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**A STUDY OF THE POTENTIAL FOR CONTAMINANT SORPTION AND
MOVEMENT OF ACCUMULATED SEDIMENT IN TWO IMPOUNDED
CREEKS IF THEY ARE REOPENED IN THE TIMUCUAN ECOLOGICAL
AND HISTORIC PRESERVE, DUVAL COUNTY, FLORIDA**

By

HUGH R. GRAHAM, JR.

**A THESIS PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE**

UNIVERSITY OF FLORIDA

1999

ACKNOWLEDGEMENTS

I wish to thank Dr. Clay Montague, chair of my committee, whose critical reviews and comments made this manuscript clearer, more coherent and freer of errors. Reviews by Dr. Ashish J. Mehta and Dr. W. Emmett Bolch also suggested valuable improvements. I also wish to thank Dr. Mehta for allowing me the use of his particle erosion simulator and settling velocity column and Dr. Montague for supplying petri dishes and filter paper. Fellow students Sandra Fox and Phil Stevens were of tremendous help in collecting cores and measuring sediment depth. I also wish to thank Ron Wheeler and Sandra Fox for instruction in using the gamma ray spectrometer. I particularly wish to thank my beloved parents, without whose support I would not have been able to complete this manuscript.

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Abstract of Thesis Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Master of Science

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By

Hugh R. Graham, Jr.

August 1999

Chairman: Clay L. Montague

Major Department: Environmental Engineering Sciences

Fine grained bed stability in two impounded creeks with recent mud deposits was assessed. Adjacent to the St. Johns River, NE of Jacksonville, Fl., is the Timucuan Ecological and Historic Preserve. Two creeks in the preserve, Hannah Mills Creek and Cedar Point Creek, have accumulated sediment since being impounded by Heckscher Drive around 1920. If the creeks are reopened the sediment may move into the river. Any contaminants sorbed to the sediment could then be exposed to organisms in the river. The accumulated sediment volume measured in Hannah Mills Creek was about 77,500 m³ and in Cedar Point Creek about 98,000 m³. The age of the sediment was estimated by Pb-210 and Cs-137 gamma ray spectroscopy. Sediment in a core from Hannah Mills Creek had a Cs-137 peak, derived from atmospheric testing of nuclear bombs conducted in 1962, at a depth of 25 cm. The Pb-210 derived date was 1966 at a depth of 25 cm. A sediment

core from Cedar Point Creek had an estimated Pb-210 derived date of 1974 at a depth of 25 cm. The core sites had a sediment depth of 1.5-3 m. The shear strength of the surface sediment of the creek beds was estimated to be 0.08 Pa. Since tidal current and wave induced shear stress are likely to be greater than 0.08 Pa, it is likely that the sediment will move out of the creeks into the St. Johns River if Heckscher Drive is removed. Contaminants sorbed to the sediment could endanger the health of organisms in the river.

CHAPTER 1 INTRODUCTION

Industrial and agricultural pollution is a threat to the health of all life systems on Earth. Every year millions of tons of metals such as Cu, Zn, Hg, etc, and pesticides such as DDT are flushed into streams and rivers around the world. These conduits of waste drain into lakes and oceans, concentrating contaminants in places of restricted circulation.

Estuaries and coastal embayments have great potential to accumulate these wastes. Estuaries are the permanent or temporary habitat of most commercial fish species and various species of crustacea that are a valuable harvest. Crustacea also belong to the same class of animals that the insecticides are designed to kill. Some organophosphorous insecticides impaired osmoregulation and caused death in shrimp (Lignot et al. 1997). Mollusks and fish concentrate and store some pesticides in concentrations many times greater than that found in their environment. Accumulations of DDT in oyster flesh have been measured at levels 70,000 times that of their habitat (Butler 1966). Organochlorides have been shown to cause reduction of shell growth and pumping action of oysters (Butler 1966) and AH's (aromatic hydrocarbons), PCB's (polychlorinated biphenols) and Cu concentrations in San Diego Bay sediment correlate with liver lesions and fin erosion of bottom dwelling fish (McCain et al. 1992). The notorious case of the Minamata disease in Japan vividly illustrates the effect of high mercury concentrations on humans. Mercury

in industrial effluent first became concentrated in fish and mollusks and other sea life.

