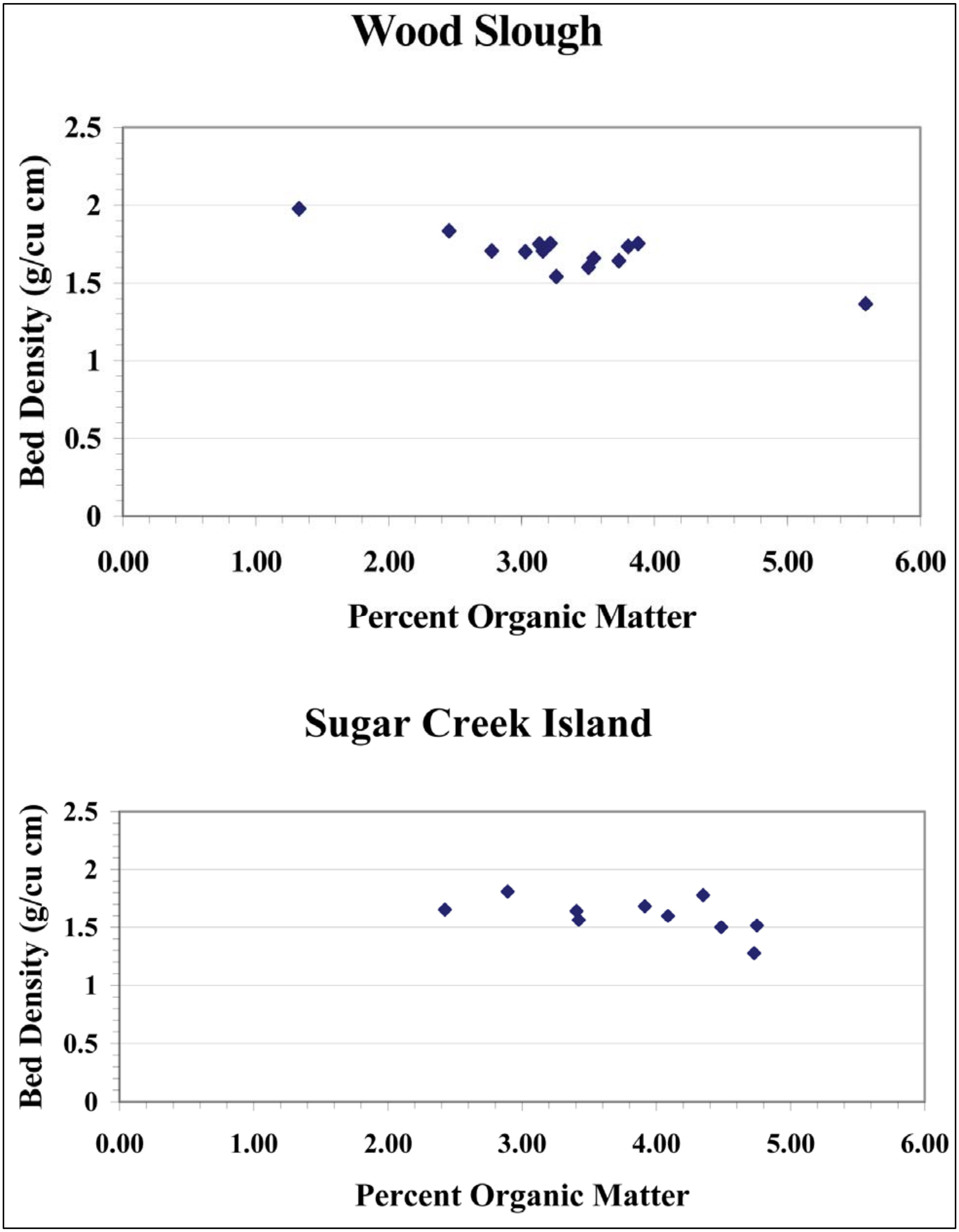


Figure B1. Bed density as a function of organic matter at Wood Slough and Sugar Creek Island

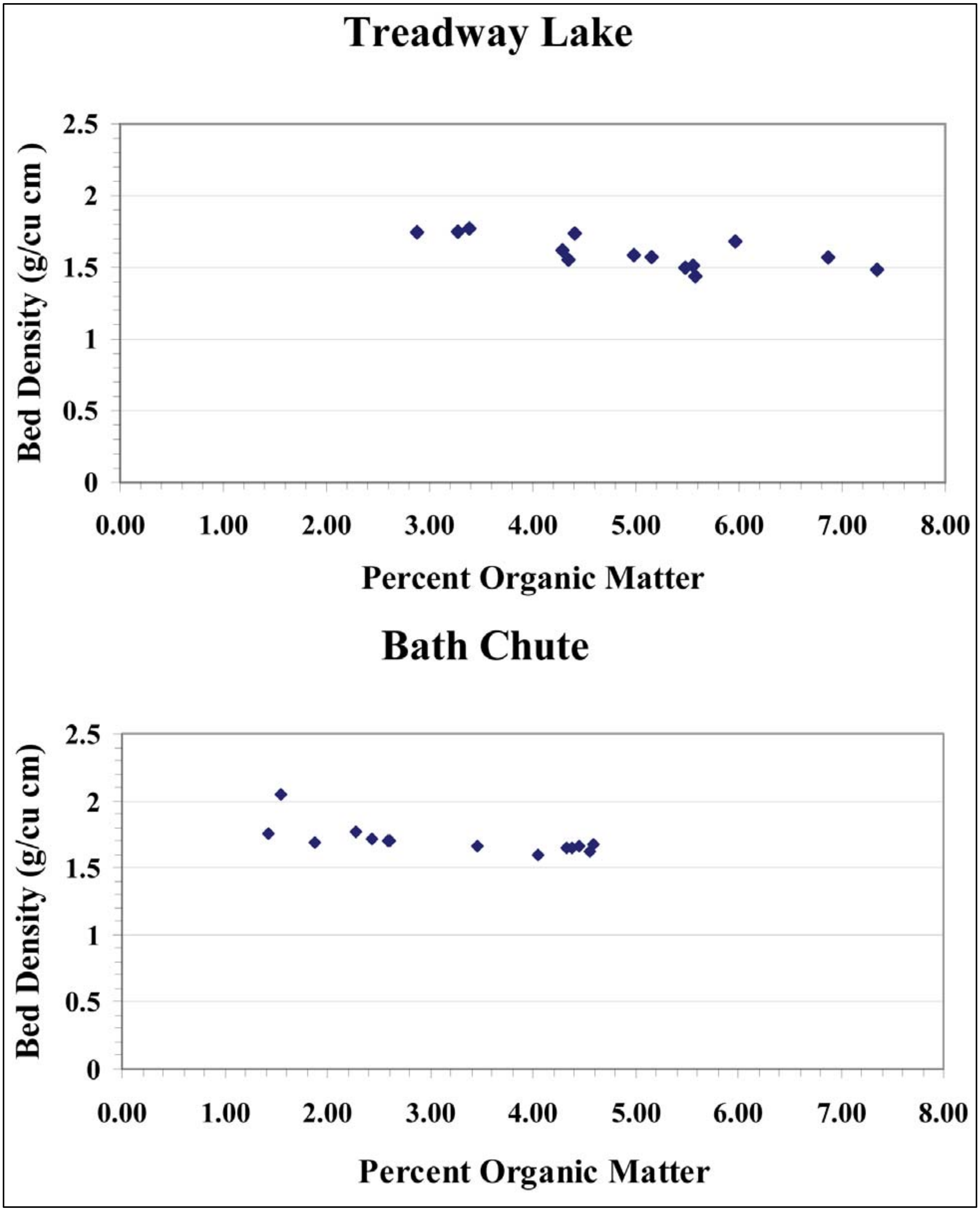


Figure B2. Bed density as a function of organic matter at Treadway Lake and Bath Chute

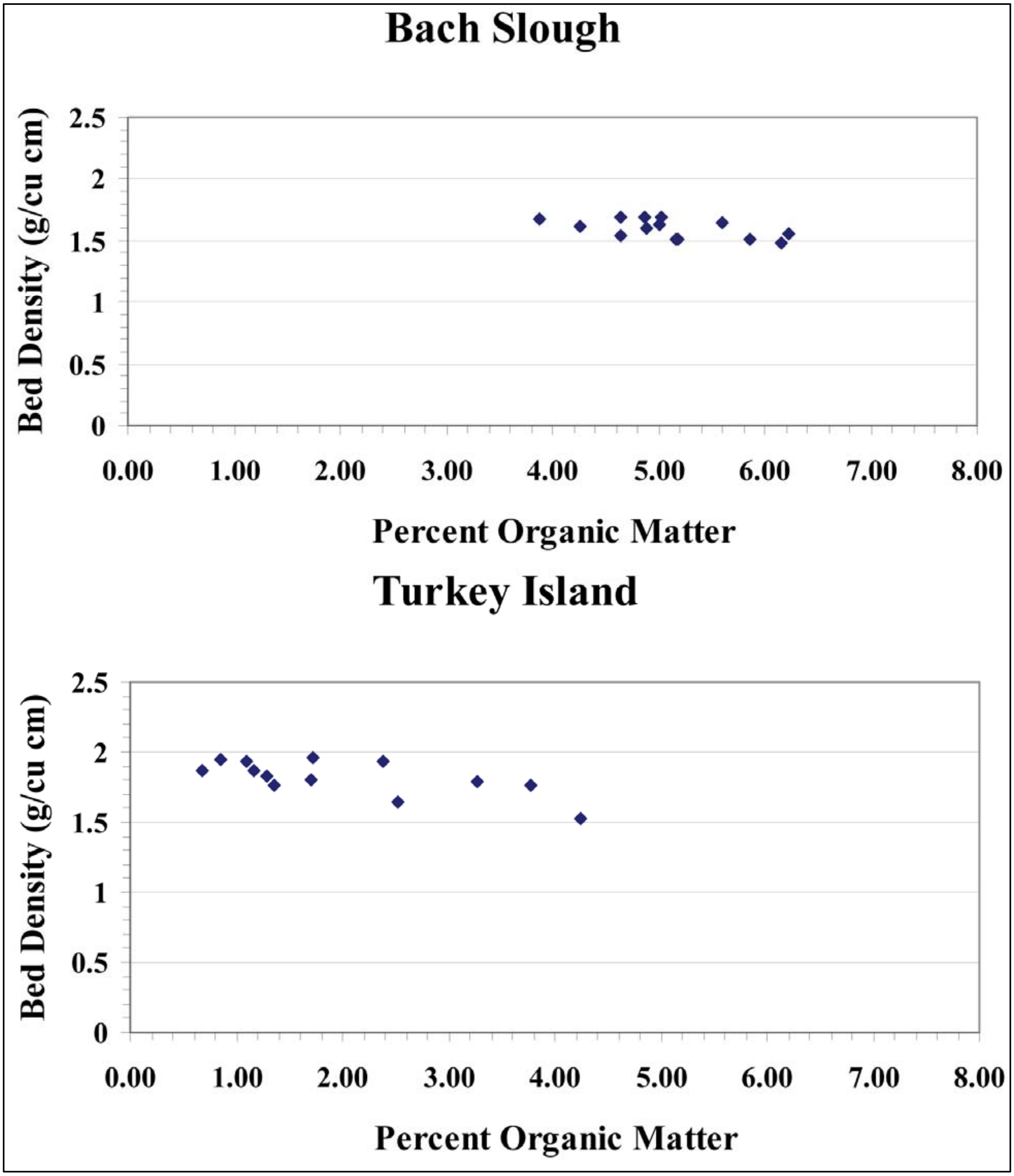


Figure B3. Bed density as a function of organic matter at Bach Slough and Turkey Island

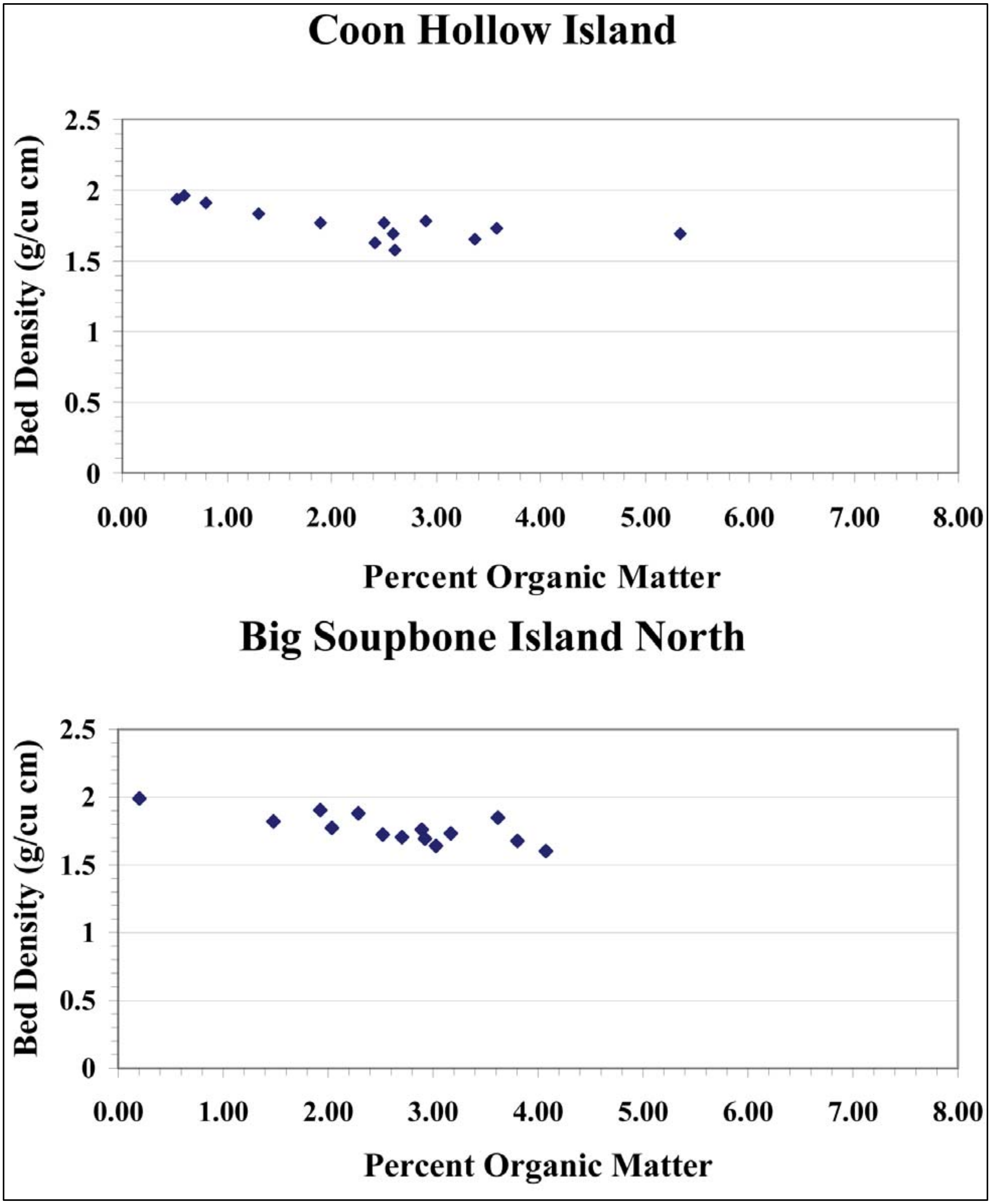


Figure B4. Bed density as a function of organic matter at Coon Hollow Island and Big Soupbone Island North

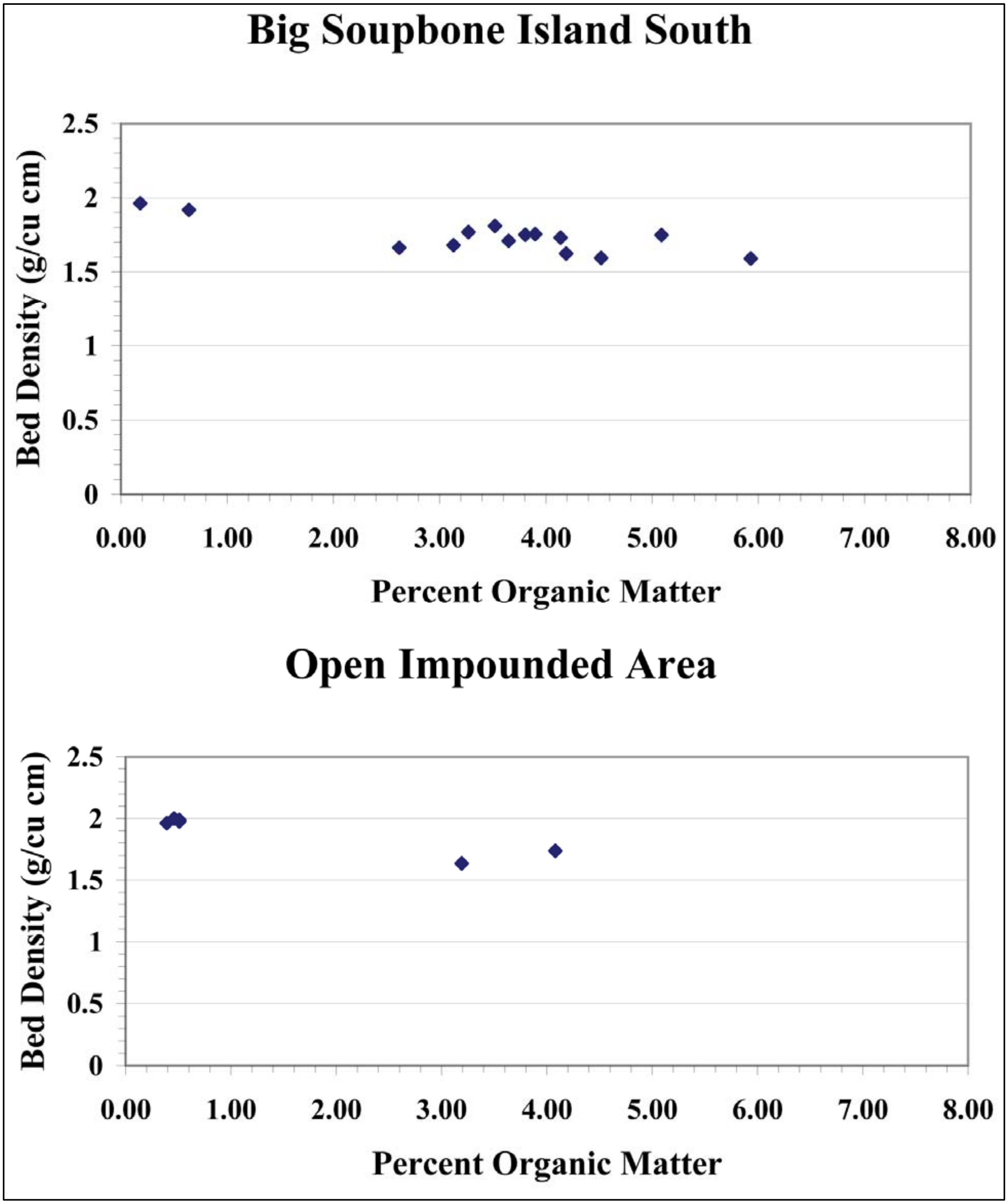
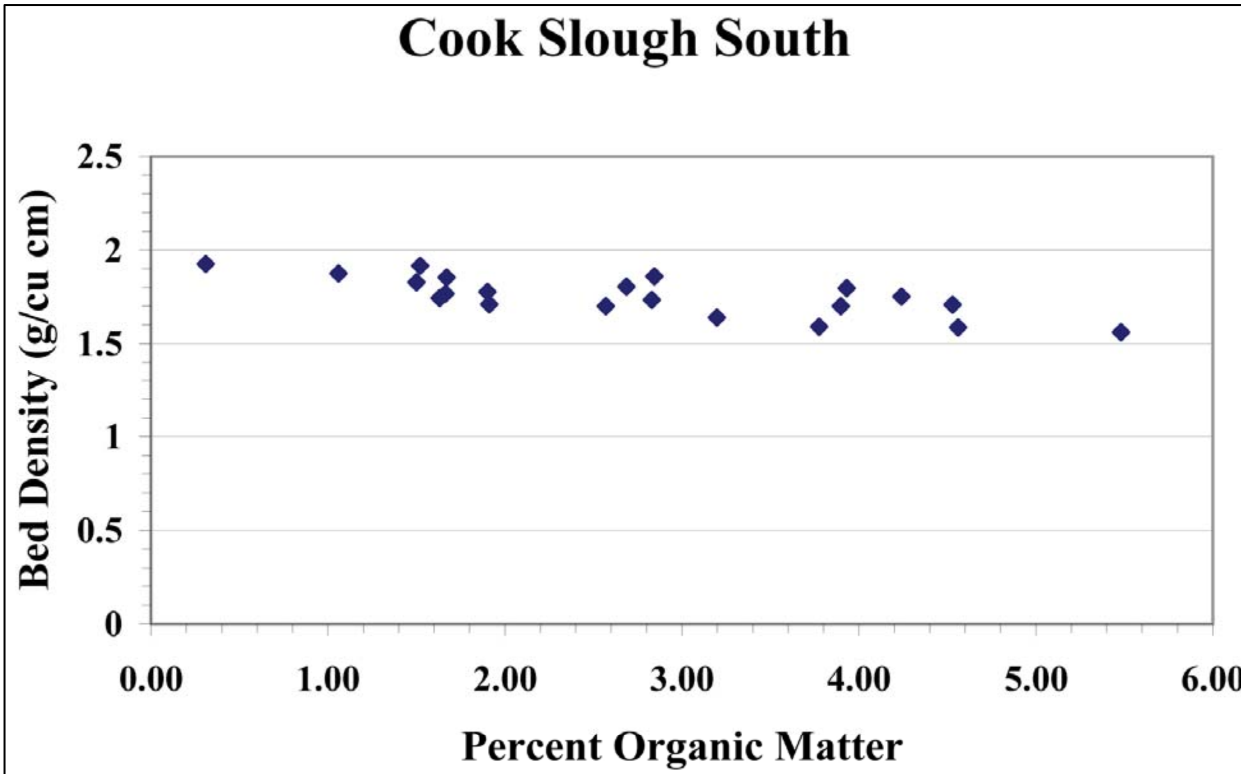


Figure B5. Bed density as a function of organic matter at Big Soupbone Island South and Open Impounded Area (River Mile 528)



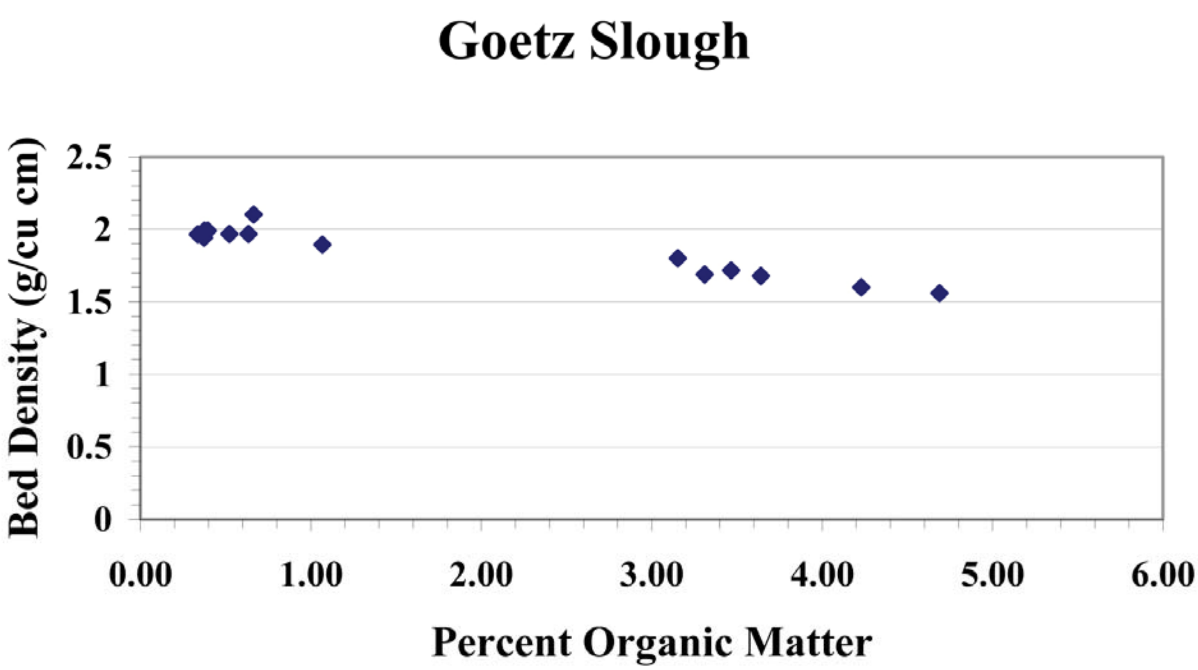


Figure B6. Bed density as a function of organic matter at Cook Slough South and Goetz Slough

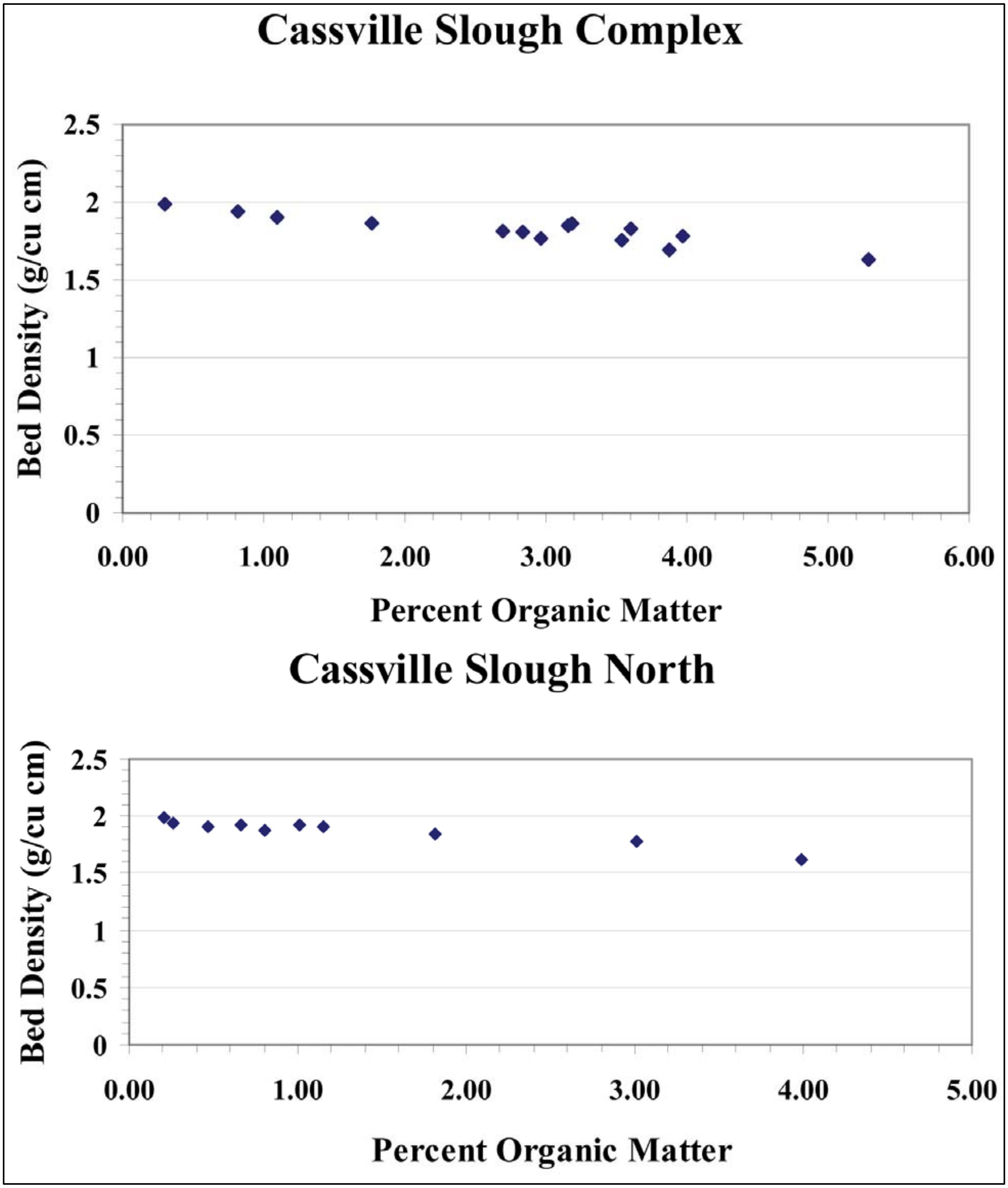


Figure B7. Bed density as a function of organic matter at Cassville Slough Complex and Cassville Slough North

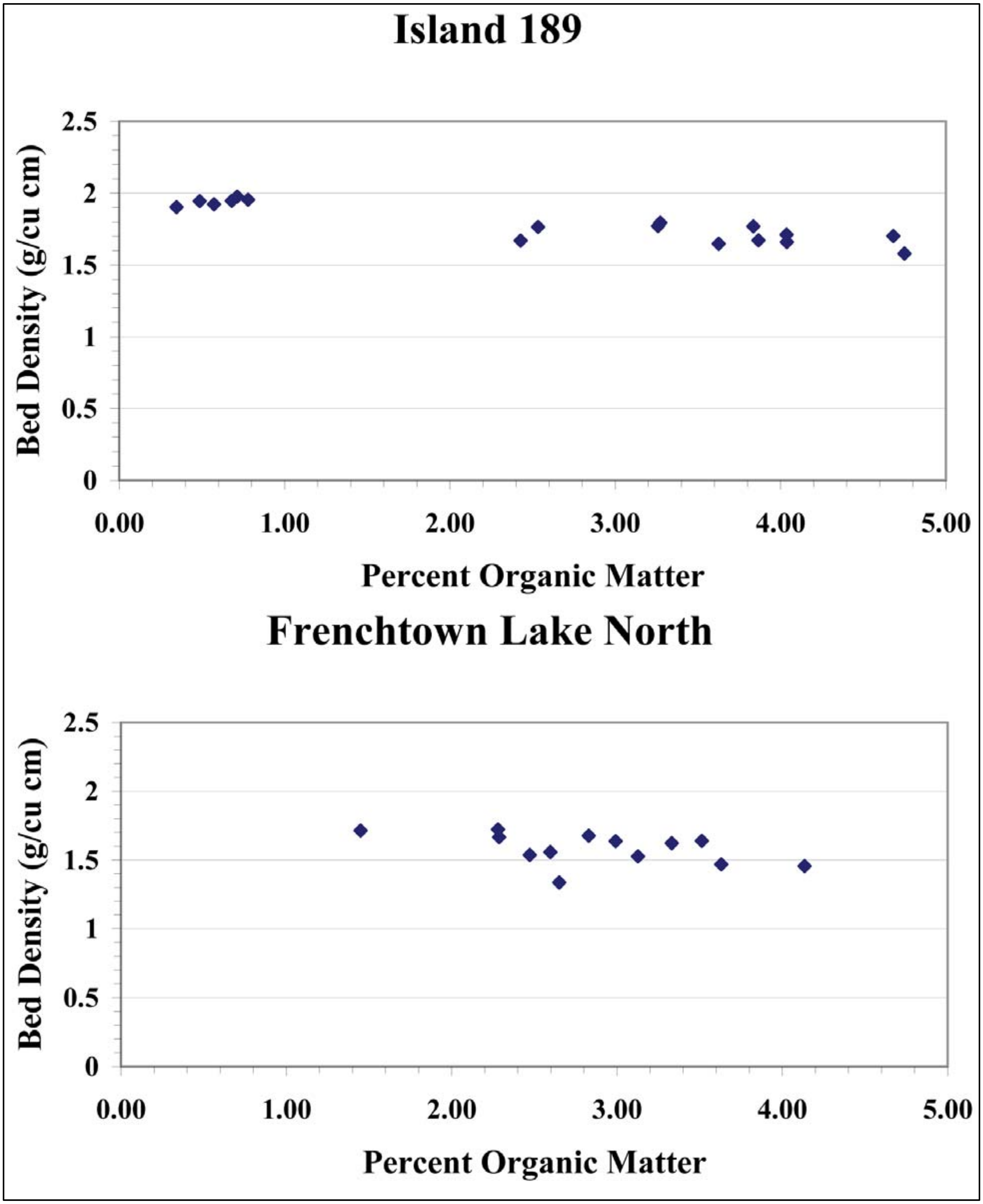


Figure B8. Bed density as a function of organic matter at Island 189 and Frenchtown Lake North

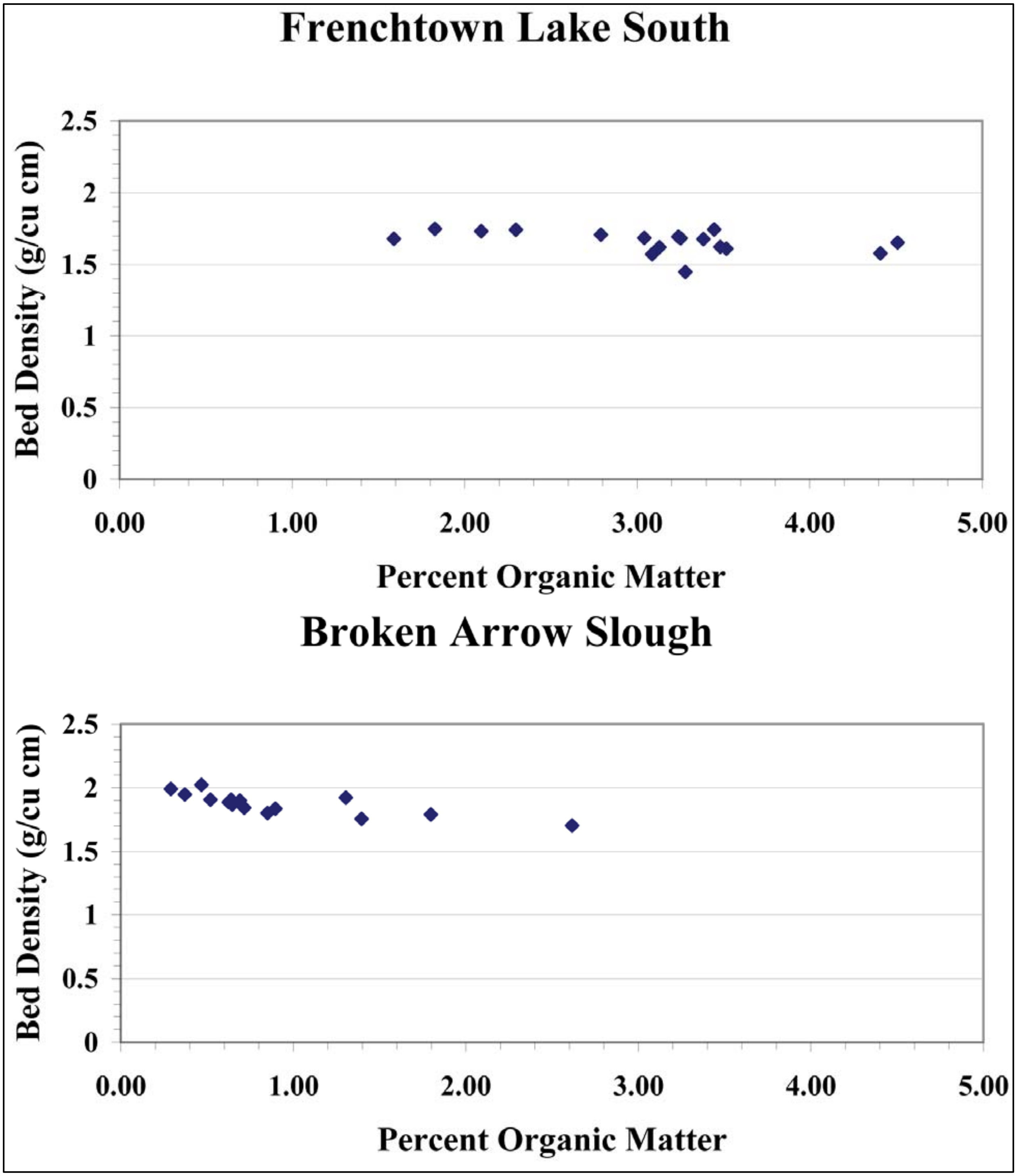


Figure B9. Bed density as a function of organic matter at Frenchtown Lake South and Broken Arrow Slough

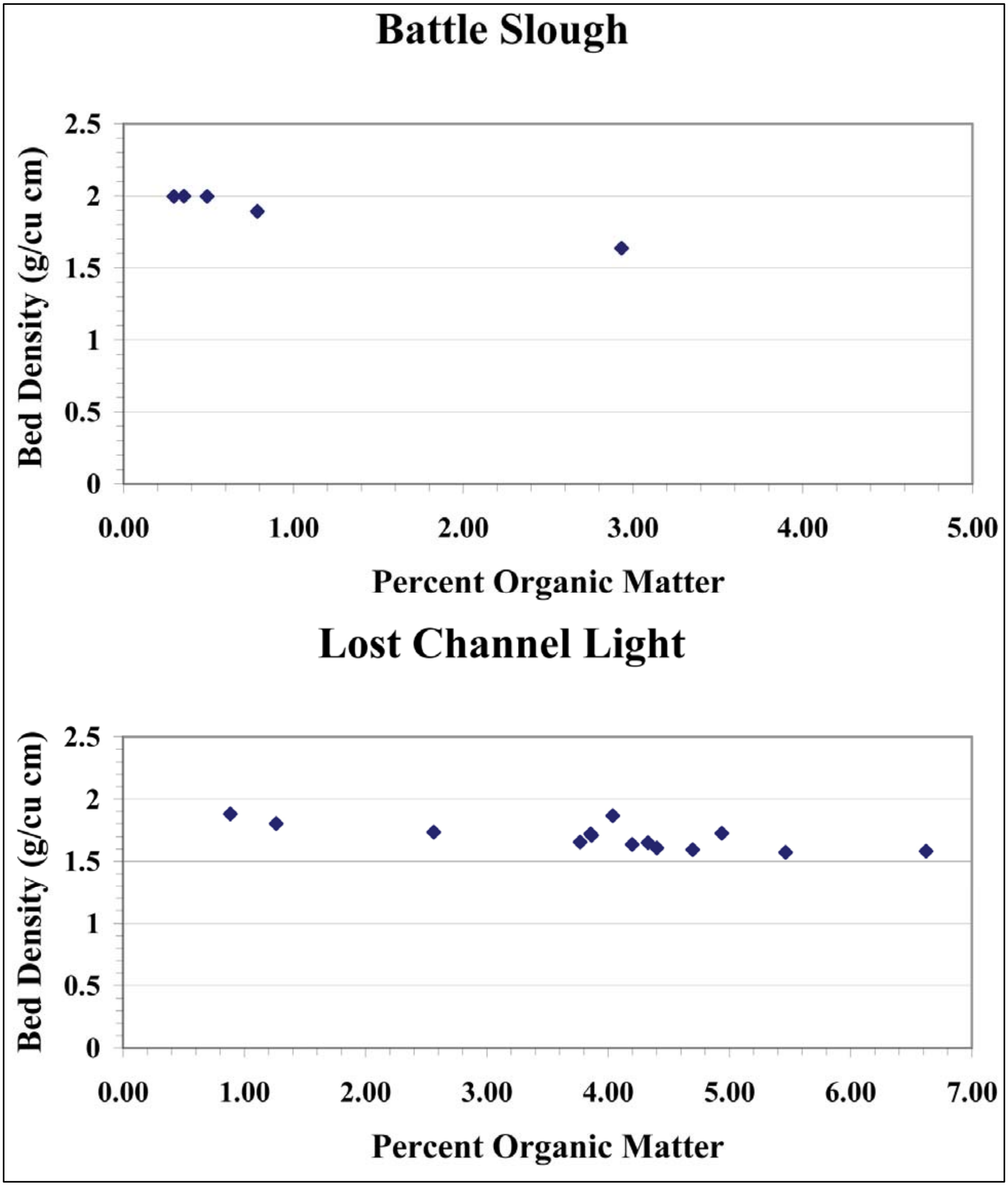


Figure B10. Bed density as a function of organic matter at Battle Slough and Lost Channel Light

Appendix C
Bed Density as a Function of Percent Moisture Content (Upper Mississippi River Data)

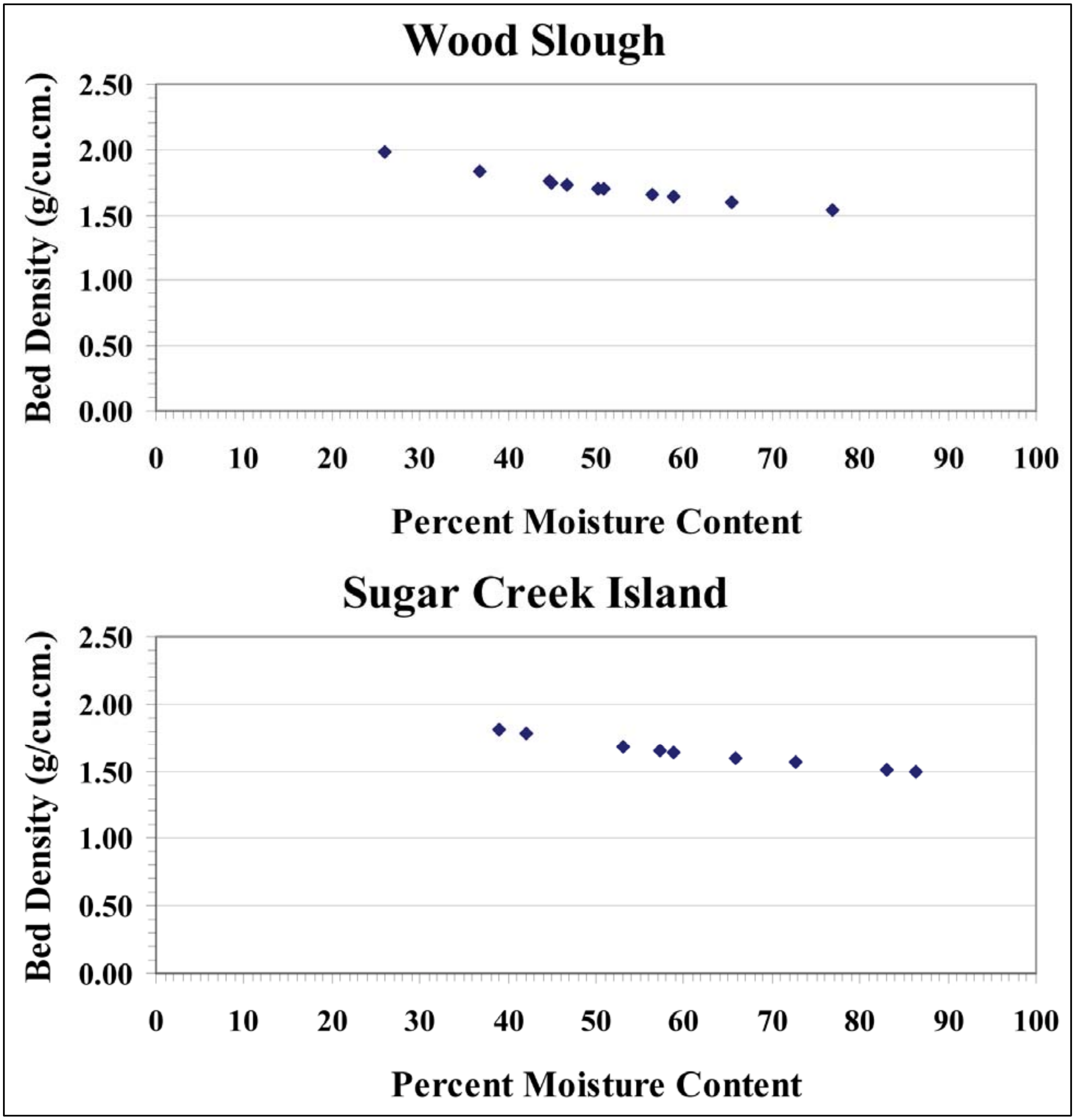


Figure C1. Bed density as a function of moisture content at Wood Slough and Sugar Creek Island

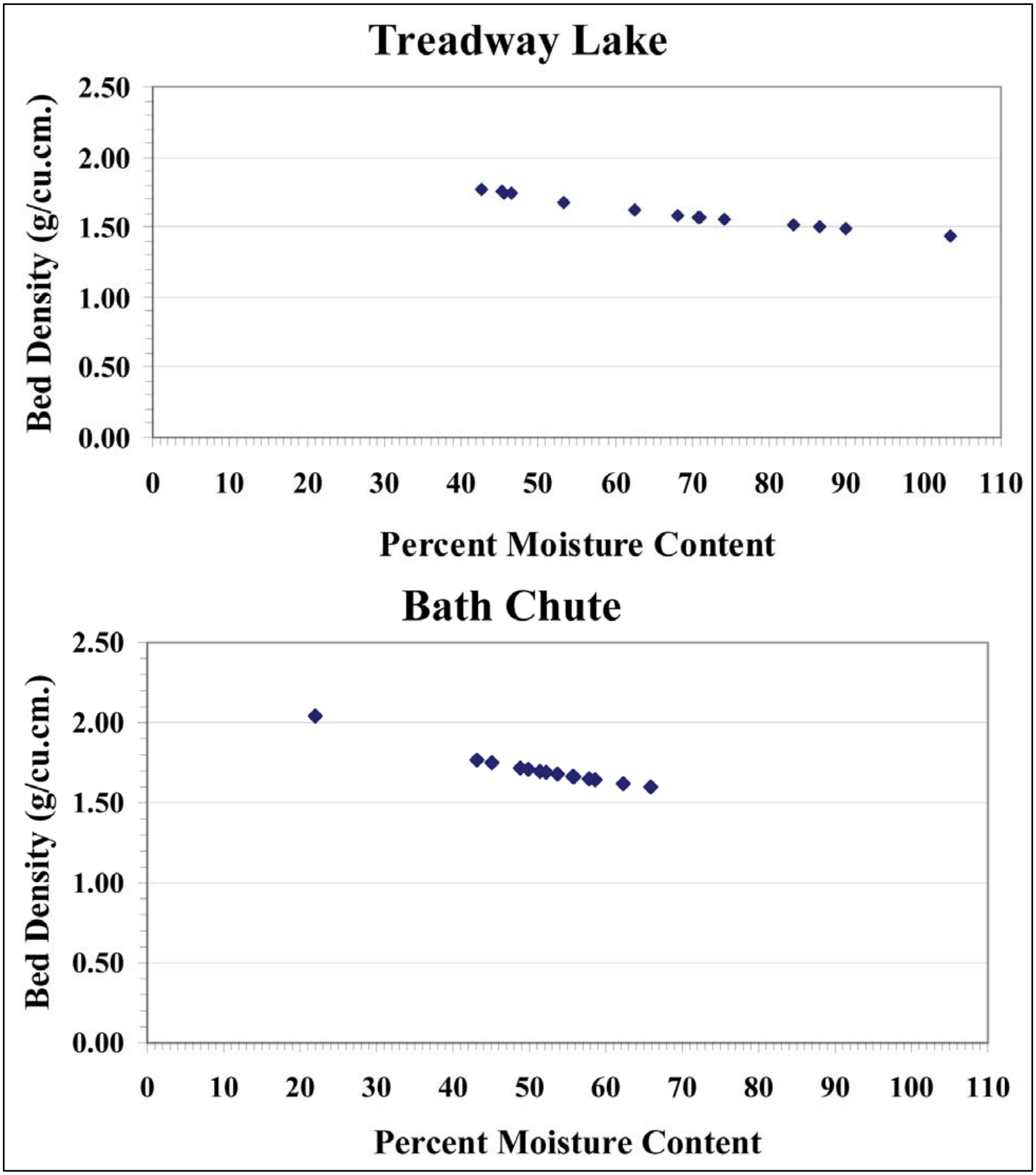


Figure C2. Bed density as a function of moisture content at Treadway Lake and Bath Chute