These in turn were eaten by humans who concentrated them further. Deterioration of the nervous system, brain damage, and death occurred in acute cases. Serious birth defects and impaired health occurred among those receiving lower doses (Smith and Smith 1975). Thousands were afflicted.

Contaminants are absorbed from water and sediment. Phytoplankton and plants absorb contaminants across cell membranes and cell walls; filter feeders absorb contaminants from the water across gills, skin (vertebrates), and/or integuments (invertebrates). Contaminants are absorbed from ingested sediment by benthic invertebrates that specialize in consuming sediment, such as polychaetes, oligochaetes, and amphipods (Butler 1966). Some contaminants, depending on how they are disposed of or metabolized, accumulate in body tissues of organisms. They are then passed up the food chain, and become more concentrated in body tissues at each higher level. Some predators accumulate the contaminants of their prey in their body tissue and so develop higher concentrations than their prey. This process is called biomagnification and was amply illustrated by the Minamata disease.

The St. Johns River flows through Jacksonville, FL, a busy river port with oil depots, a coal-fired power plant, paper mills, and docking facilities lining the shore. The industrial activity in Jacksonville employs a wide variety of metals and organic compounds that may be a source of contaminants to the St. Johns River. Agriculture further up stream may contribute pesticides to the river. Suspended sediment in the river and sediment at the water/sediment interface sorbs contaminants in the water. Unlike rapidly changing water chemistry, sediments integrate pollution over time, thus indicating the

history of pollution at the site (*St. Johns River Sediment Quality: Physical and Chemical Characteristics* 1998).

Adjacent to the Saint Johns River, NE of Jacksonville, is the Timucuan Ecological and Historic Preserve (Fig. 1.1). The preserve is dominated by *Spartina* and *Juncus* salt marsh, which is divided by numerous tidal creeks that serve as corridors for estuarine water to surge into the marsh at high tide and drain away at low tide. Two of these creeks, Cedar Point Creek and Hannah Mills Creek, originally connected to the St. Johns River, have been cut off since ca. 1920 by the construction of Heckscher Dr. (Fig. 1.2).