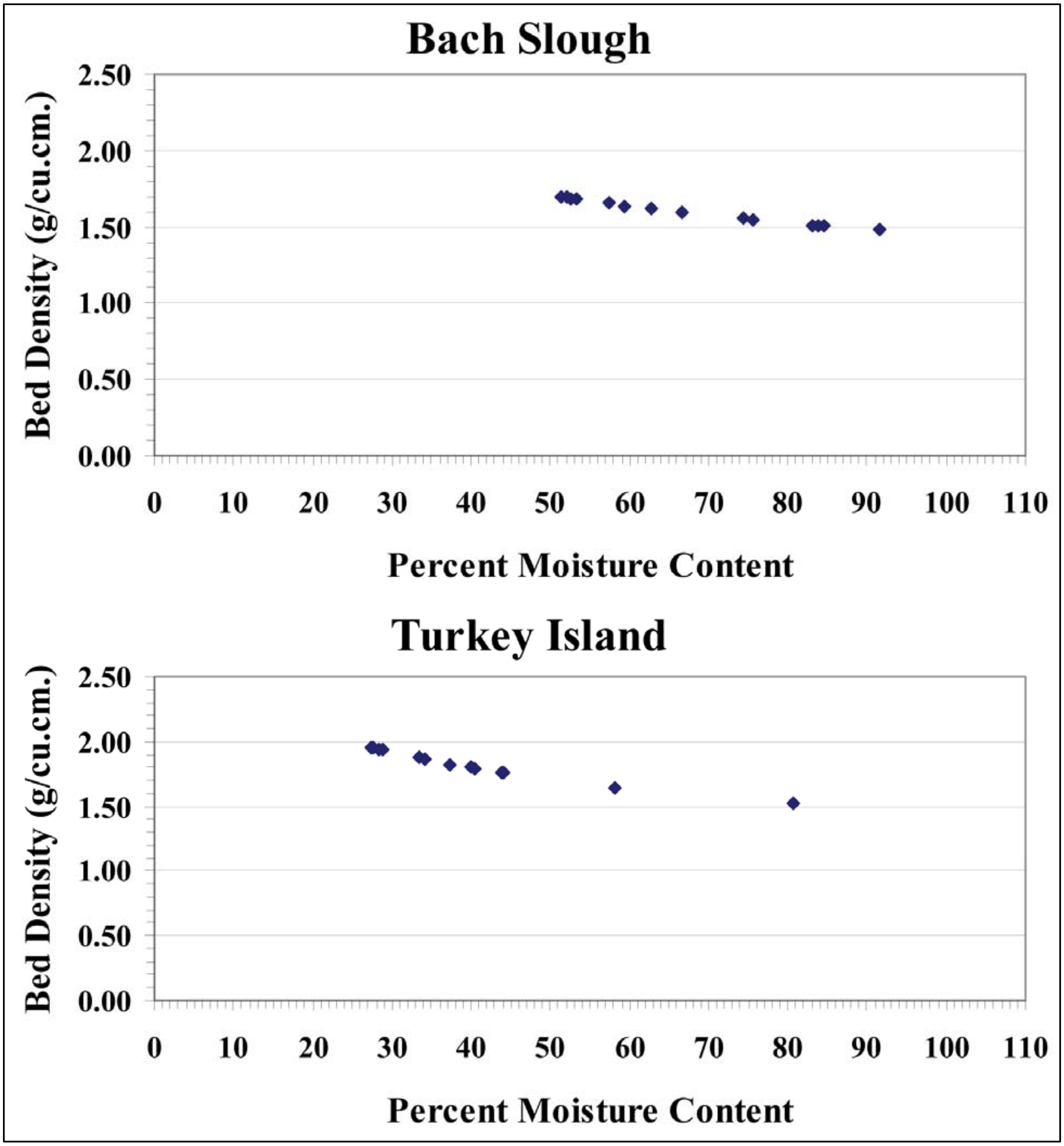


Figure C3. Bed density as a function of moisture content at Bach Slough and Turkey Island

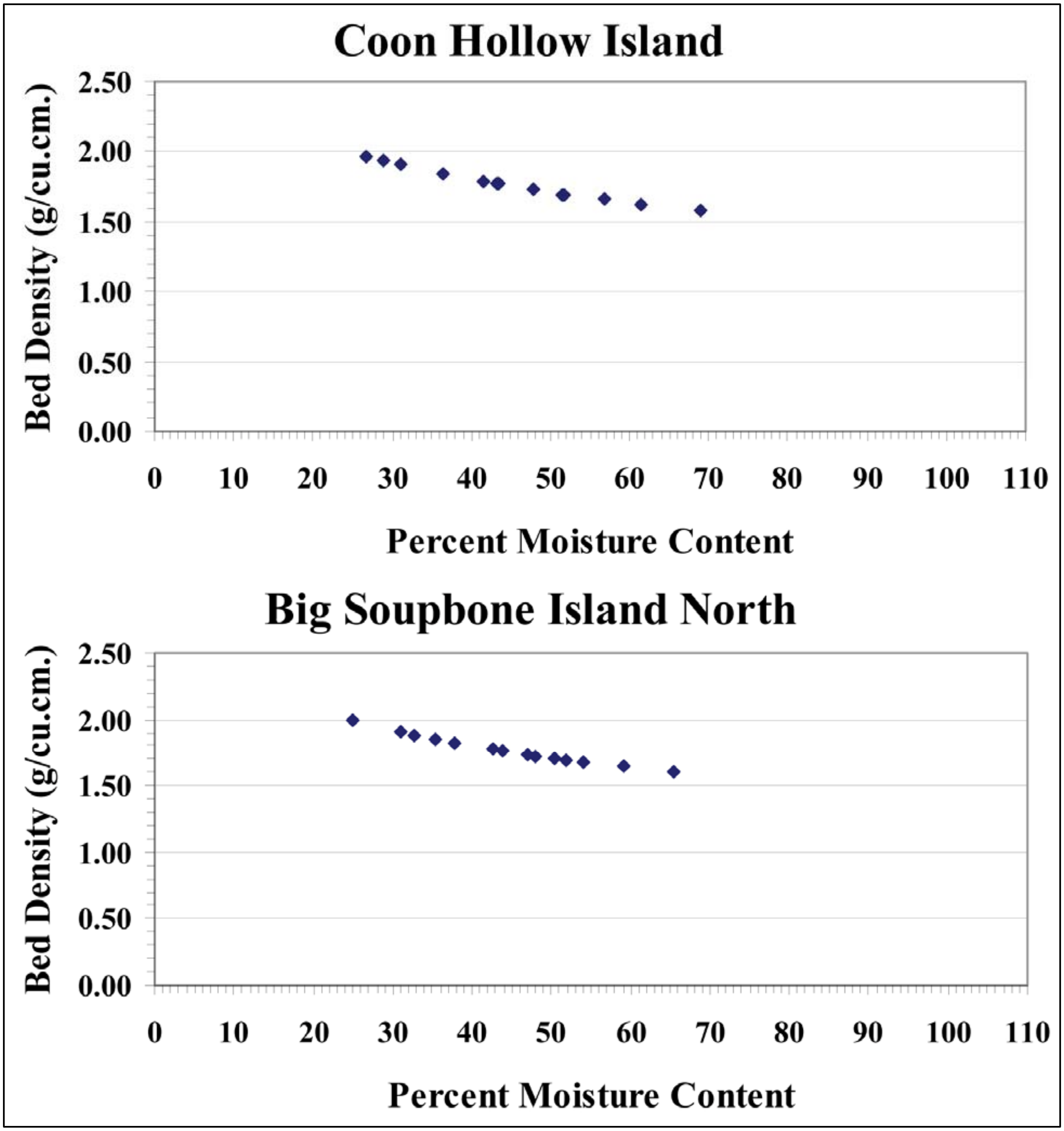


Figure C4. Bed density as a function of moisture content at Coon Hollow Island and Big Soupbone Island North

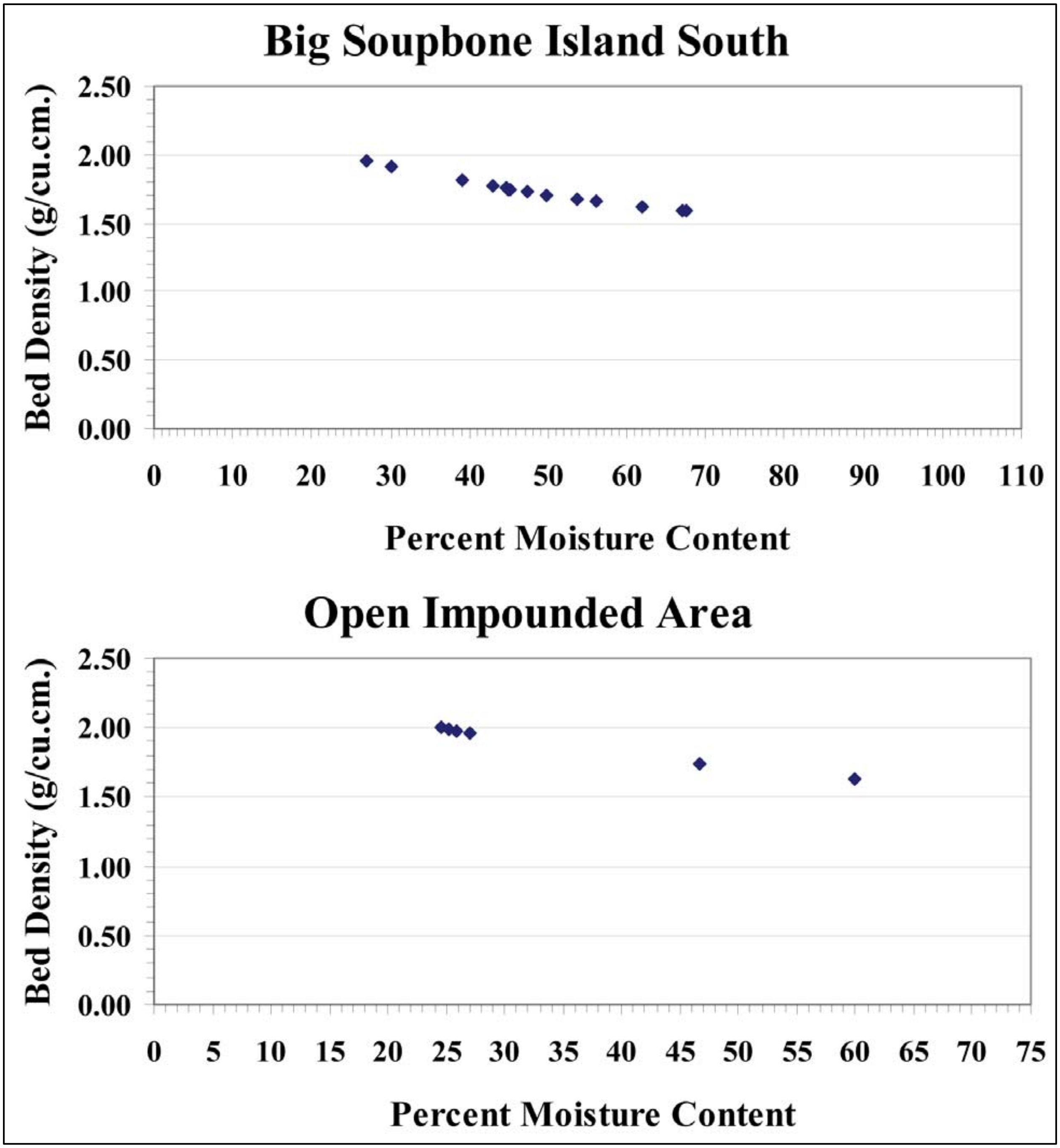


Figure C5. Bed density as a function of moisture content at Big Soupbone Island South and Open Impounded Area (River Mile 528)

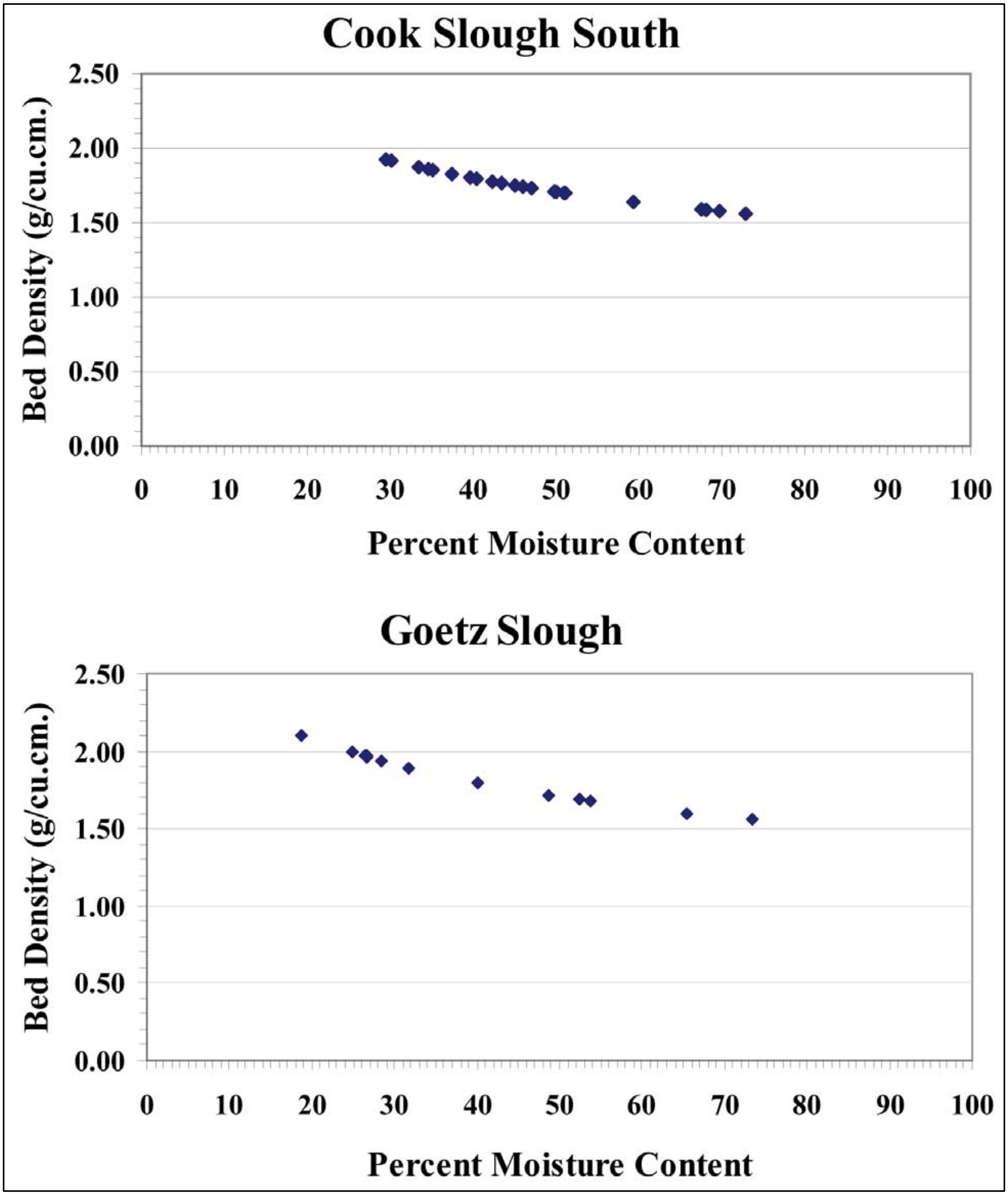


Figure C6. Bed density as a function of moisture content at Cook Slough South and Goetz Slough

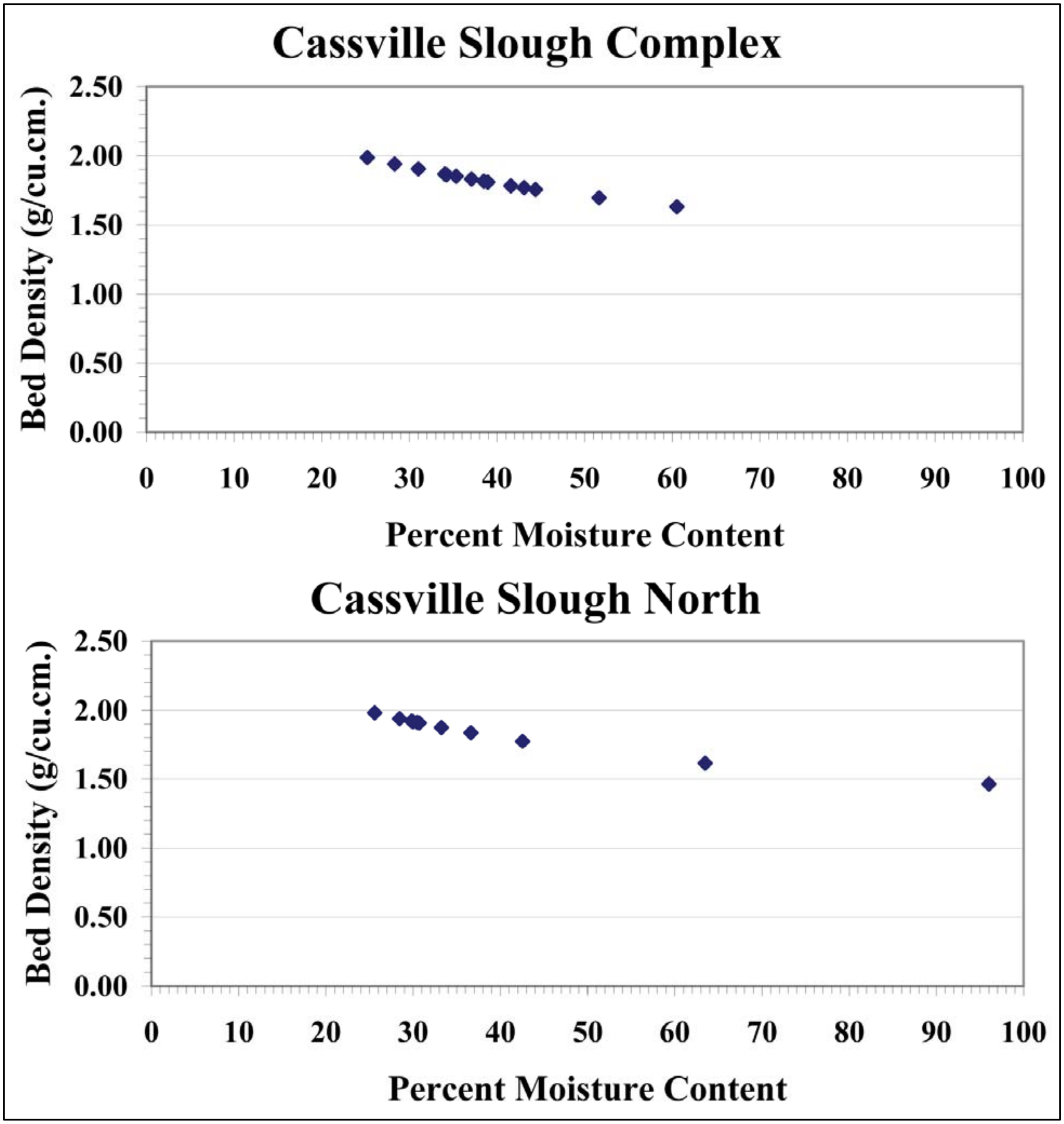


Figure C7. Bed density as a function of moisture content at Cassville Slough Complex and Cassville Slough North

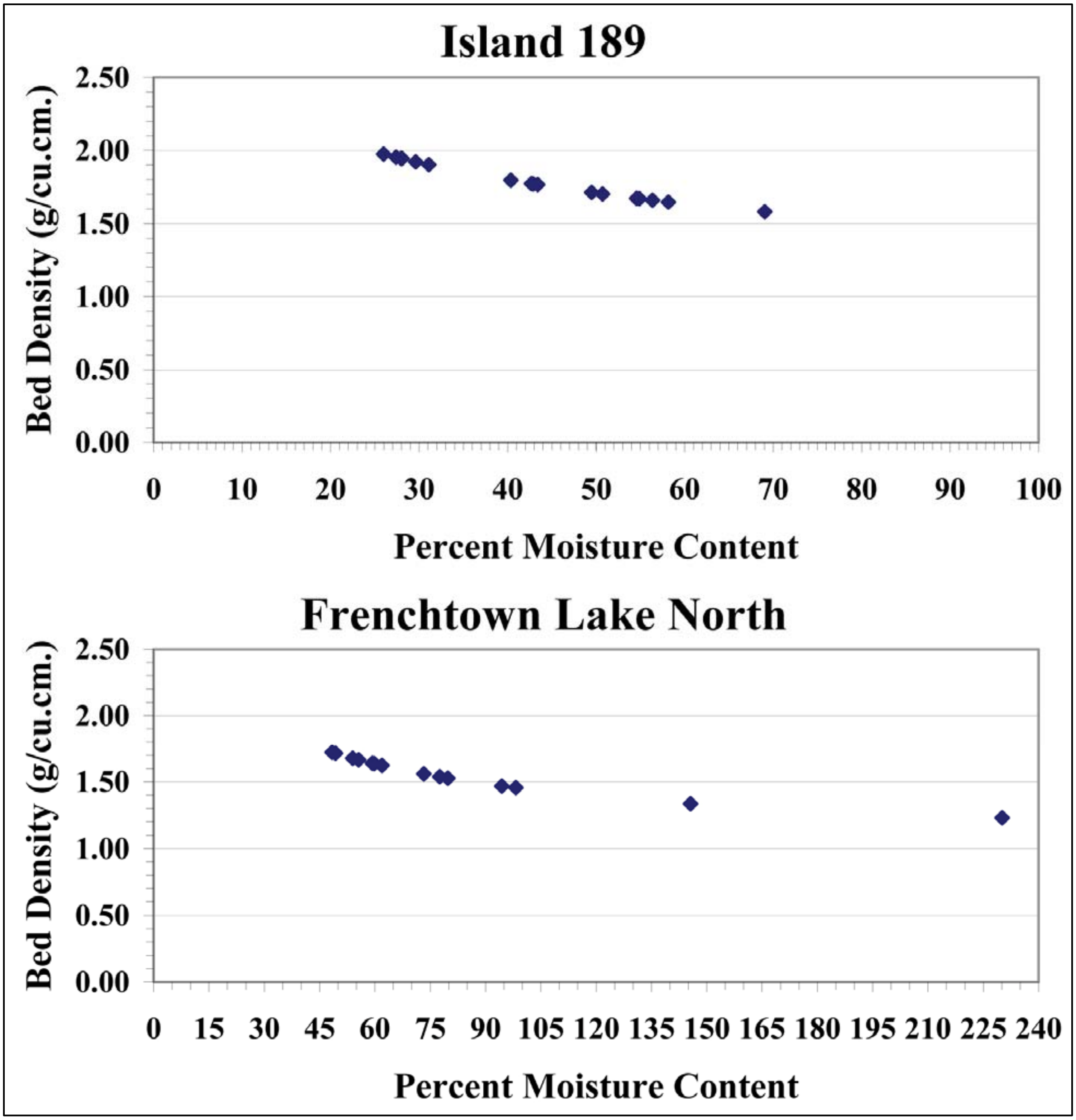


Figure C8. Bed density as a function of moisture content at Island 189 and Frenchtown Lake North

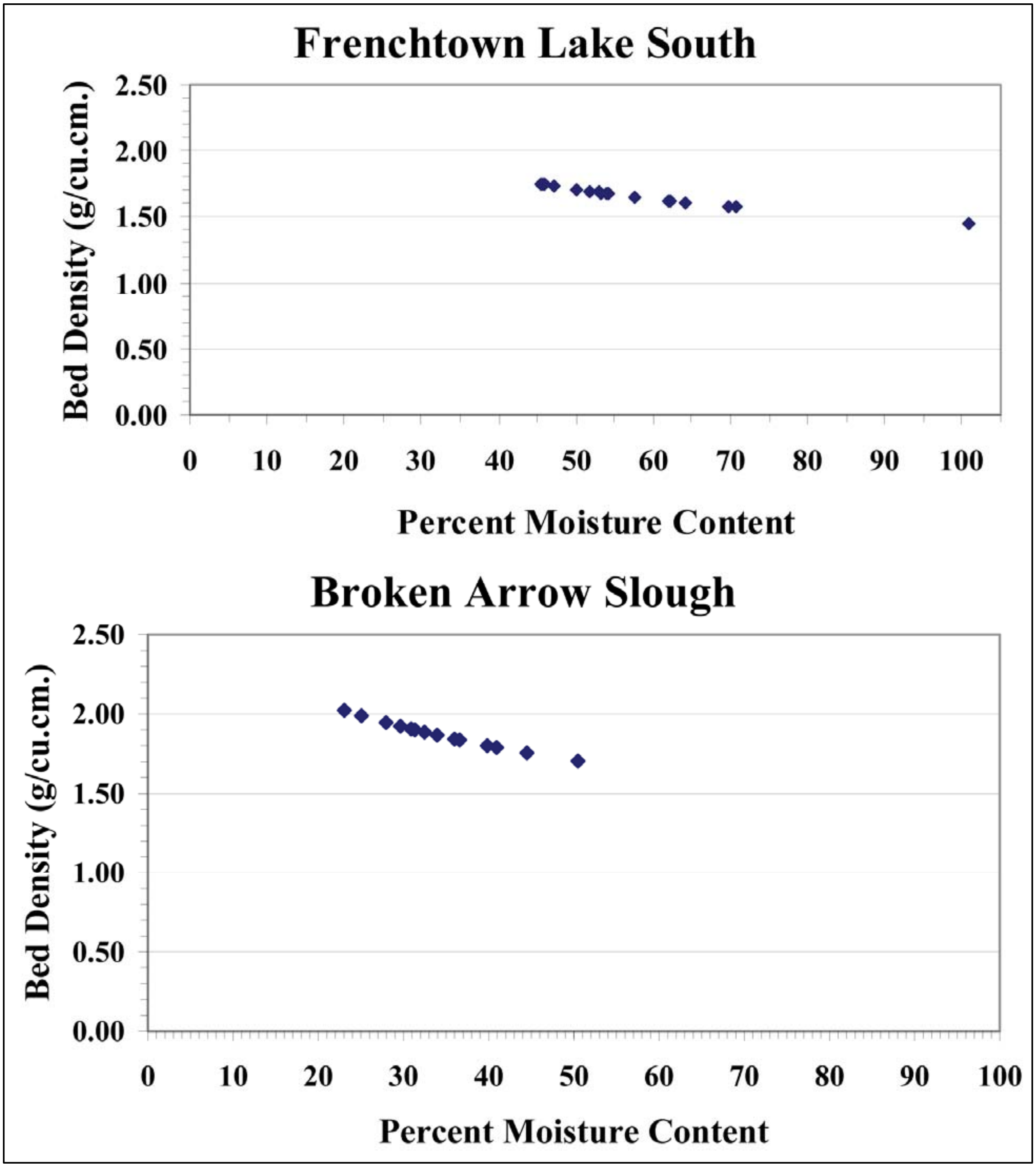


Figure C9. Bed density as a function of moisture content at Frenchtown Lake South and Broken Arrow Slough