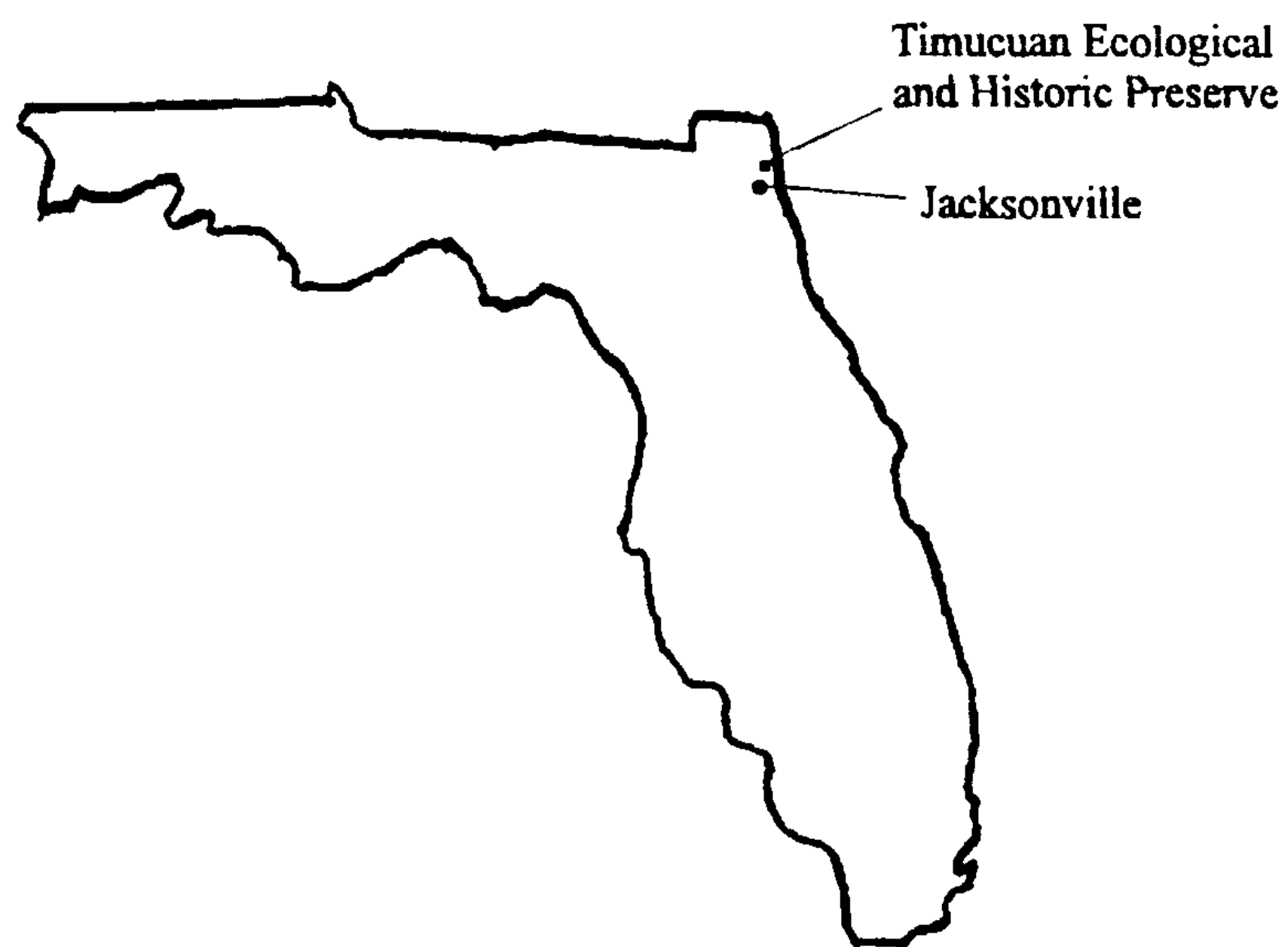


Fig. 1.1 Map showing location of Timucuan Ecological and Historic Preserve

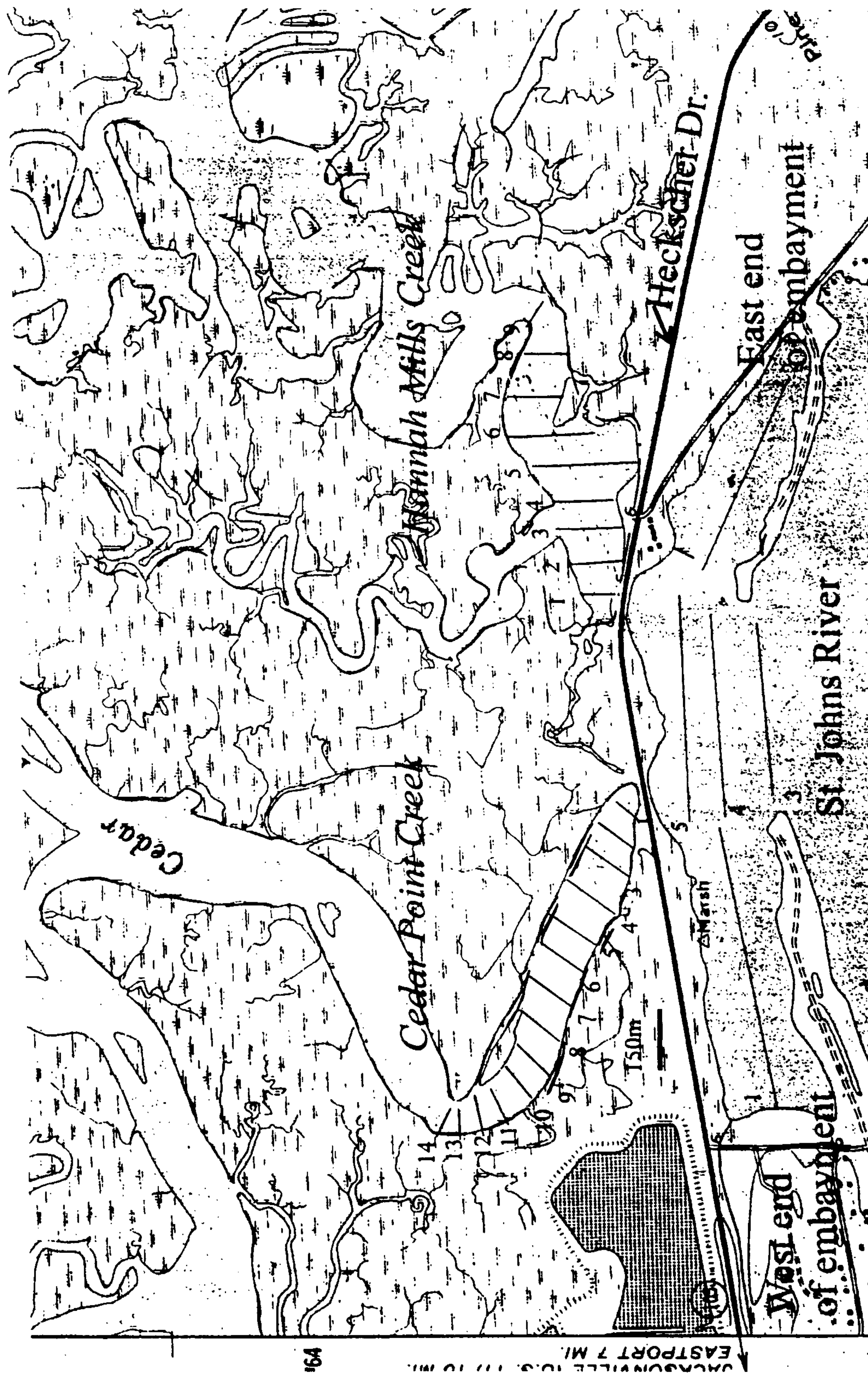


Fig. 1.2 Location of numbered transects for depth measurement

If the sedimentation rate in the creeks during the last 100 years were known, the effect Heckscher Dr. has on sediment accumulation in the Hannah Mills Creek and Cedar Point Creek could be better assessed. An increase after ca. 1920, for example, would imply that the road may have blocked sediment export from the creeks, increasing sediment accumulation. Also, by knowing the sediment age one can assess the likelihood that the sediment is contaminated.

Jacksonville experienced its greatest growth as a river port in the 1920s (Wagman 1988). Sediment deposited earlier than this may be cleaner than sediment deposited after the increase in industrial activity. Also, many pesticides came into large-scale use after World War II.

The sediment that has accumulated in these impounded creeks may pose a contaminant risk to the St. Johns River should reconnection be established. Contaminants in the St. Johns River water may have become sorbed by the sediment in the creeks as the river water surged into the marsh on high tide; contaminated suspended sediment in the St. Johns River also may have become deposited in the creeks. After removal of the causeway, the sediment may also sorb new pollutants from the river water and transport them along. Organisms that consume this sediment could then pass some of the contaminants up the food chain to humans. The more sediment present in the creeks, the greater the amount of sediment that is contaminated or could potentially sorb new contaminants after being flushed into the St. Johns River.

Grain size and organic matter content relate to erodibility and potential to sorb contaminants. Large grains, such as sand ($> 59 \mu\text{m}$), have greater settling velocity and require greater force to suspend it in water and transport it. Smaller grains, such as silt

($59\ \mu\text{m} > \text{silt} > 2\ \mu\text{m}$) and clay ($< 2\ \mu\text{m}$), have greater surface area per unit mass and a greater electrical charge; they can thus sorb more contaminants per unit mass of particle. Organic matter, because it is electrically polar, has a high affinity for many contaminants. Because of its low density, little force is required to move it. Organic matter also functions as a link, binding particles together in aggregates called flocs. This binding action can affect the force required to suspend sediment (Parchure 1984).