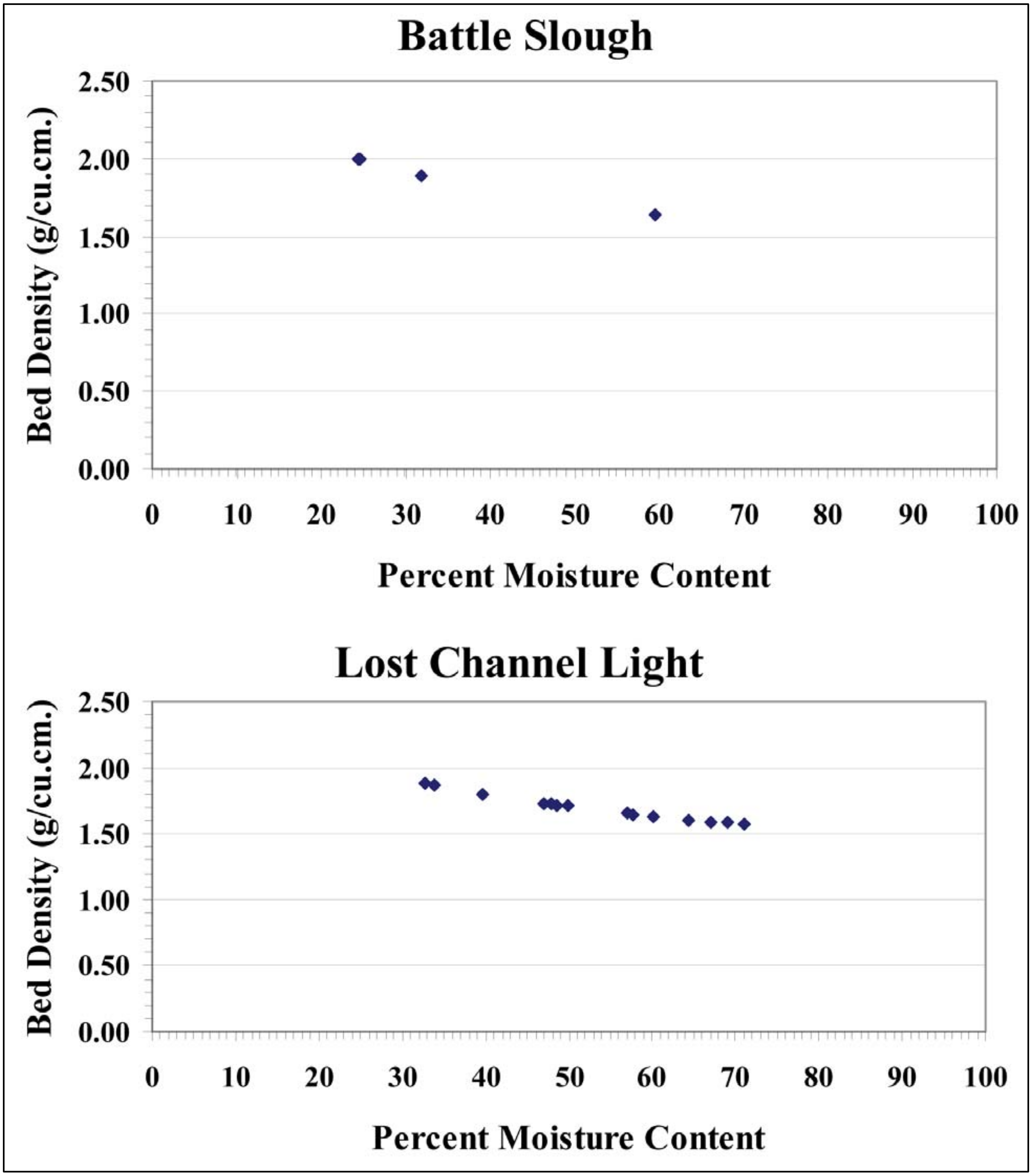


Figure C10. Bed density as a function of moisture content at Battle Slough and Lost Channel Light

Appendix D
Percent Organic Matter as a Function of Percent Finer than 64 μ (Upper Mississippi River Data)

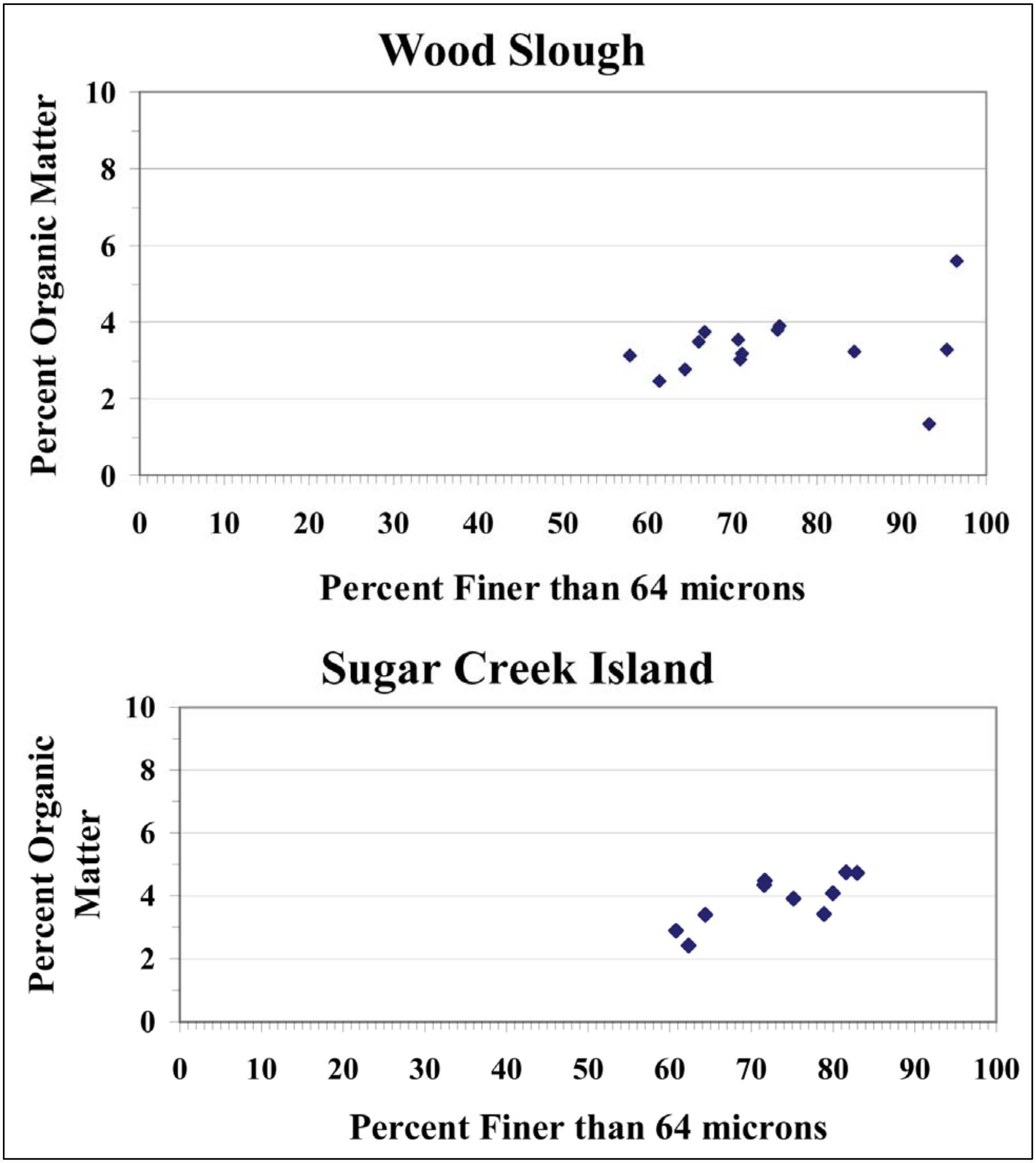


Figure D1. Organic matter as a function of percent finer than 64 μ at Wood Slough and Sugar Creek Island

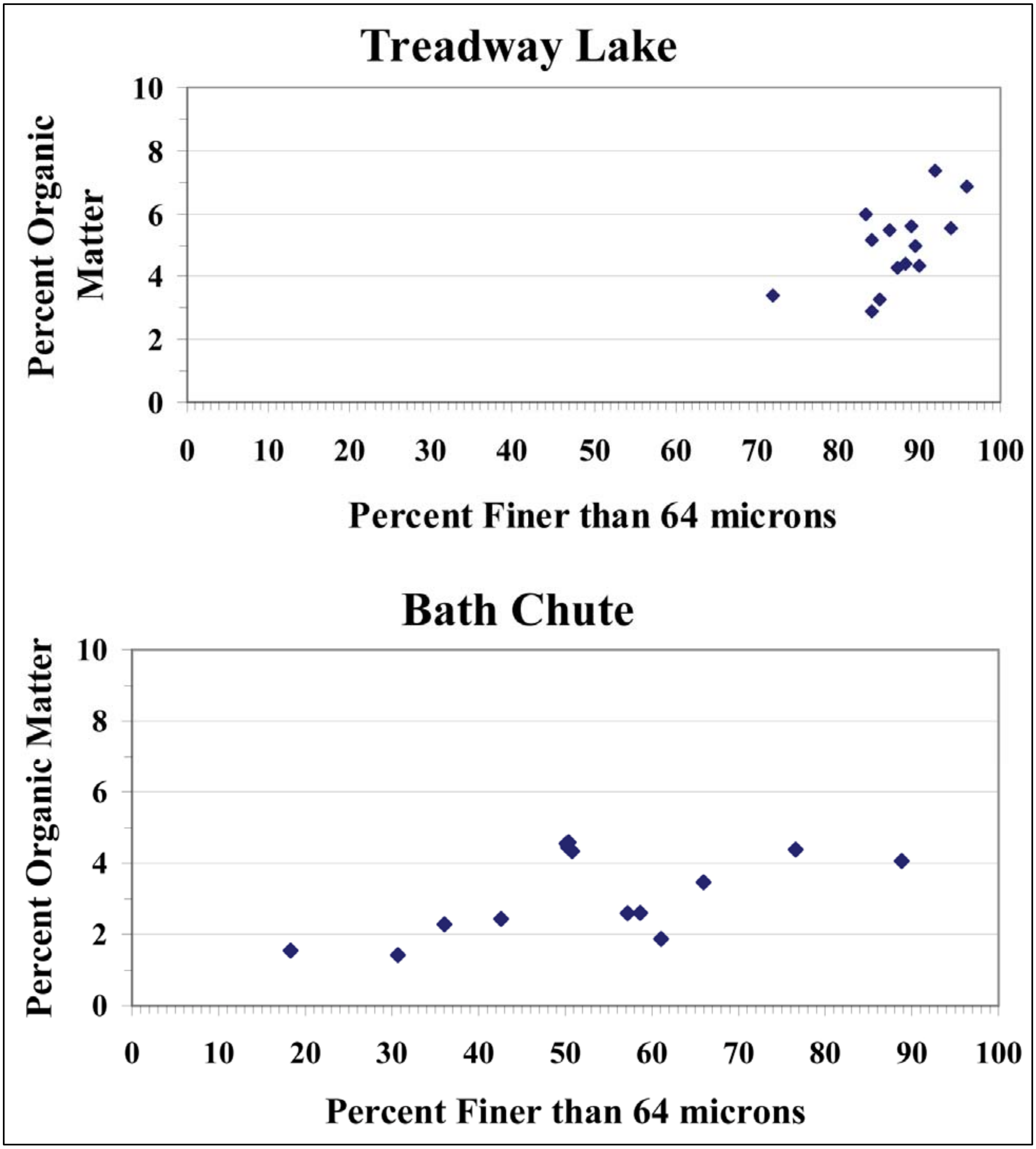


Figure D2. Organic matter as a function of percent finer than 64 µ at Treadway Lake and Bath Chute

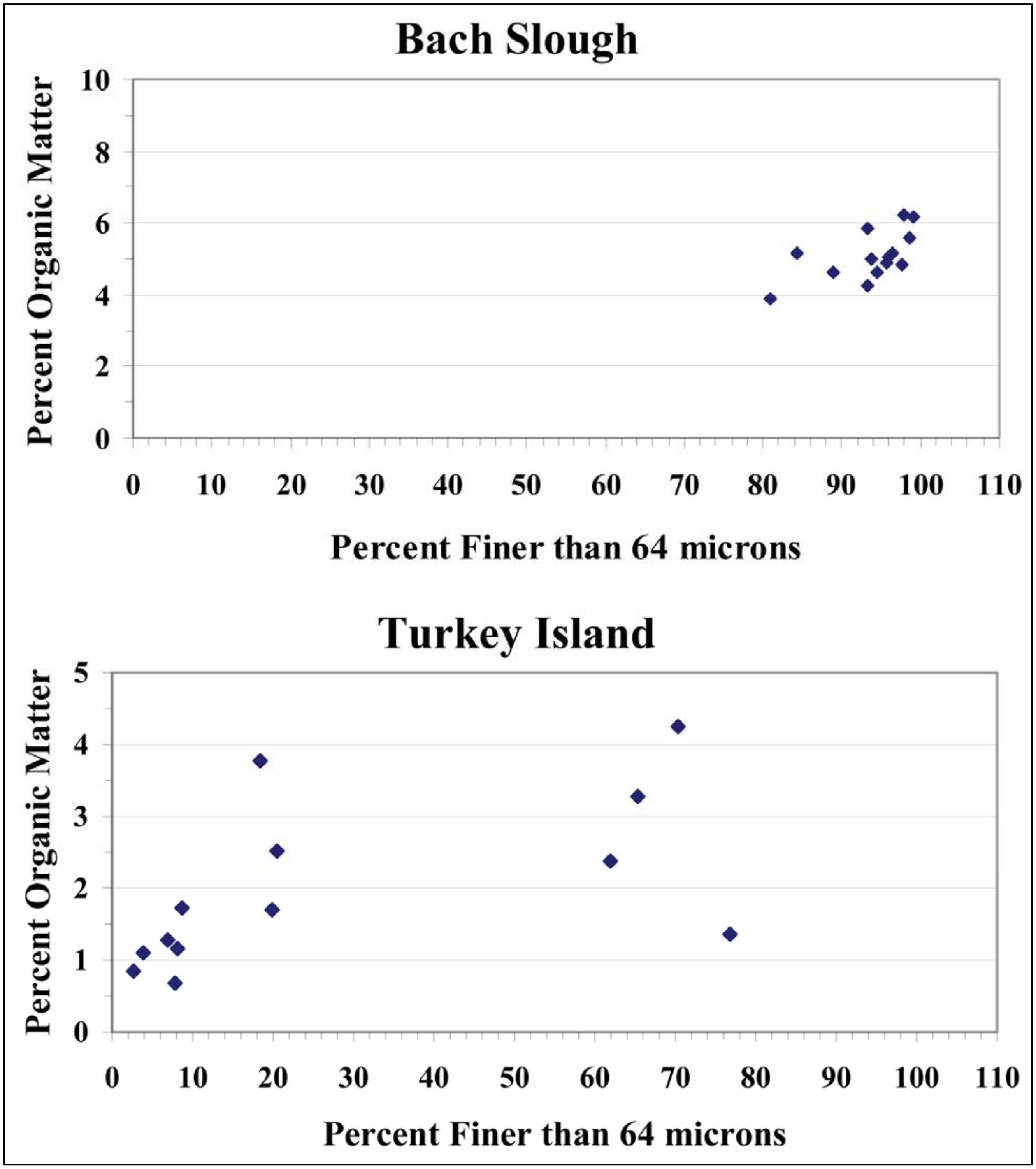


Figure D3. Organic matter as a function of percent finer than 64 μ at Bach Slough and Turkey Island

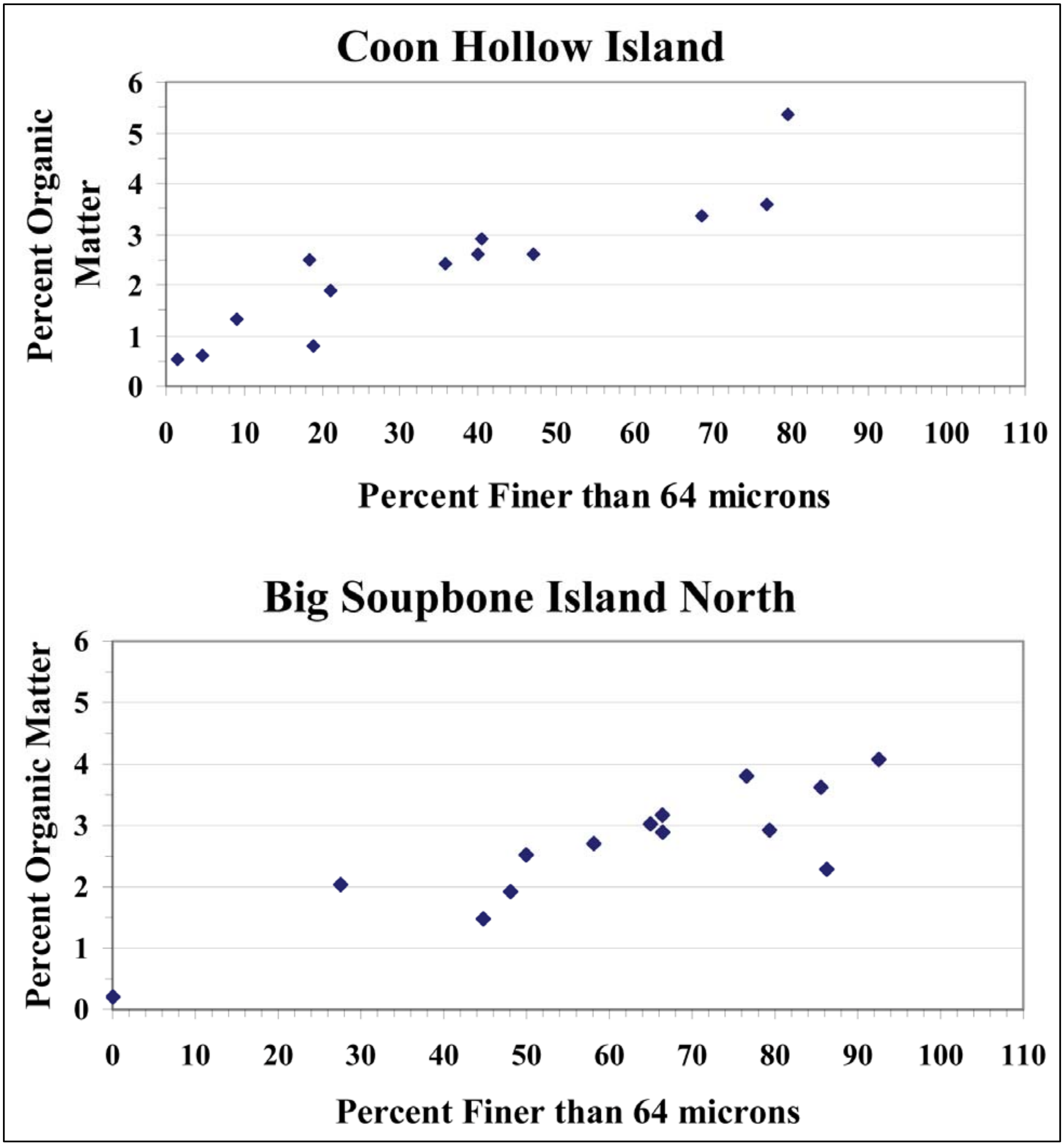


Figure D4. Organic matter as a function of percent finer than 64 µ at Coon Hollow Island and Big Soupbone Island North

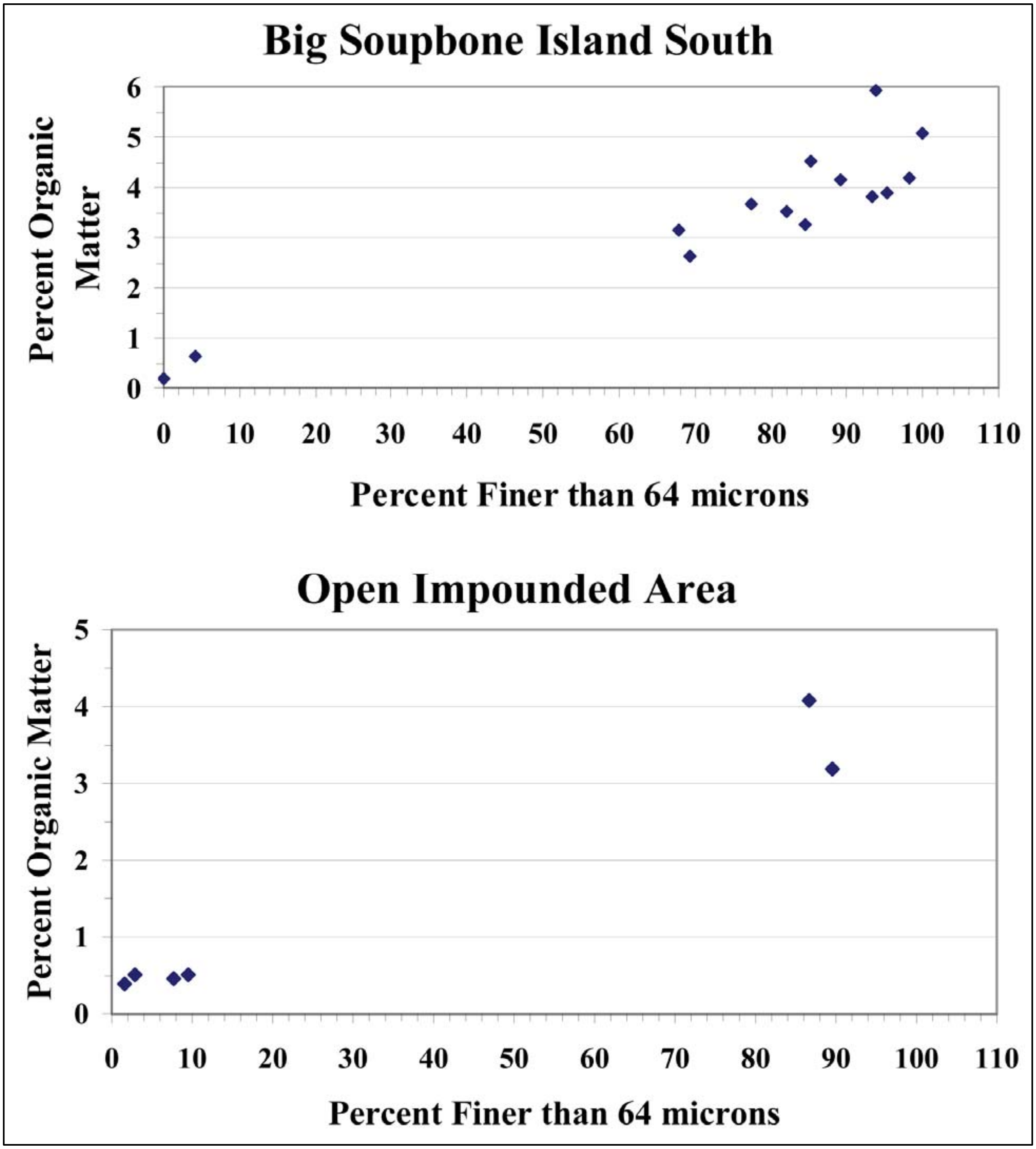


Figure D5. Organic matter as a function of percent finer than 64 µ at Big Soupbone Island South and Open Impounded Area (River Mile 528)

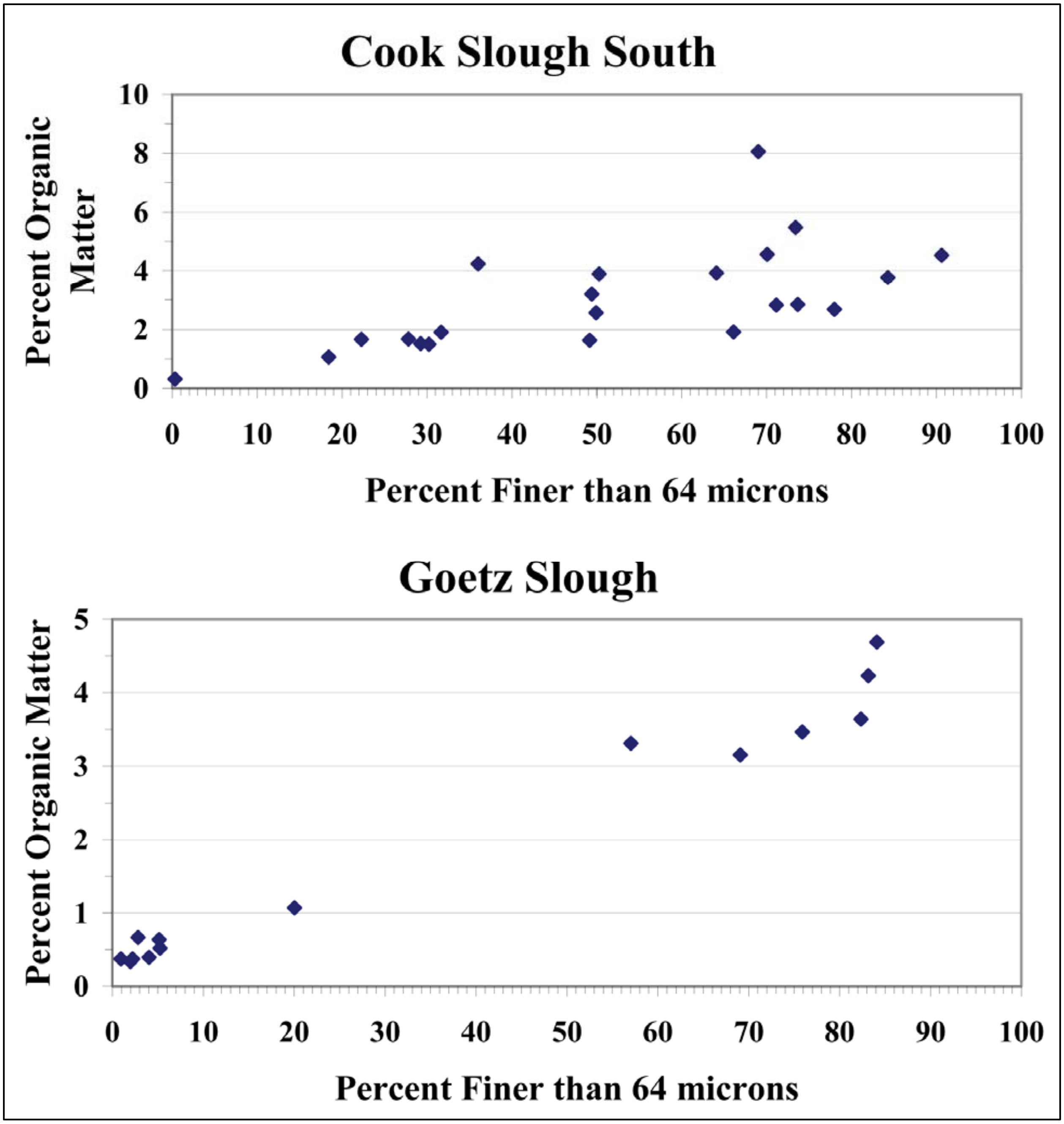


Figure D6. Organic matter as a function of percent finer than 64 μ at Cook Slough South and Goetz Slough

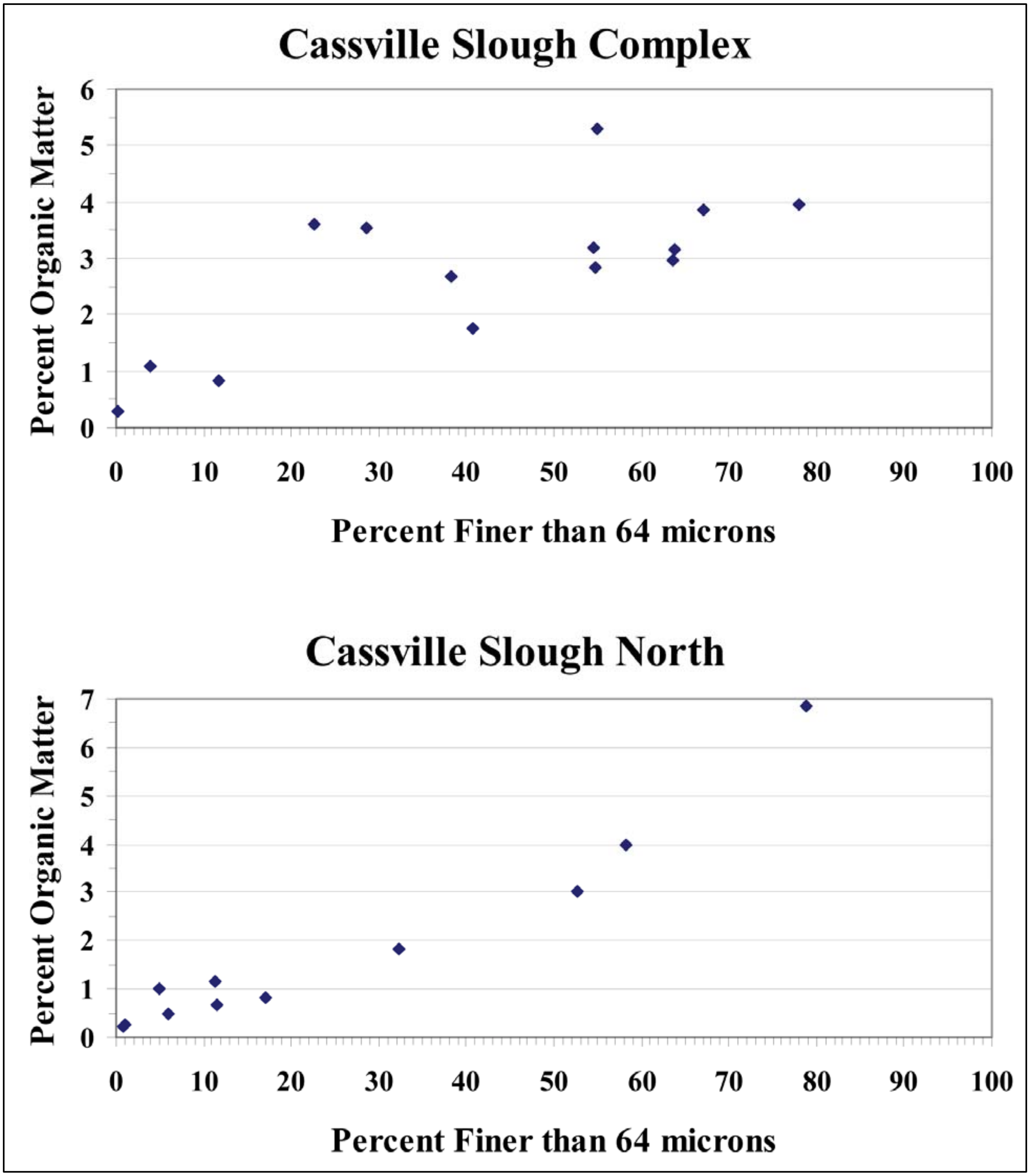


Figure D7. Organic matter as a function of percent finer than 64 μ at Cassville Slough Complex and Cassville Slough North

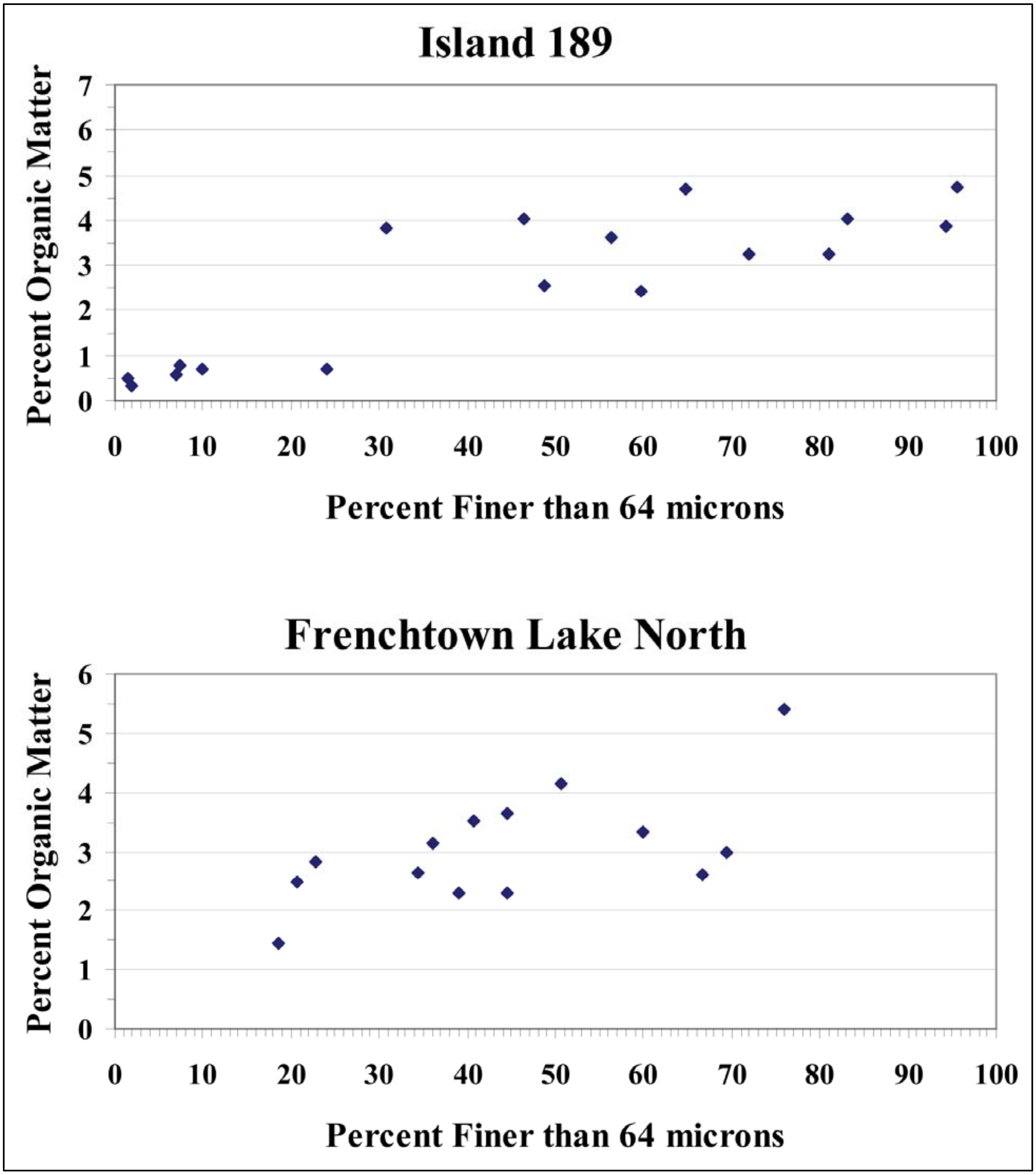
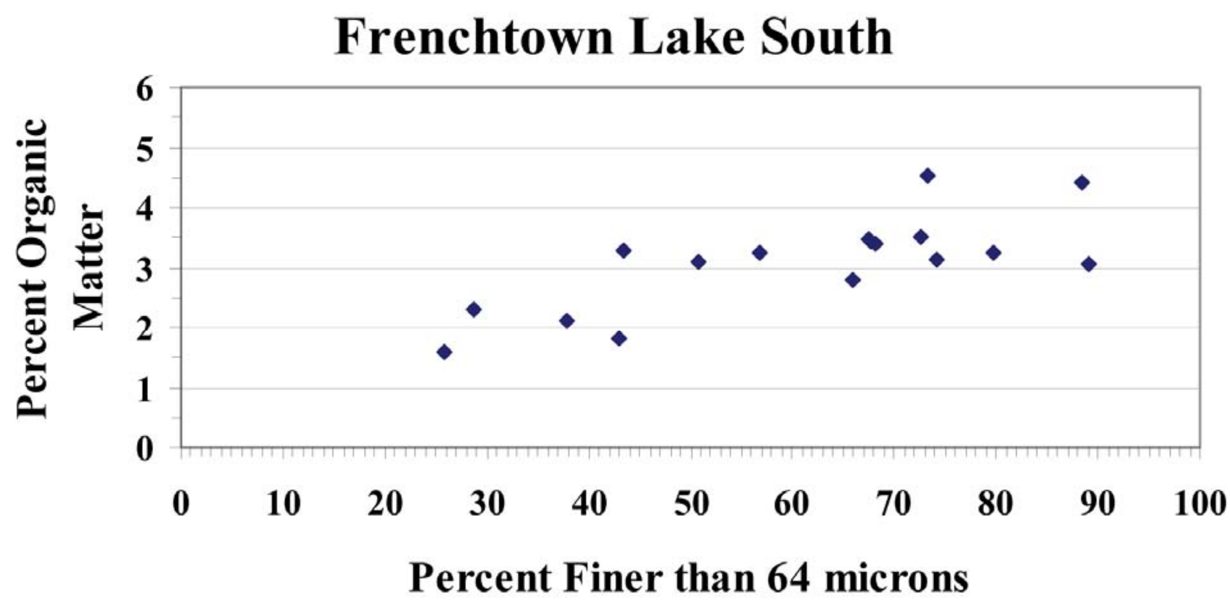


Figure D8. Organic matter as a function of percent finer than 64 μ at Island 189 and Frenchtown Lake North



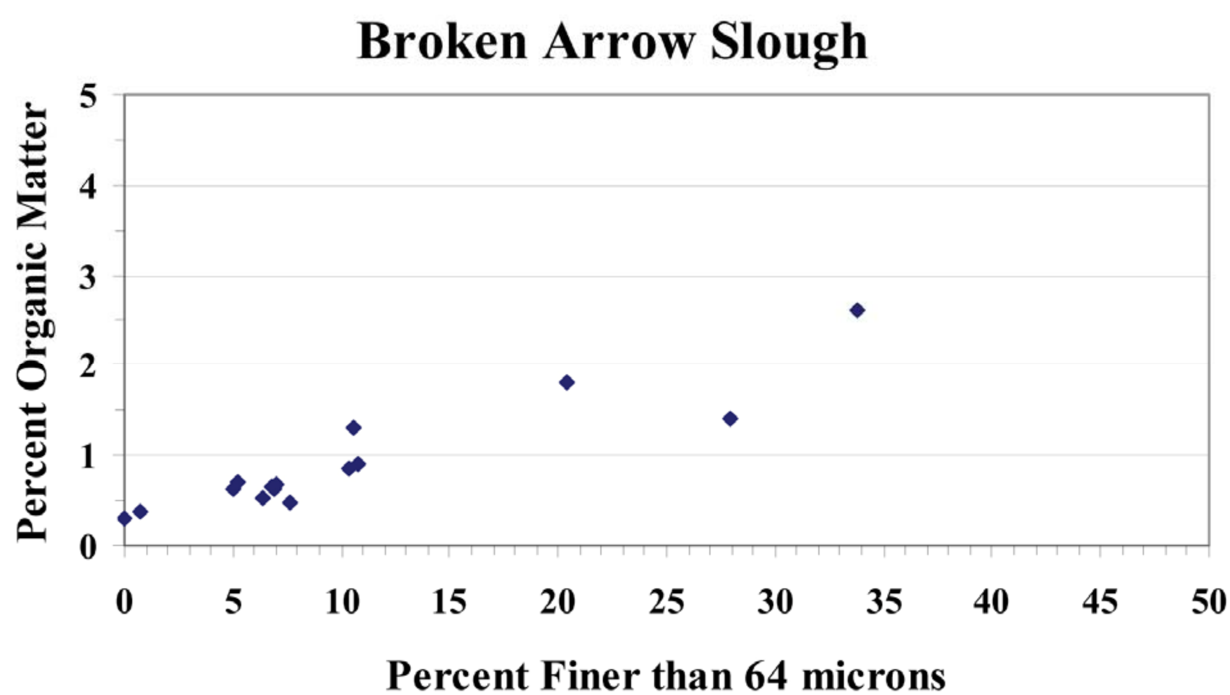


Figure D9. Organic matter as a function of percent finer than 64 µ at Frenchtown Lake South and Broken Arrow Slough

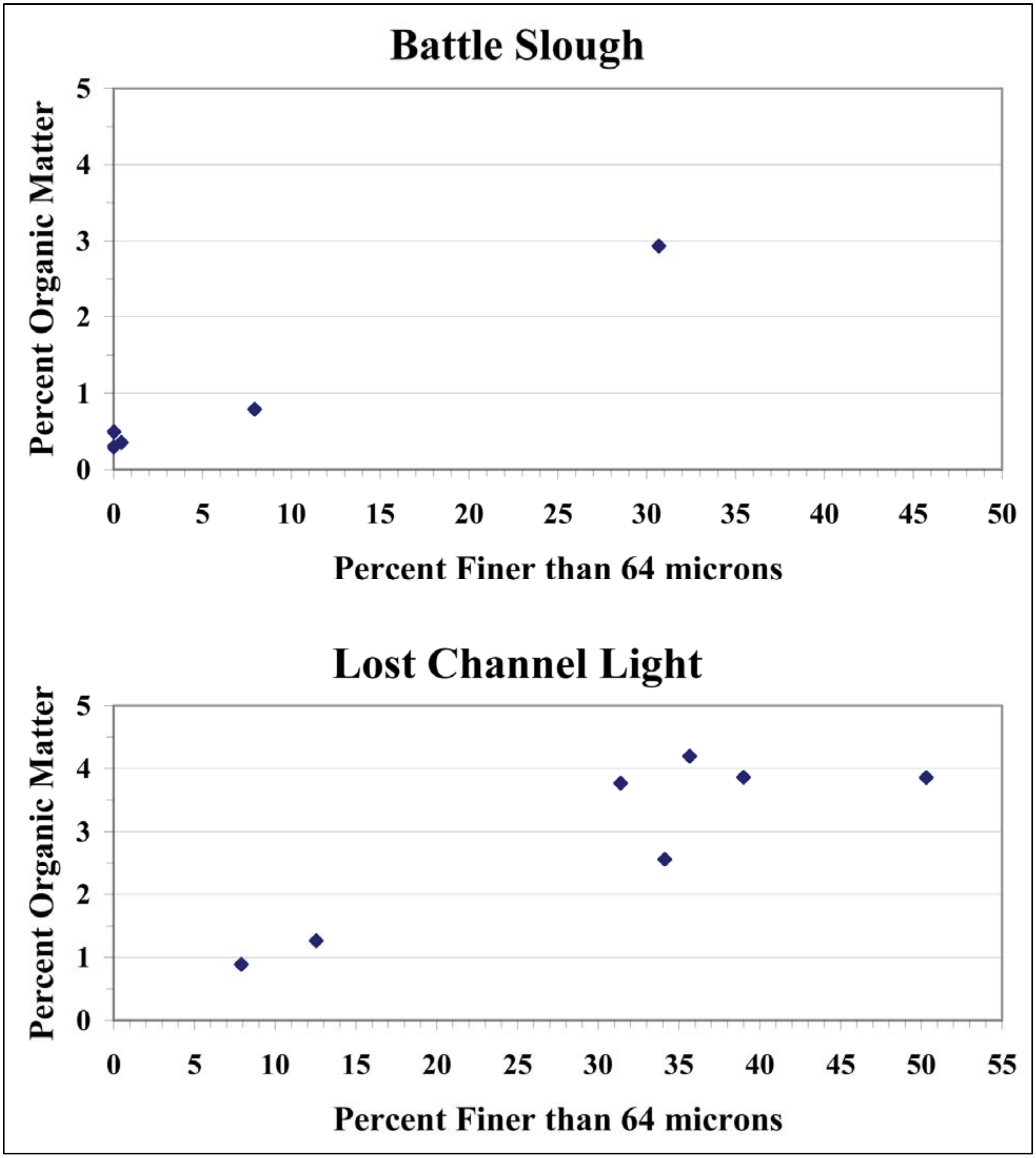


Figure D10. Organic matter as a function of percent finer than 64 µ at Battle Slough and Lost Channel Light

Appendix E
Percent Moisture as a Function of Percent Finer than 64 μ (Upper Mississippi River Data)

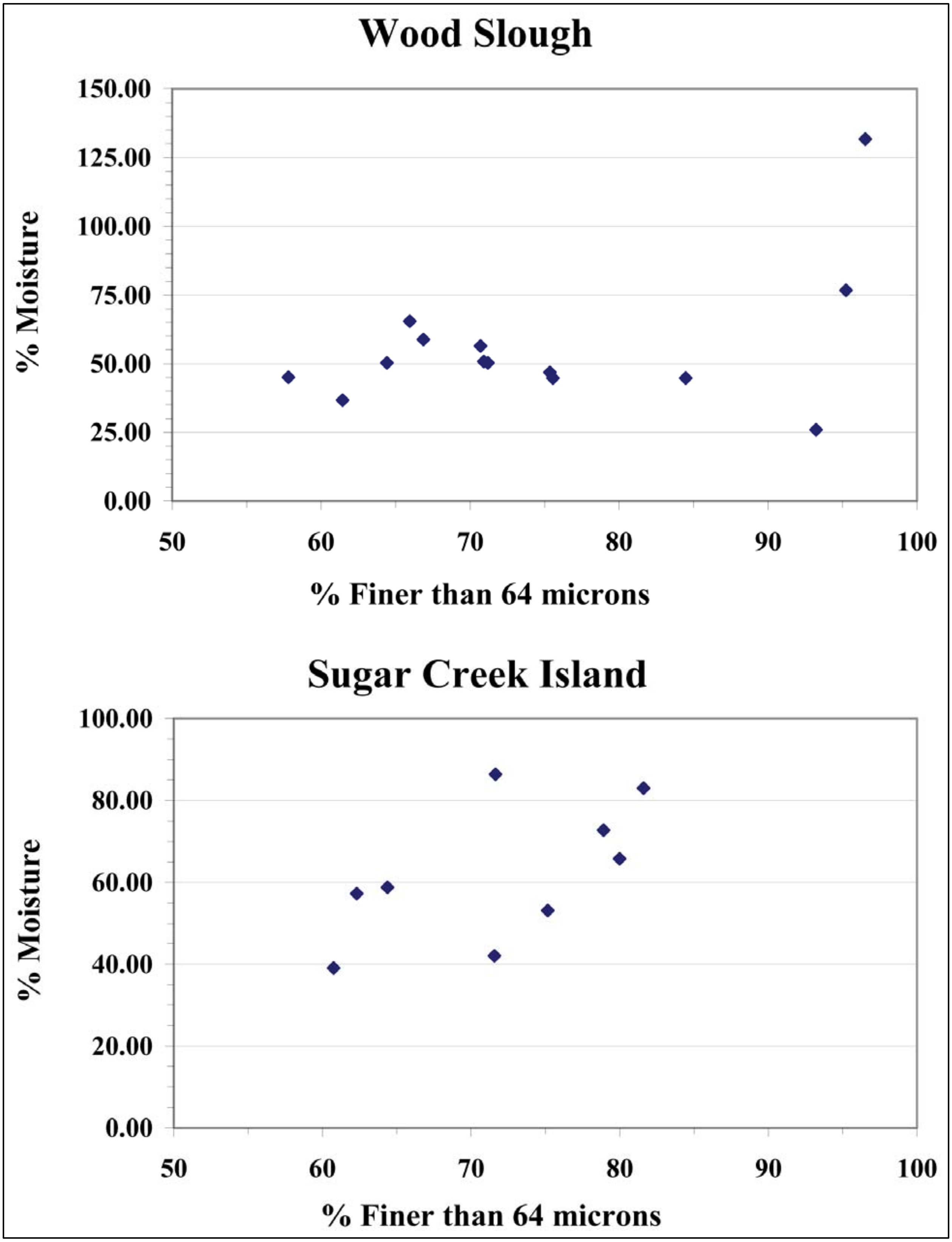


Figure E1. Bed density as a function of percent finer than 64 μ at Wood Slough and Sugar Creek Island