Finally, a comparison of the shear stresses likely to occur in the creeks and the shear stresses required to move the sediment will allow one to estimate how much of the sediment, and to what depth the sediment is likely to erode, into the St. Johns River if Heckscher Dr. is removed.

CHAPTER 2 SEDIMENT DEPTH

2.1 Introduction

The depth of soft cohesive sediment, predominantly silt and clay, was measured in Cedar Point Creek and Hannah Mills Creek to determine the maximum amount of sediment that could be released into the Saint Johns River if connection with the two creeks is restored. Restored connection may also erode sediment from the embayment into which the former creeks flowed. Depth of mud in the embayment was also measured as well to determine how much of this mud could be flushed into the St. Johns River if connection with the creeks is reestablished. The depth of soft cohesive sediment in the unblocked mouth of the adjacent Clapboard Creek was also measured for a comparison. The unblocked creek was expected to have little soft cohesive sediment since its current, unblocked by the road, is much greater than that of the blocked creeks. Faster currents can erode and suspend more sediment than slow currents. Also, the export path of sediment out of the open creek is not blocked by the road. In the blocked creeks, sediment may collect behind the road.

2.2 Materials and Methods

The depth of the soft cohesive sediment was estimated using poles made of steel electrical conduit rigid enough to resist bending. The poles were pushed into the mud until they hit siliceous sand. Two 3 m lengths of conduit screwed together were sufficient. Depth was measured along transects perpendicular to the banks. Transects were placed

every 50 m along the creeks from the blocked mouths to the first bend in each creek (Fig 1.2); the sediment beyond the bends in the creeks was sandier and was assumed to be less of a potential threat to the ecosystem. Transects began and ended 10 m off each bank, for the sediment along the banks was sandy and thus not the soft cohesive sediment that has a high potential for contaminant sorption. Each transect was roughly 100 m long in the blocked creeks and 300 m long in Clapboard Creek. Five evenly spaced depth measurements were taken along each transect; when a difference of more than 100% occurred in adjacent measurements, another measurement was taken between them to create a more accurate depth profile.

Water depth was measured using a 2.5 cm diameter pvc pole. The sediment surface could be more easily felt with the wider diameter pole than with the electrical conduit. The cross sectional area of the creek's mud deposit was approximated by drawing straight lines between the sediment depths and calculating the area of the resulting trapezoids. The cross sectional area was multiplied by 50 m, the longitudinal distance to the next transect, to give an estimate of the sediment volume between each transect. Each 50 m section of sediment was then added together to obtain the total measured creek sediment volume.

Soft cohesive sediment depth was also measured along transects 1-5 in the embayment (Fig. 1.2). Depth was measured at points evenly spaced along the transects and an average depth obtained for each side of the embayment. The cohesive sediment volume of the west side of the embayment was estimated by multiplying the west side's average cohesive sediment depth by the west side's width and length. The same was done

for the east side and middle section of the embayment. Finally, soft cohesive sediment depth was measured along a transect across the open mouth of adjacent Clapboard Creek.

2.3 Results

The two creeks contain a large amount of sediment, approximately 98,400 m³ of sediment in Cedar Point Creek and 77,500 m³ in Hannah Mills Creek. Assuming an average dry density of 0.33 g/cm³ (obtained from cores taken for dating) for the entire bed, 3.25x10⁴ metric tons of soft mud reside in Cedar Point Creek and 3.14x10⁴ metric tons are in Hannah Mills Creek. The cross section diagrams for the first transect from each creek are shown in Fig. 2.1 and 2.2. The first transect is the one closest to each creek's former mouth. The vertical scale is 7 m and the horizontal scale is 95 m. The ends of the transects are about 10 m off the marsh banks. The banks are indicated at the bottom corners of the drawings: North and South for Hannah Mills Creek cross sections and East and West for Cedar Point Creek cross sections (see Appendix A for the cross sections for the rest of the transects).

More sediment resides in the embayment than in the creeks. The west end of the embayment contains about 253,000 m³ of mud with an average sediment depth of 2.6 m; the east end contains about 290,000 m³ of mud with an average depth of 3.7 m; and the middle section contains 125,000 m³ of mud with an average depth of 0.95 m. The dry mass of the embayment was about 8.4x10⁴, 9.7x10⁴, and 4.17x10⁴ metric tons respectively.

About 19,000 m³ of soft sediment was measured over 300 m up the open mouth of Clapboard Creek. Some of the sediment was pumped in from Blount Island opposite Clapboard Creek.

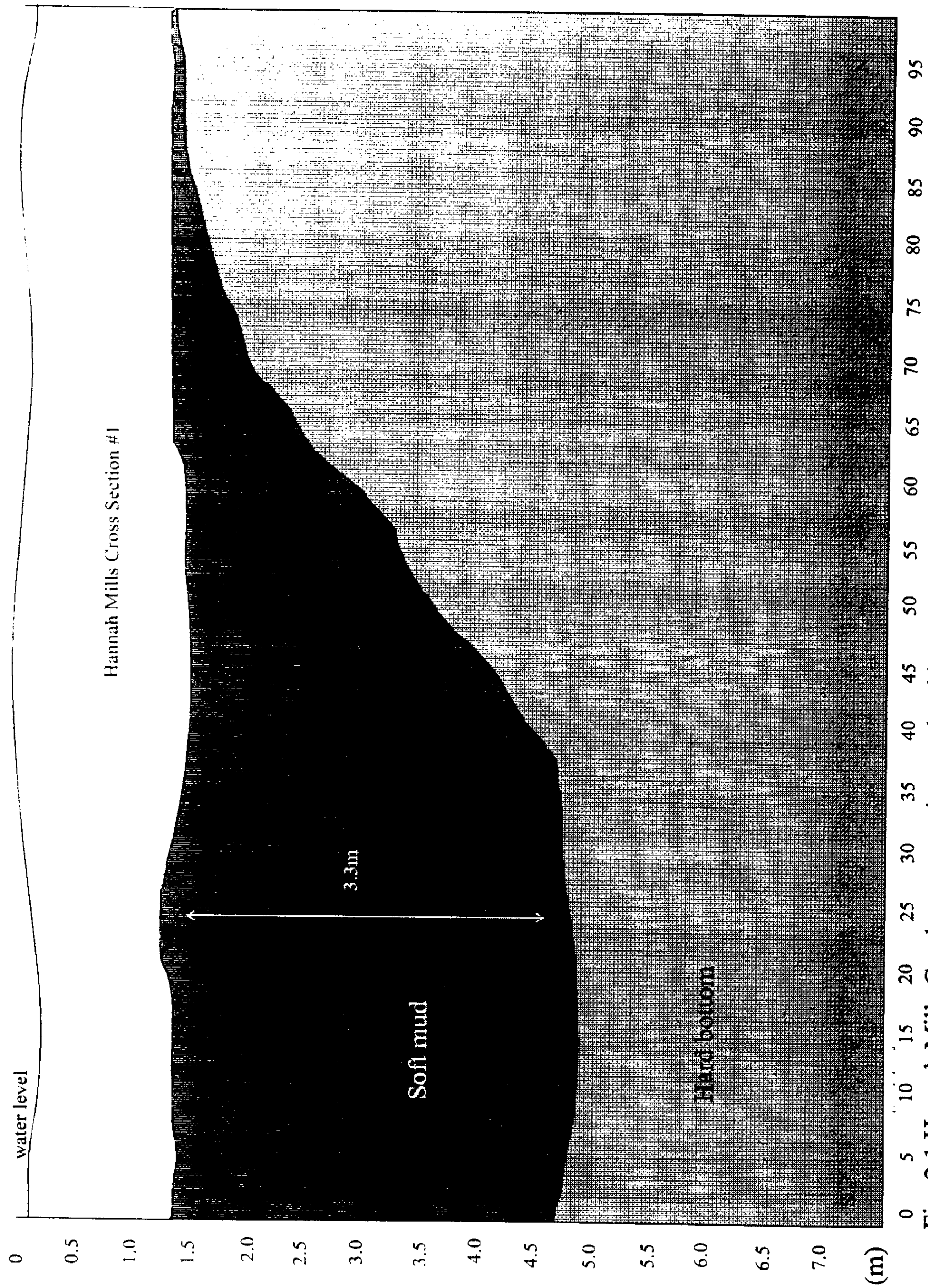


Fig. 2.1 Hannah Mills Creek cross section # 1 (hard bottom refers to siliceous sand)