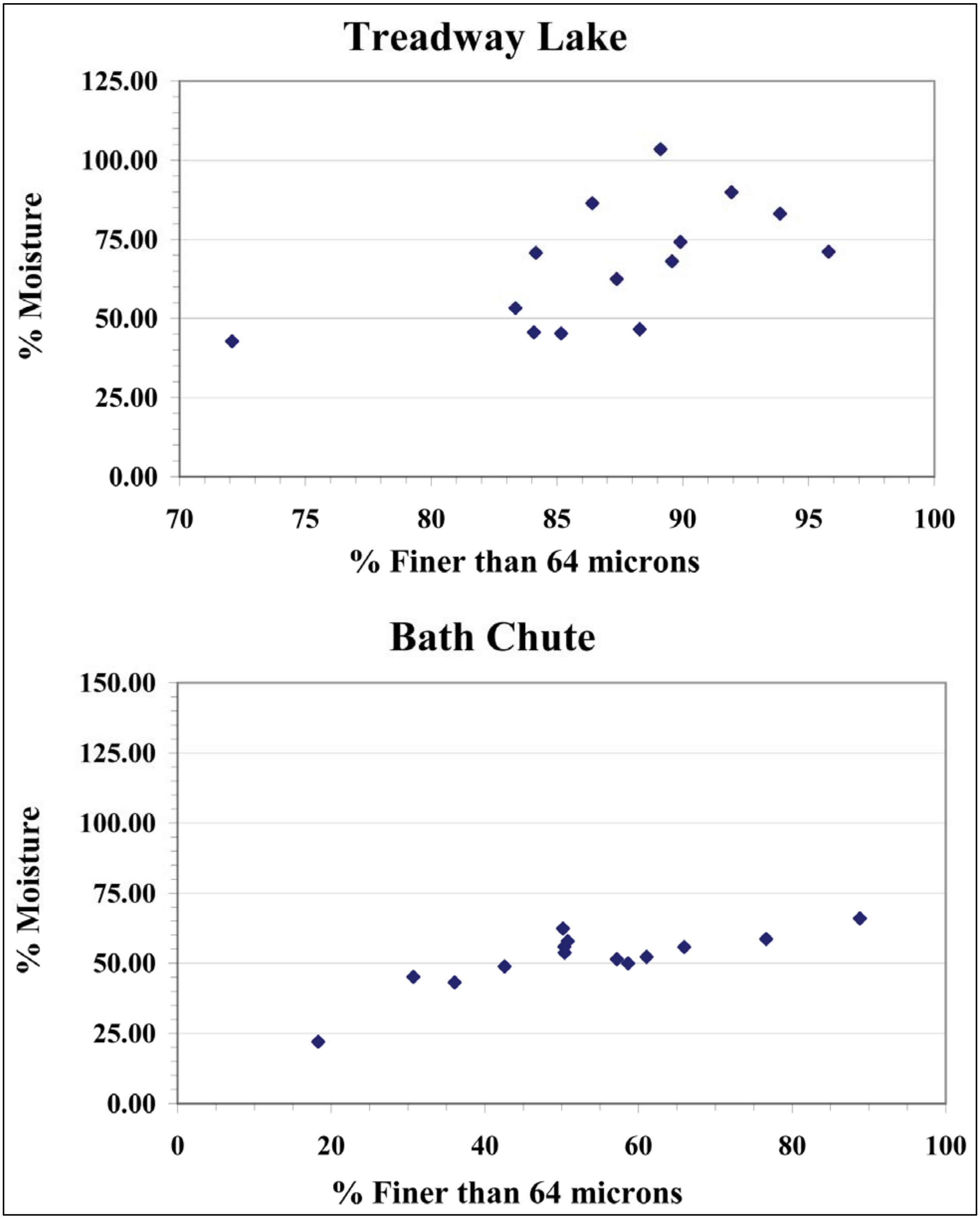


Figure E2. Bed density as a function of percent finer than 64 μ at Treadway Lake and Bath Chute

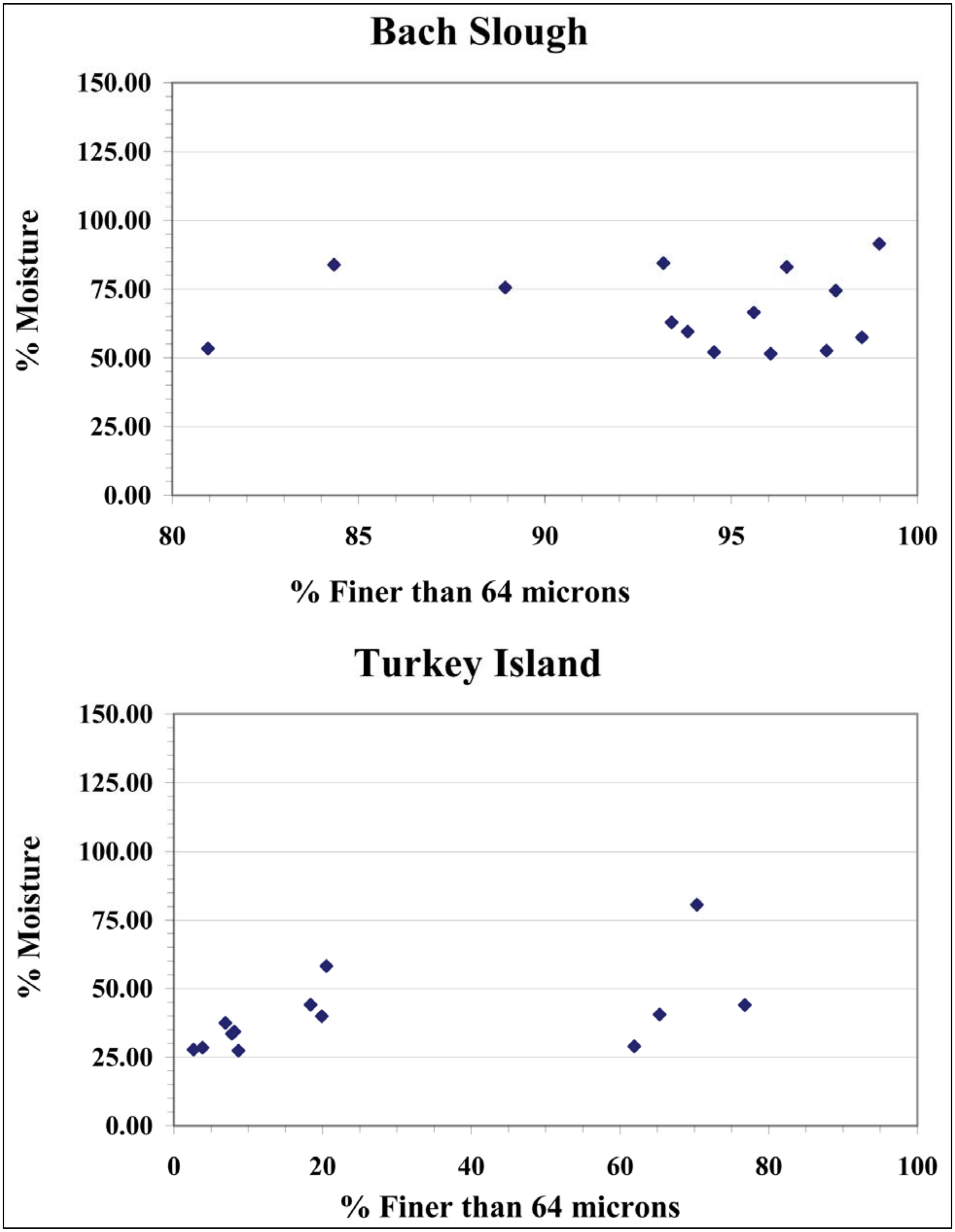


Figure E3. Bed density as a function of percent finer than 64 µ at Bach Slough and Turkey Island

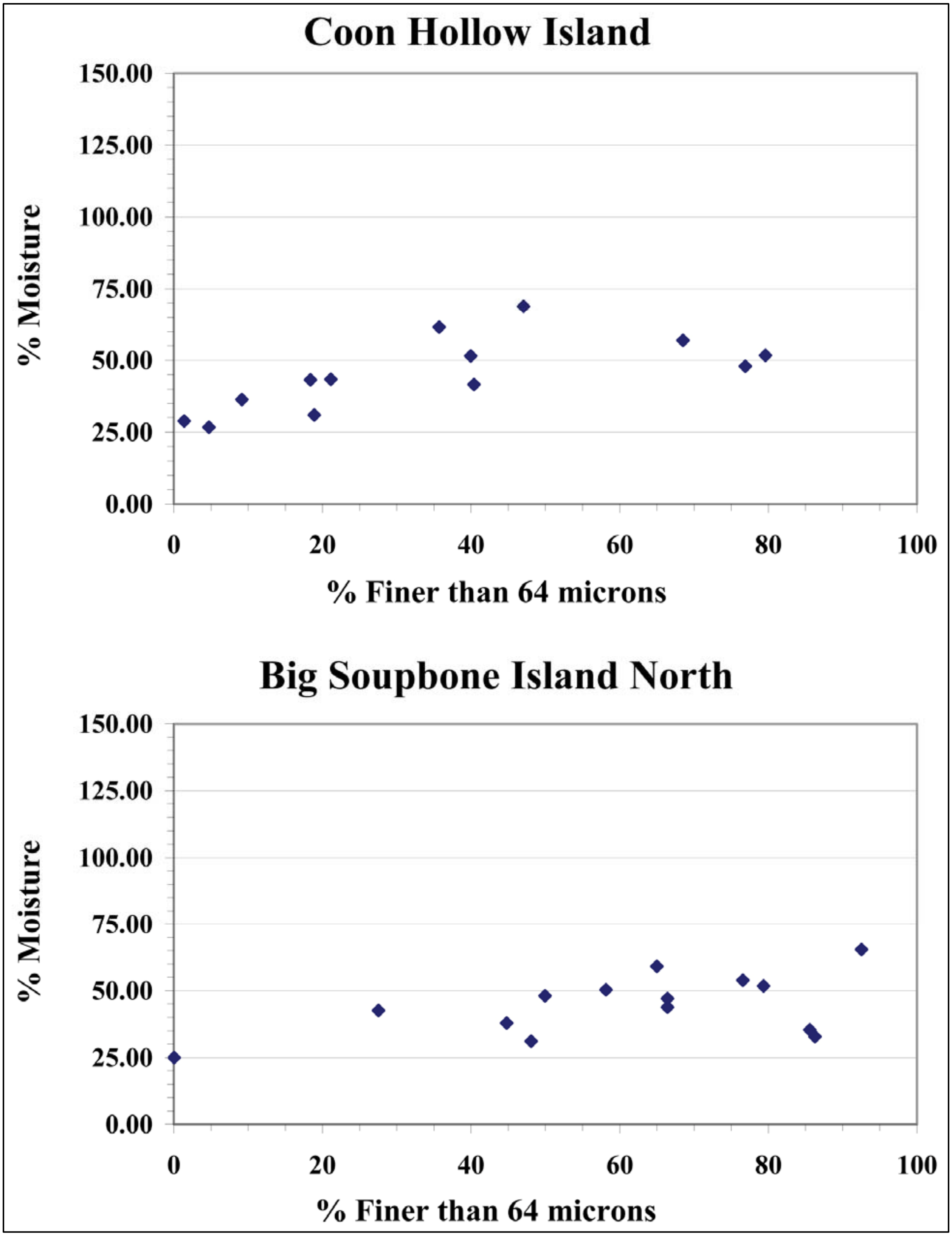


Figure E4. Bed density as a function of percent finer than 64 µ at Coon Hollow Island and Big Soupbone Island North

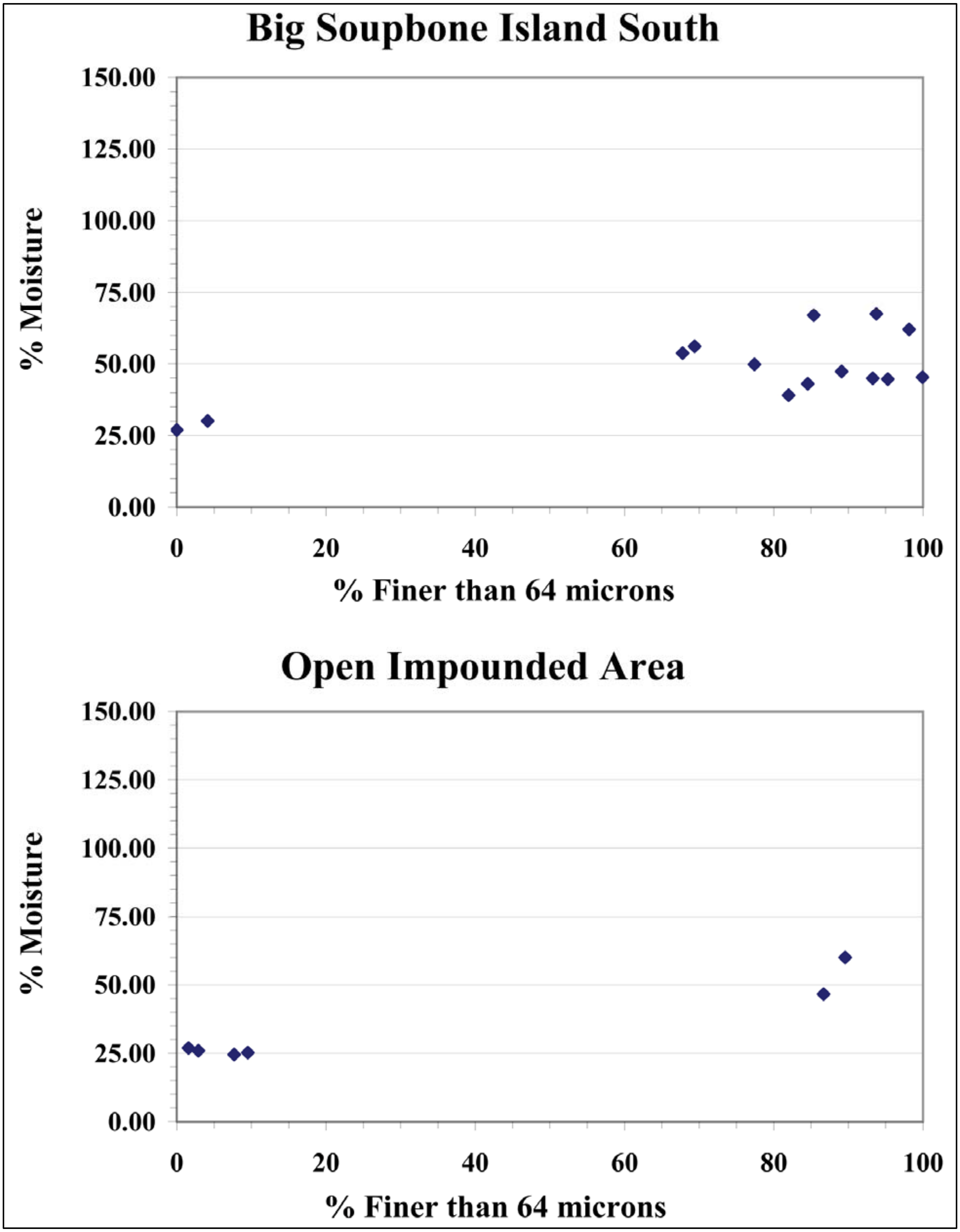


Figure E5. Bed density as a function of percent finer than 64 μ at Big Soupbone Island South and Open Impounded Area (river mile 528)

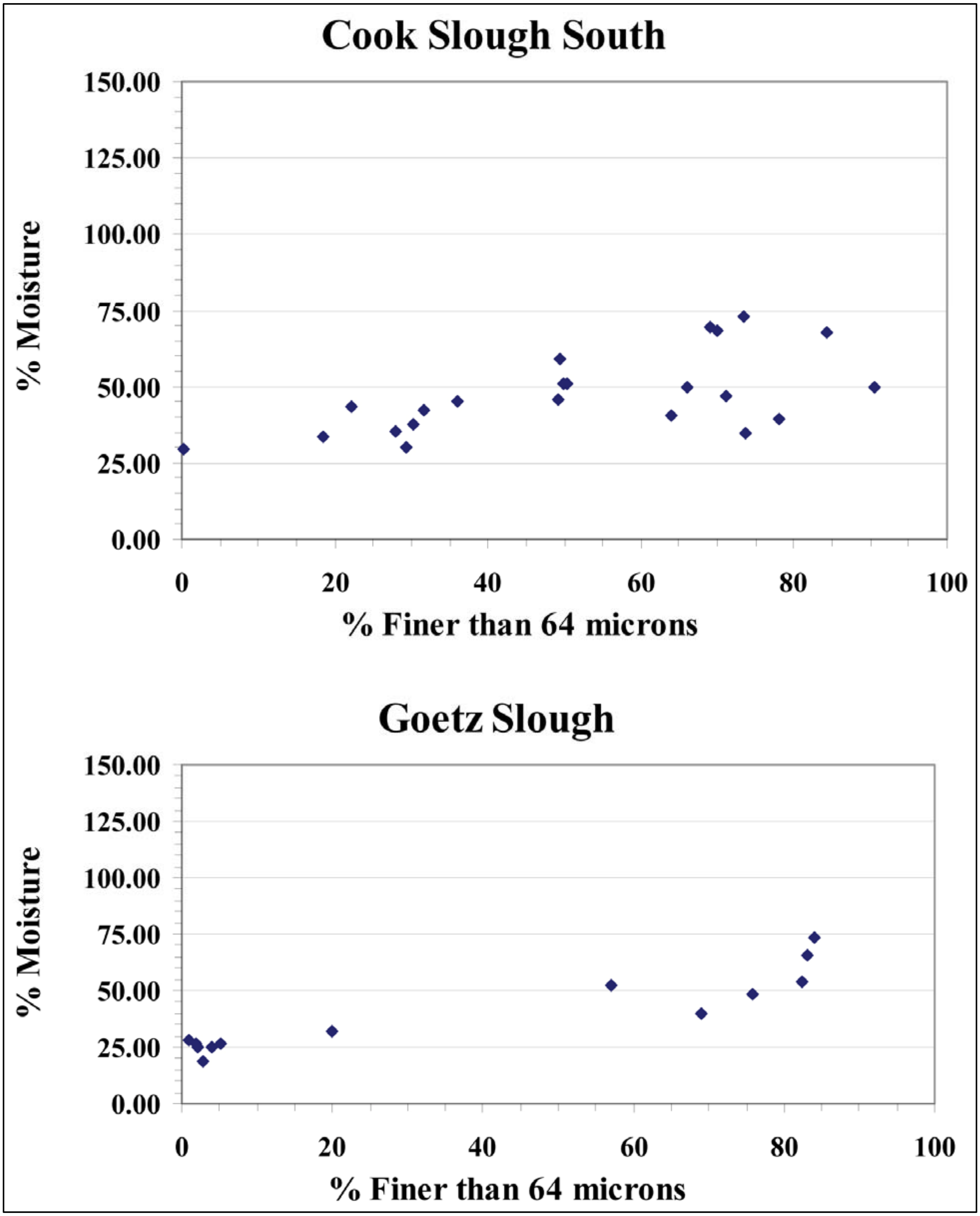


Figure E6. Bed density as a function of percent finer than 64 µ at Cook Slough South and Goetz Slough

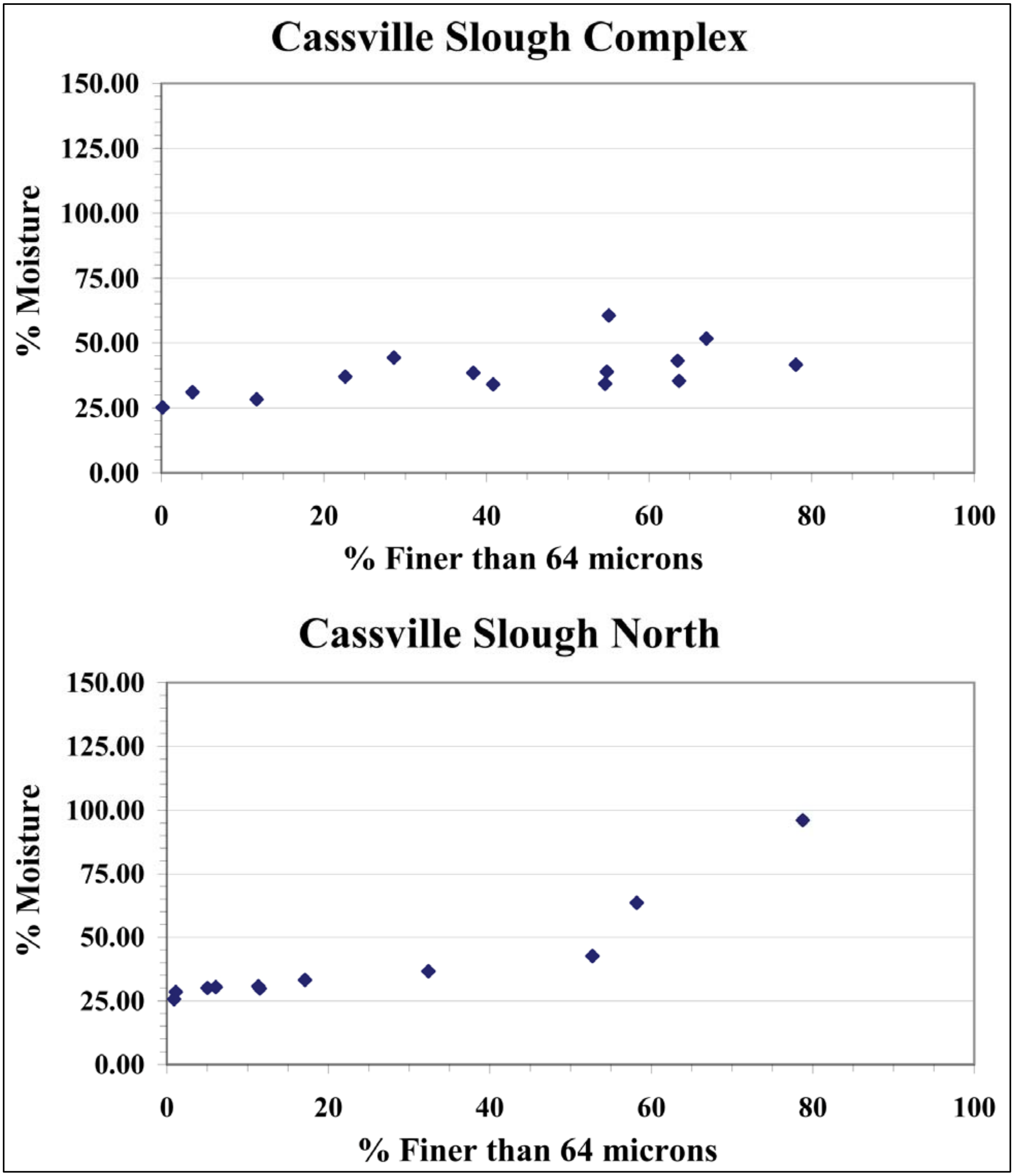


Figure E7. Bed density as a function of percent finer than 64 µ at Cassville Slough Complex and Cassville Slough North

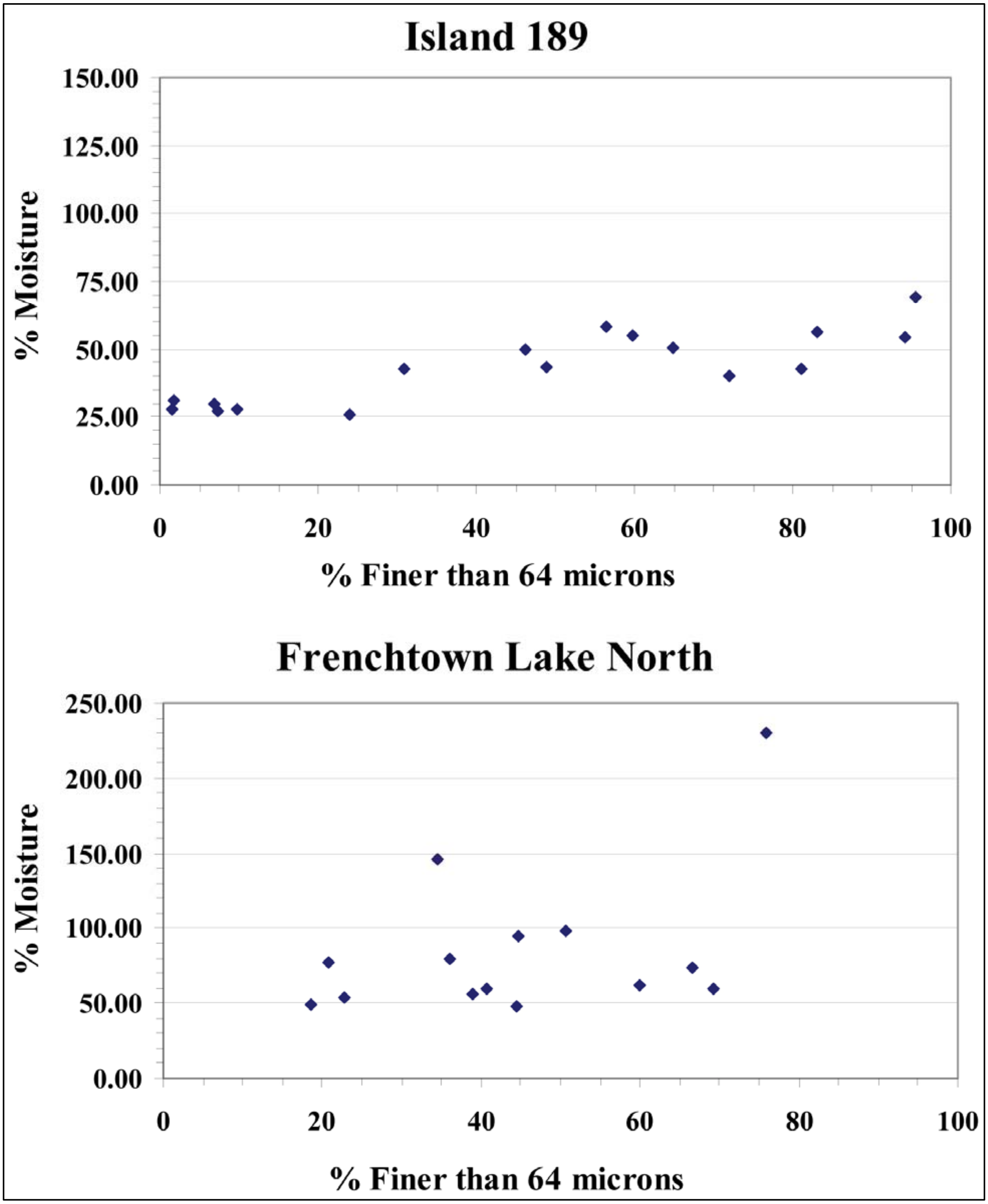


Figure E8. Bed density as a function of percent finer than 64 µ at Island 189 and Frenchtown Lake North