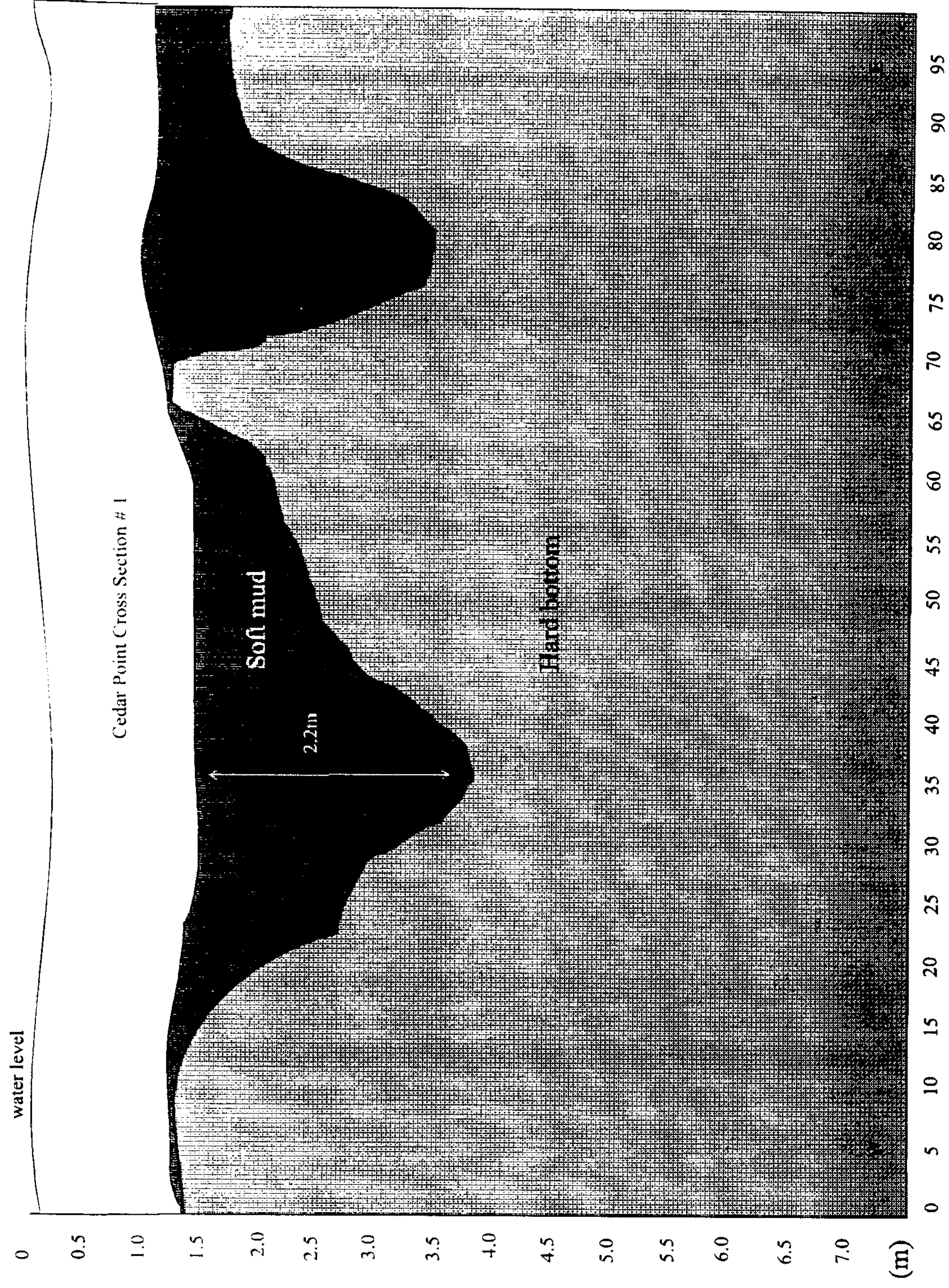


Fig. 2.2 Cedar Point Cross Section #1 (hard bottom refers to siliceous sand)

2.4 Discussion

The sediment in the creeks may come from bank sloughing (slumping of banks into the tidal creeks) of the adjacent marshes. If one assumes that marsh on both sides of Cedar Point Creek contribute equally to the sediment in the creek ($98,400\text{m}^3$), and the depth of the marsh bank eroded into the creek was 1 m, then the marsh on each side of the 1km section of creek would have to have been 46.7 m wider than it is today to account for all the mud in the creek. Perhaps after Heckscher Dr. was built, the creek expanded by this distance onto the marsh since its outlet at the mouth was cut off, causing the marsh bank to slump into the creek. Making the same assumptions for Hannah Mills Creek and substituting a length of 675 m and a volume of $77,500\text{ m}^3$, the width of the marsh eroded would have to be 57.4 m. The width of the creeks before the construction of Heckscher Dr. was not recorded, so the actual change, or constancy, in creek width is unknown. The marsh has probably laid down more sediment, via the sediment trapping and production of marsh plants, to replace some of what may have slumped into the creeks. The width of the creek could have then remained constant even if bank sloughing occurred. An alternative source of the mud is suspended solids carried in from the St. Johns River or from marsh bank sloughing further up the creek. This water has to wind through well over a kilometer of creeks before arriving at the blocked mouths of Cedar Point Creek and Hannah Mills Creek. A large portion of the suspended sediment may settle in the reduced current of the circuitous creeks before reaching its destination. The lift force caused by moving water decreases rapidly in magnitude vertically away from the sediment bed as the velocity and pressure gradients decline (Knighton, 1998). Clay