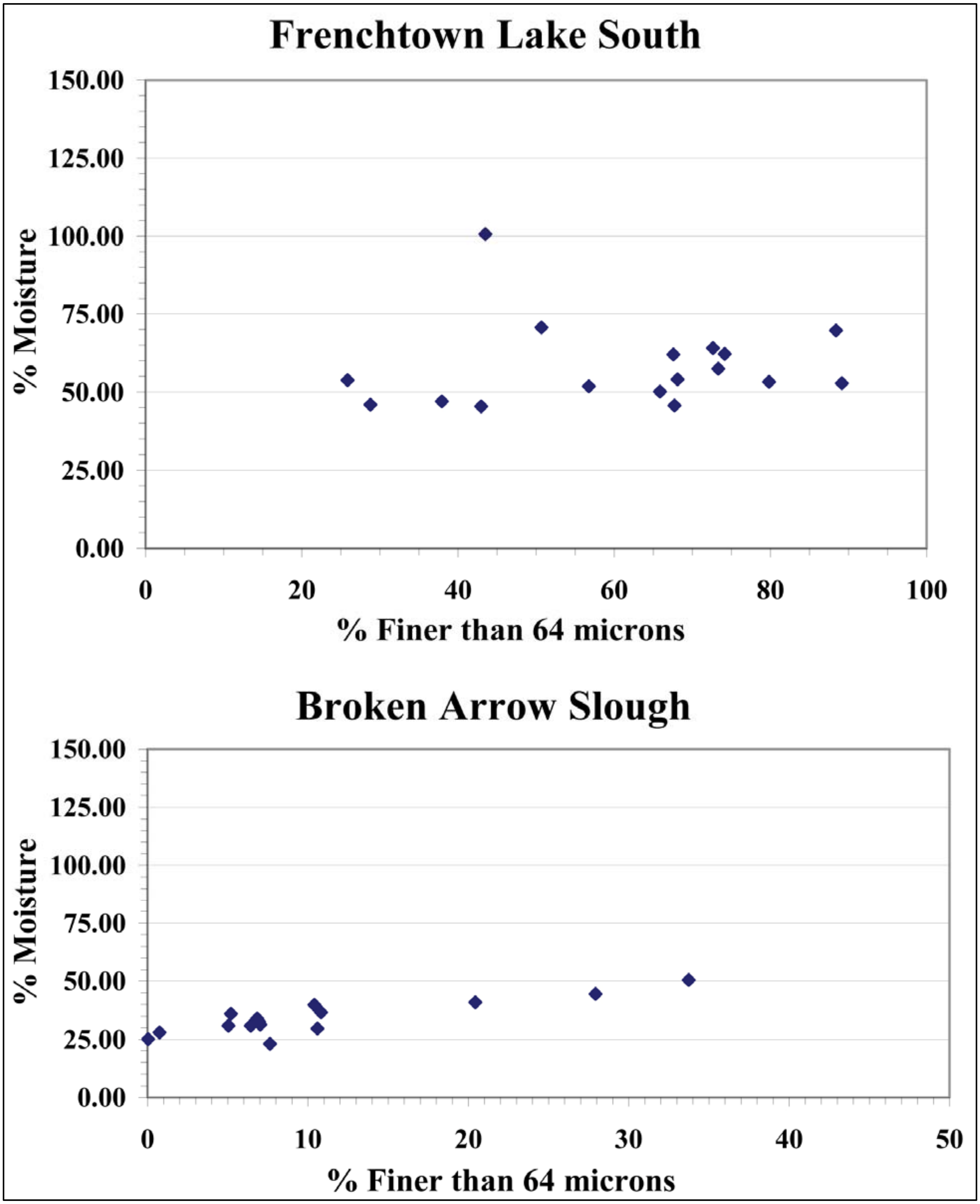


Figure E9. Bed density as a function of percent finer than 64 µ at Frenchtown Lake South and Broken Arrow Slough

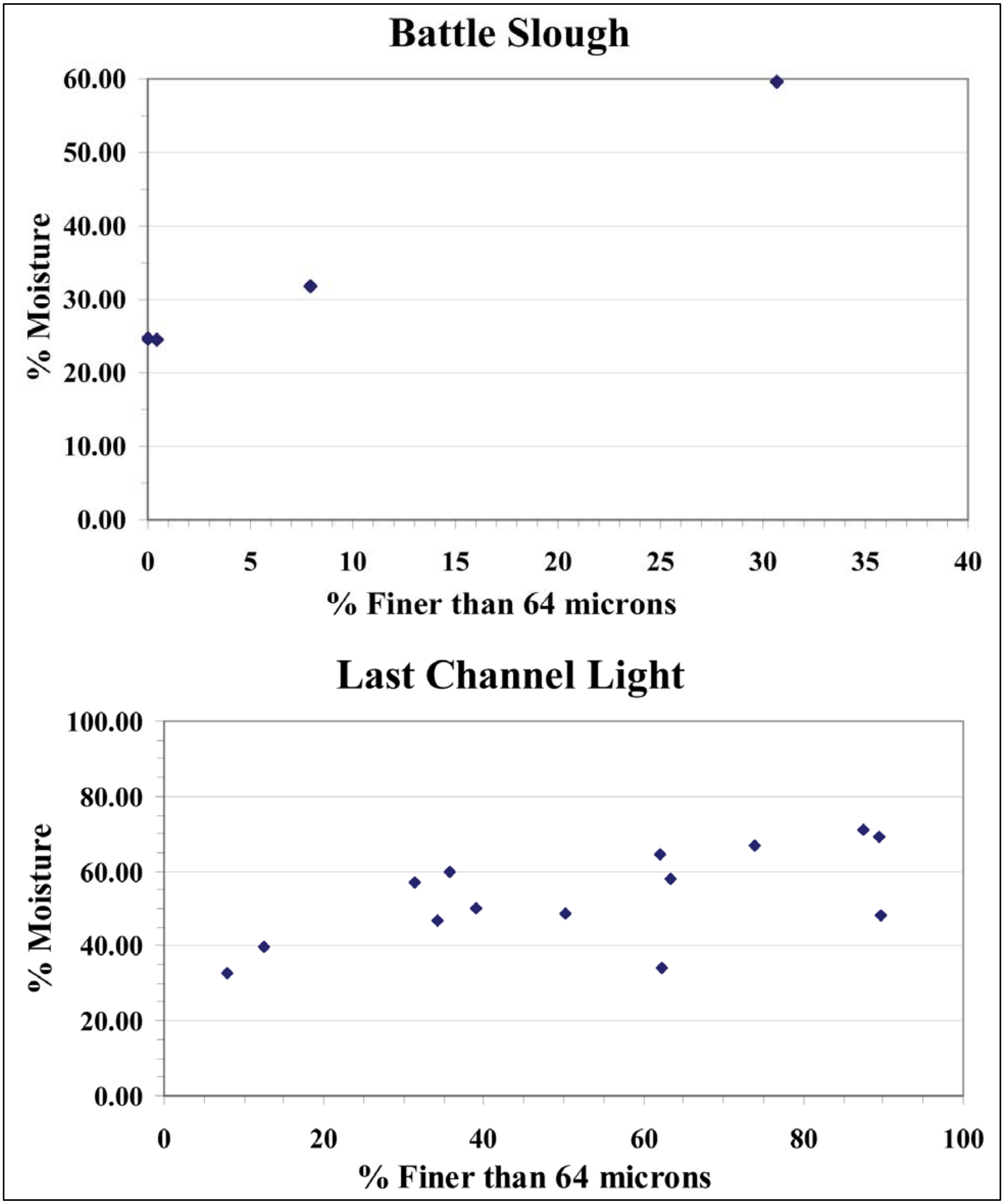


Figure E10. Bed density as a function of percent finer than 64 µ at Battle Slough and Lost Channel Light

Appendix F
Bed Density as a Function of Percent Finer than 64 μ (Upper Mississippi River Data)

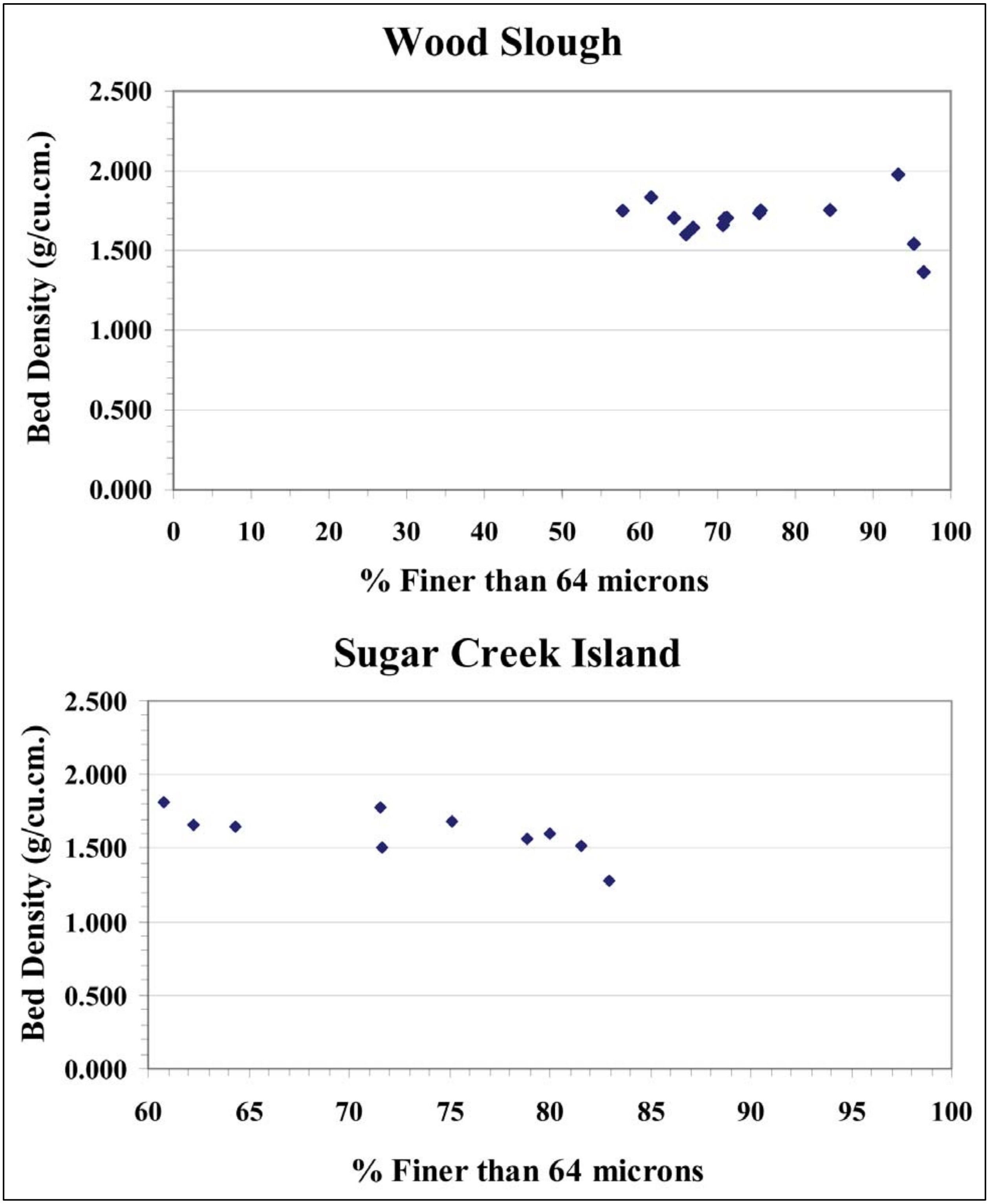


Figure F1. Percent moisture as a function of percent finer than 64 μ at Wood Slough and Sugar Creek Island

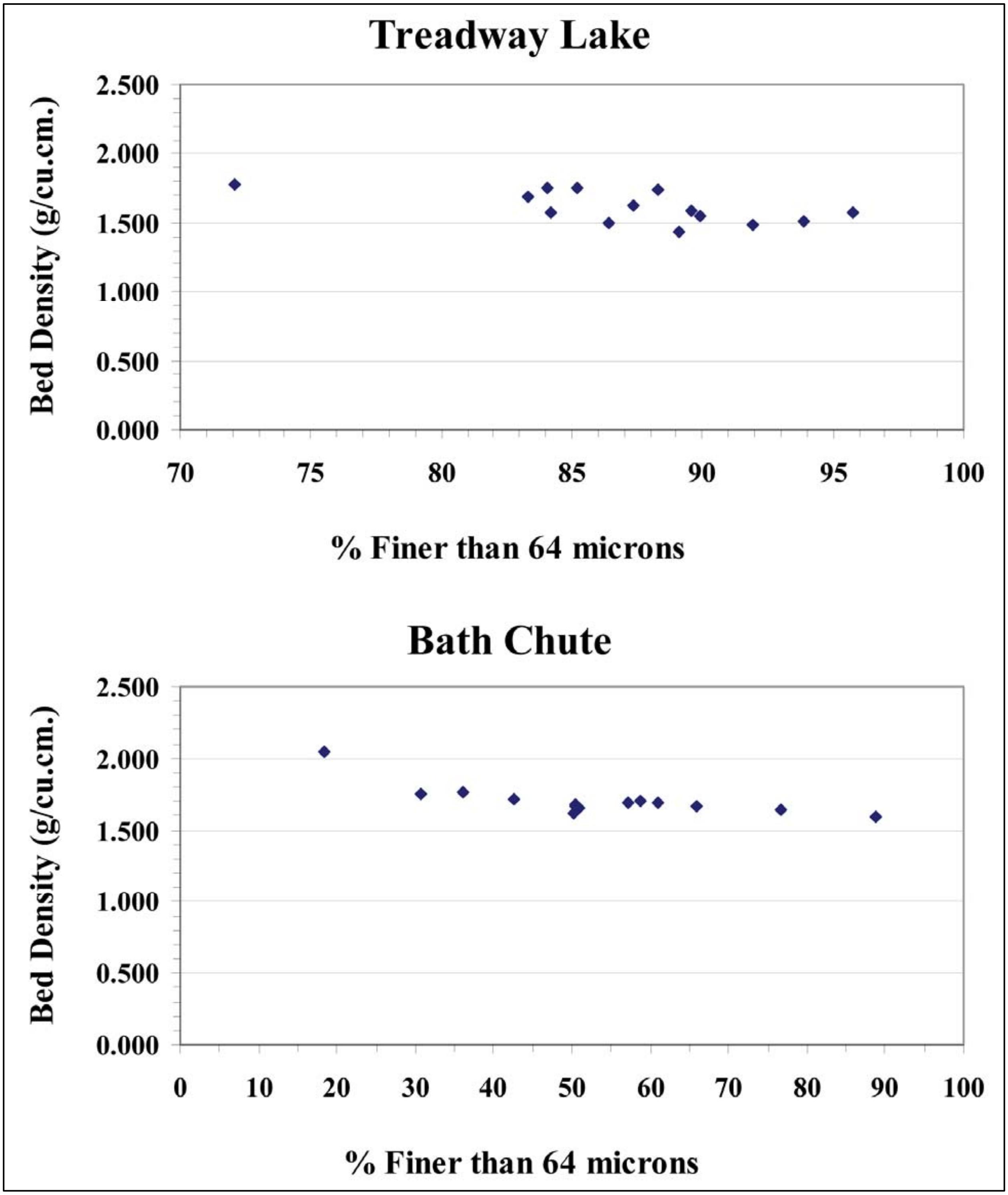


Figure F2. Percent moisture as a function of percent finer than 64 μ at Treadway Lake and Bath Chute

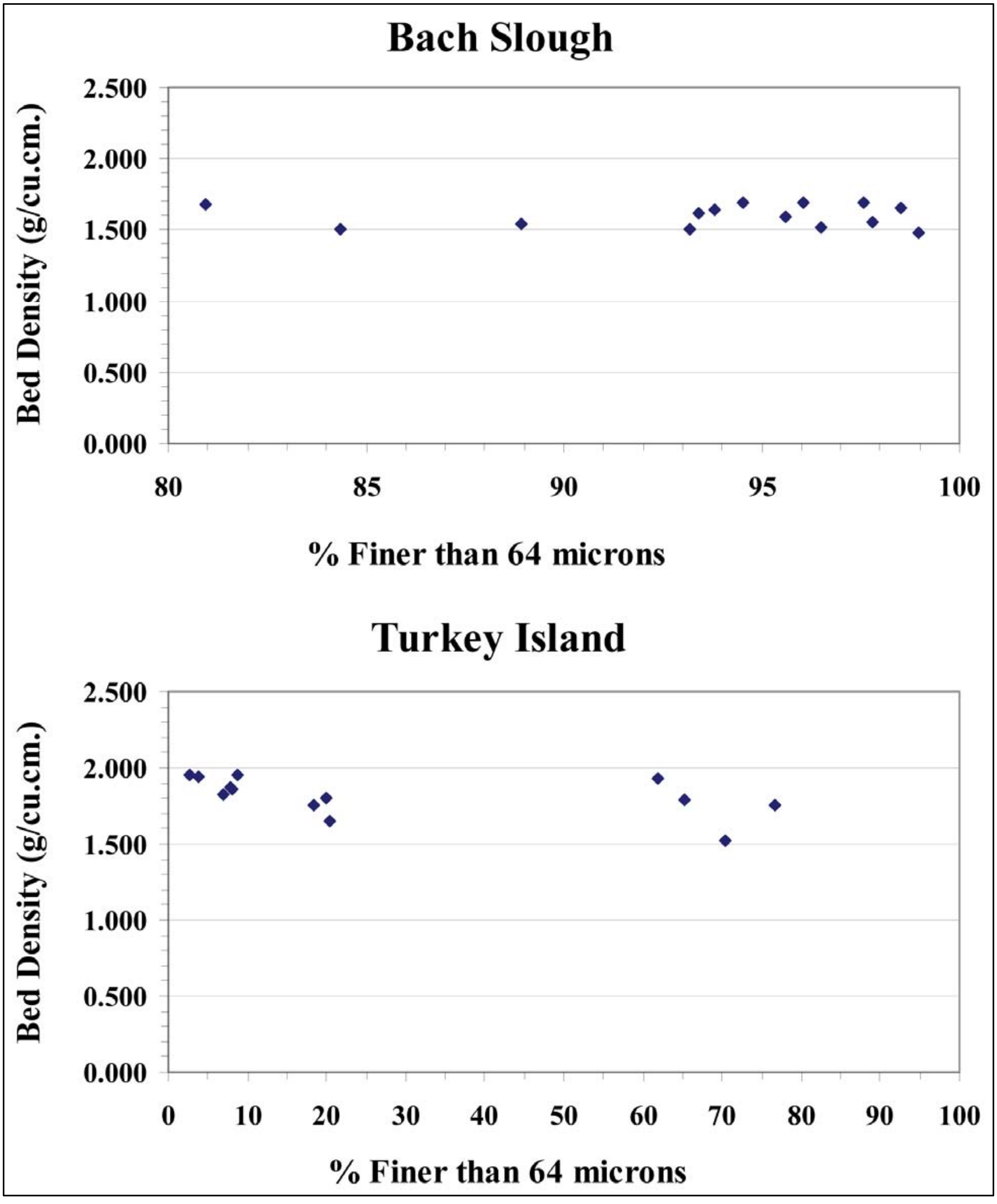


Figure F3. Percent moisture as a function of percent finer than 64 µ at Bach Slough and Turkey Island

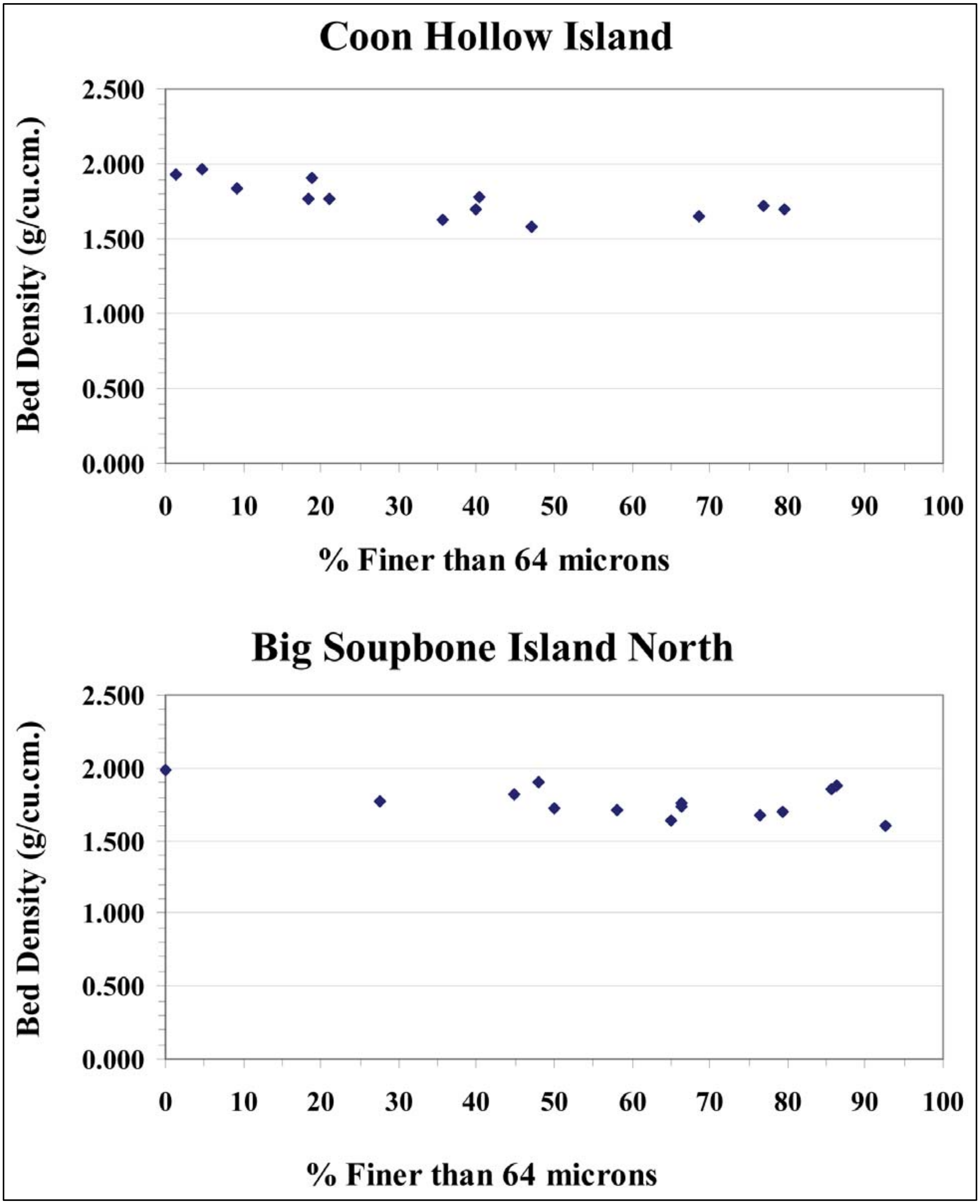


Figure F4. Percent moisture as a function of percent finer than 64 µ at Coon Hollow Island and Big Soupbone Island North

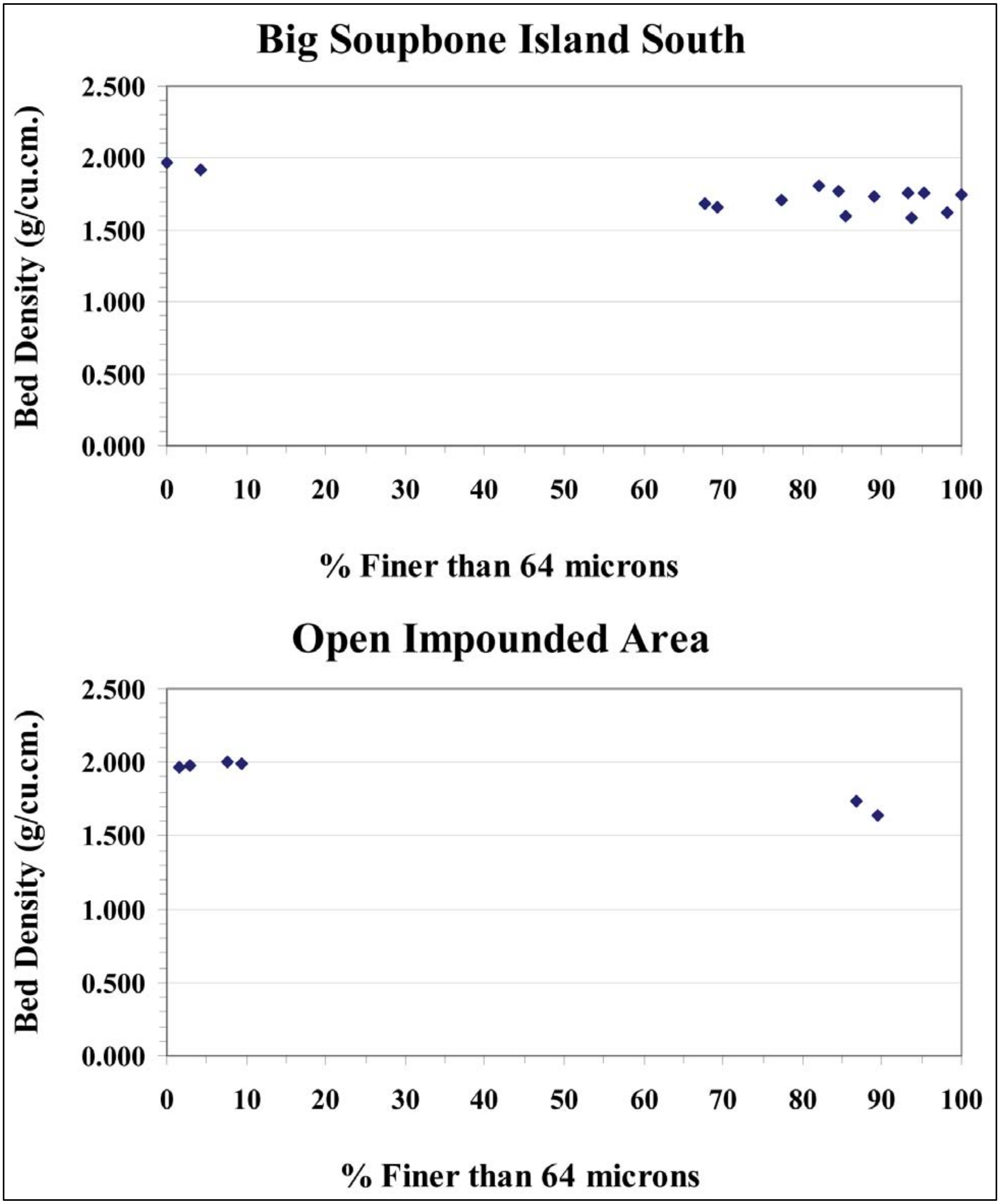


Figure F5. Percent moisture as a function of percent finer than 64 µ at Big Soupbone Island South and Open Impounded Area (river mile 528)

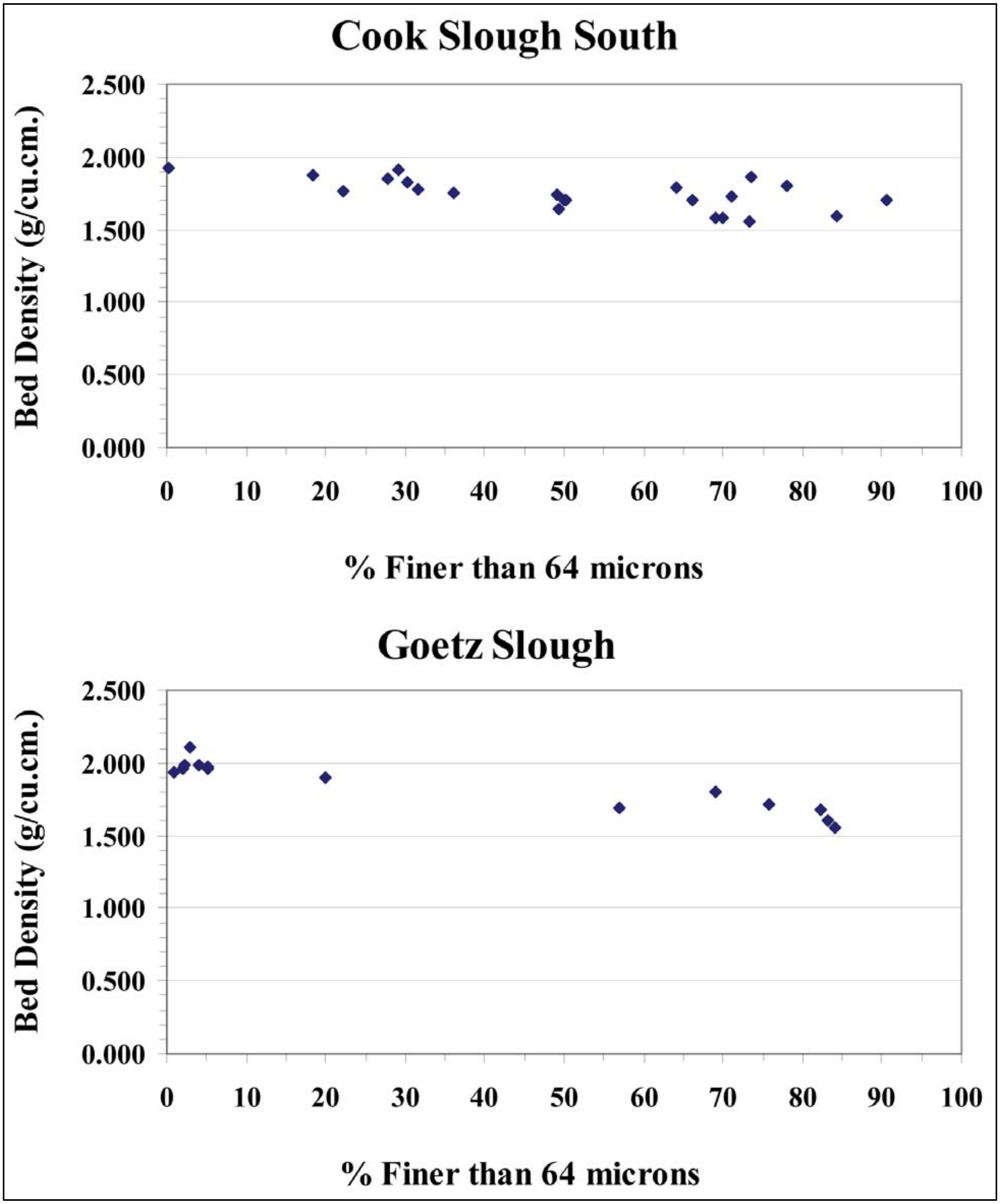


Figure F6. Percent moisture as a function of percent finer than 64 µ at Cook Slough South and Goetz Slough

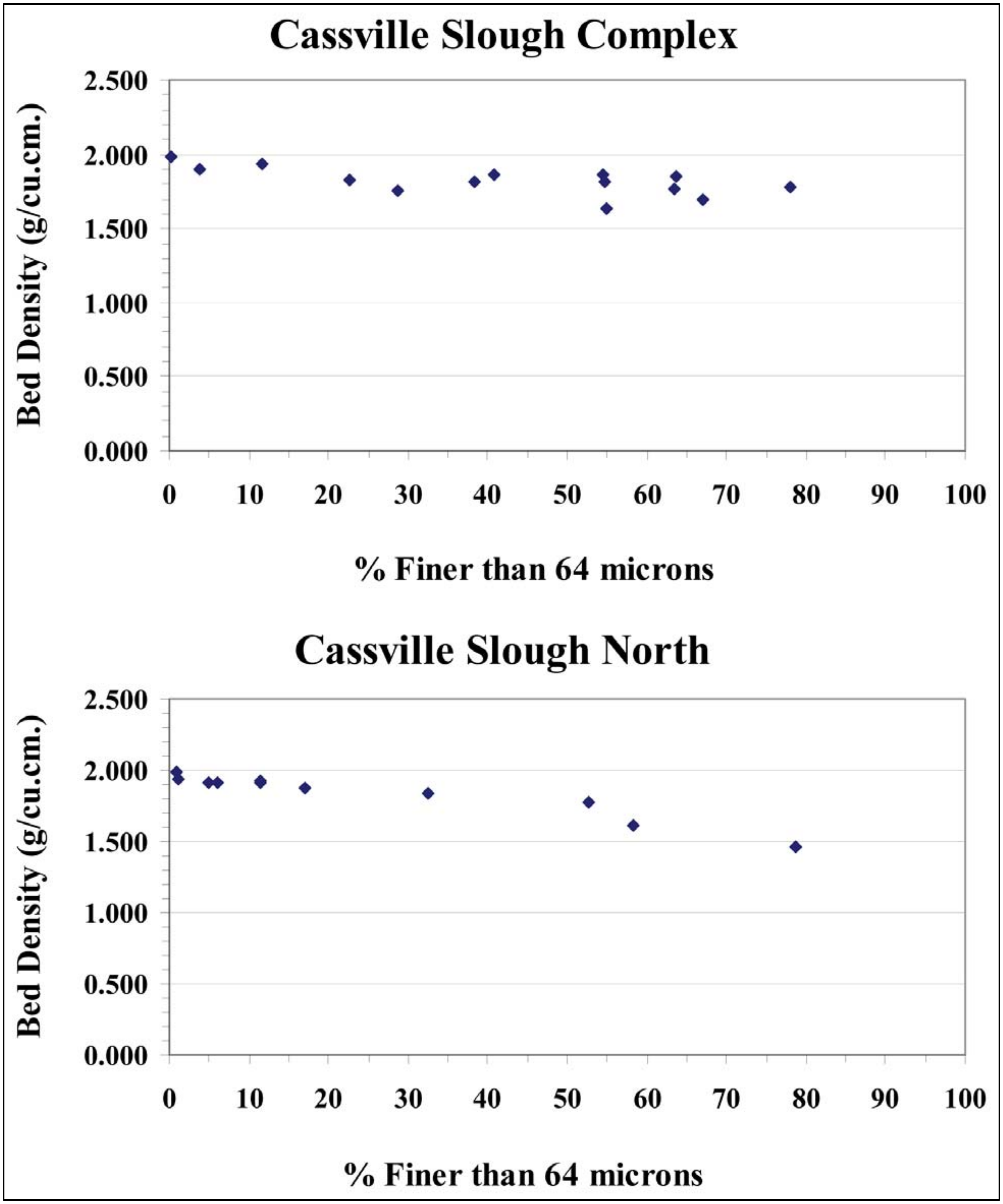


Figure F7. Percent moisture as a function of percent finer than 64 μ at Cassville Slough Complex and Cassville Slough North

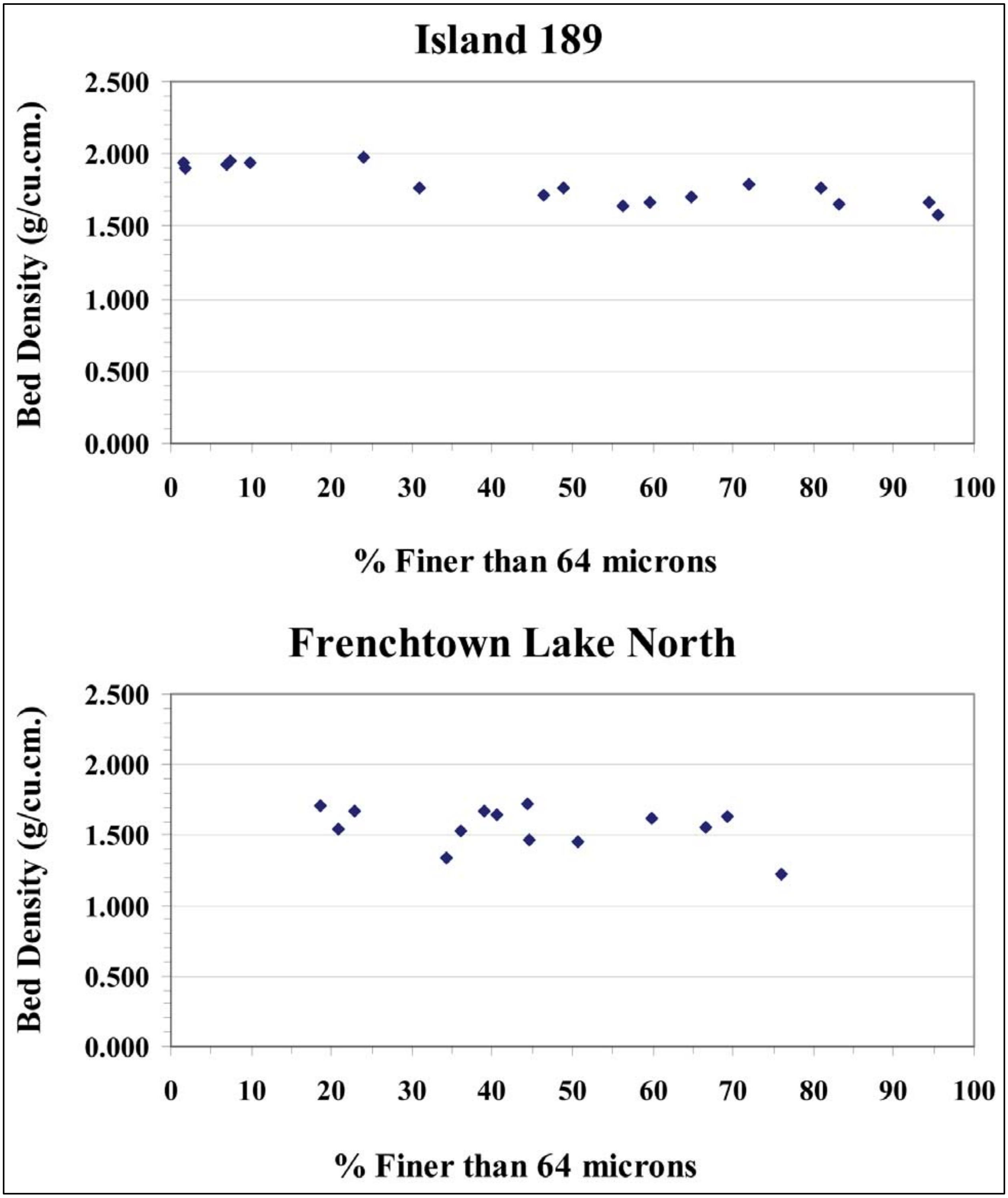


Figure F8. Percent moisture as a function of percent finer than 64 μ at Island 189 and Frenchtown Lake North

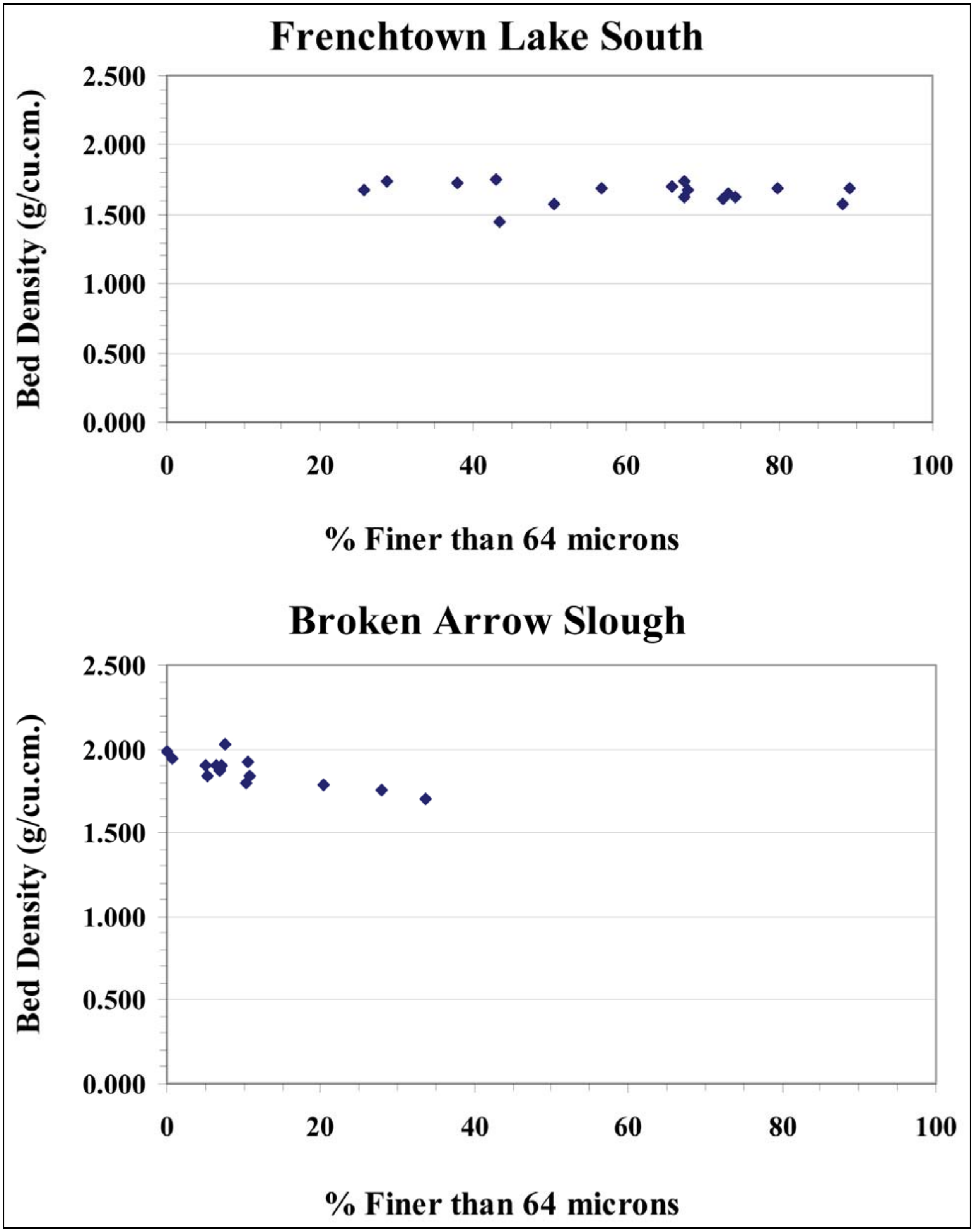


Figure F9. Percent moisture as a function of percent finer than 64 μ at Frenchtown Lake South and Broken Arrow Slough

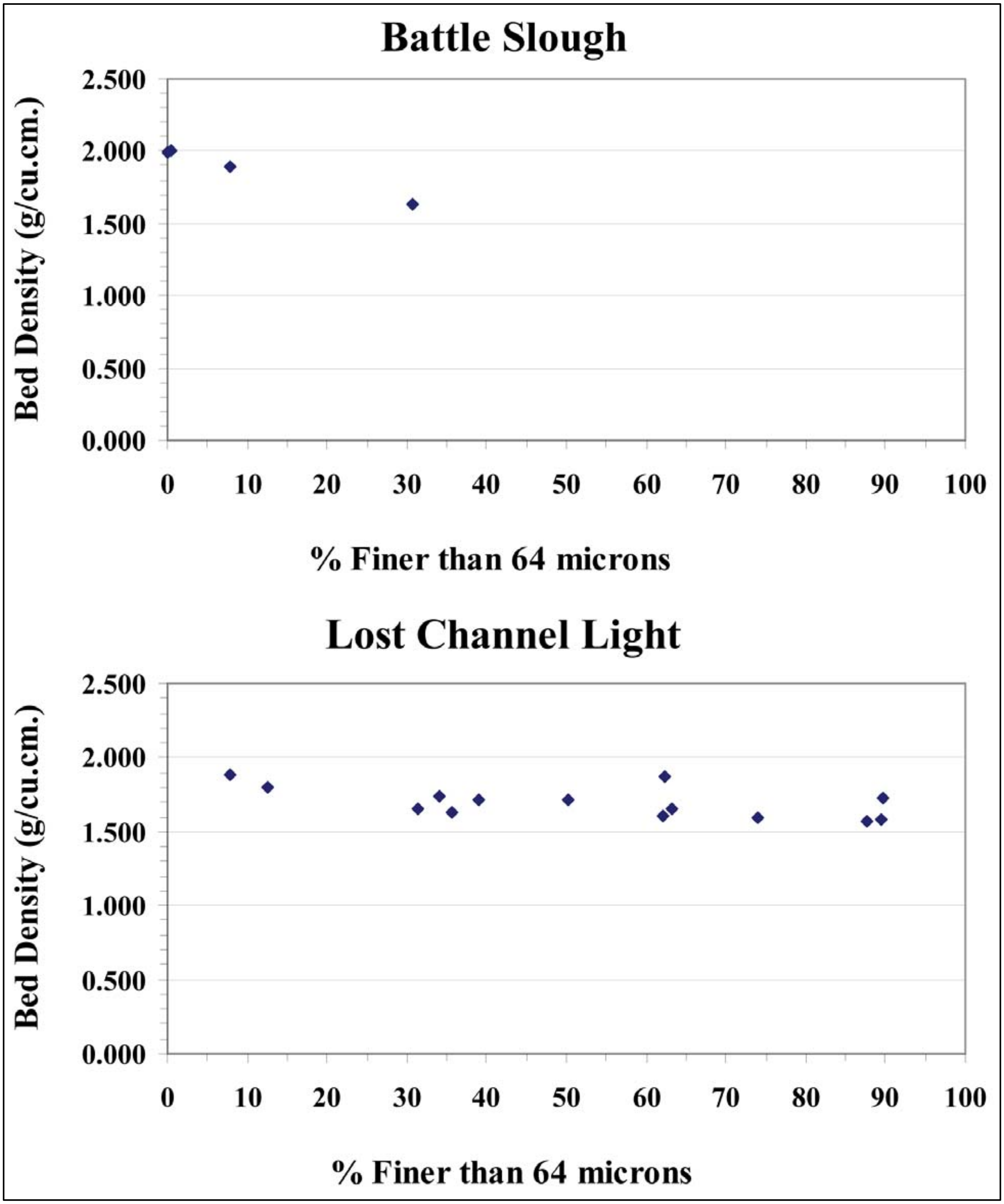


Figure F10. Percent moisture as a function of percent finer than 64 μ at Battle Slough and Lost Channel Light

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14. ABSTRACT

Despite more than a century of research on sediment processes, there still exist a number of knowledge gaps regarding key sediment processes. Research is needed on the description and analysis of sediment processes. The objective of research on sediment processes is to provide new knowledge of cohesive sediment erosion processes and release of associated nutrients plus development of improved algorithms for erosion/release rate as a function of bulk density, organic content, and other easily measured parameters.

Most of the fine sediments occurring in natural environments such as lakes, wetlands and estuaries contain organic material. The type and amount of organic contents are site-specific and may vary to a great extent. The bulk density and erosion rates of fine sediment beds are known to be significantly affected by the organic contents; however, their influence has not been adequately quantified. Bulk density and erodibility are the properties of cohesive sediments that are affected by the presence of organic substances. It is essential to know bulk density to be able to predict the erosion rates of cohesive sediment beds because shear strength is often related to bed density of cohesive sediments.

The purpose of this report is to present results of laboratory measurements conducted at CHL on the influence of organic contents on bed density and erodibility of cohesive sediments at various project sites. Background information on the basic properties of fine sediments, their characterization, and fine sediment beds is also given. *(Continued)*

15. SUBJECT TERMS

Bed density	Erodibility	Fine sediments
Cohesive sediments	Erosion rate	Organic contents

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14. ABSTRACT (continued)

A literature review was undertaken to compile information on the effect of organic substances on the properties of cohesive sediments. Laboratory measurements were conducted at the Coastal and Hydraulics Laboratory (CHL) of the U.S. Army Engineer Research and Development Center (ERDC), for determining the physical properties of sediments collected from many project sites. These included determining the bed density and erodibility of cohesive sediment beds. This report contains relevant information obtained through literature search and the laboratory results of sediment analysis for many project sites.

Correlation of erosion and nutrient release rate with organic content and other simple parameters will improve the accuracy of numerical models used for prediction of erosion of natural sediments occurring at the U.S. Army Corps of Engineers (USACE) projects. Improved knowledge of the processes and physically accurate models will increase public confidence in our project evaluations and enable USACE to design and operate projects that enhance the aquatic environment.