requires 3 days or more to fall a distance of 1 m in still water; silt from a few minutes to a couple of days depending on grain size; and sand, from several seconds to a few minutes.

Bank sloughing is a normal part of the life of a salt marsh tidal creek. Some salt marsh tidal creeks tend to maintain their widths over a period of many decades. (Redfield, 1972). A steady state scenario has been envisioned by Redfield where sediment accumulates in cracks formed by the slumping of the bank. The sediment subsequently becomes vegetated by the outgrowth of rhizomes and by seeding. Sediment is also deposited on the slumped surface, a great deal of which is marsh plant material. Hence, marsh plants can maintain creek width. Marsh is formed which counteracts the effect of erosion. Undercutting of the bank by water moving through the creek can lead to a tidal creek becoming filled with sediment. Only the ultimate branches of the creek system become totally filled. There, the current is insufficient to prevent the accumulation of sediment. When the water depth in the creek becomes sufficiently shallow, vegetation will become established. The soil shear strength is increased through an increase in cohesion brought about by the binding action of the plant fiber-soil composite and adhesion of soil particles to the roots. *S. alterniflora*, the dominant plant in the marsh adjacent to the Hannah Mills Creek and Cedar Point Creek, is especially adept at holding soil with its extensive robust rhizomes and network of fine roots of which greater than 85% have a diameter less than 1 mm (Morgan and Rickson 1995). The vegetation will also slow the current of water flowing around it, increasing settling of suspended solids. Thus a tidal creek can be transformed into marsh (Chapman 1974).

Hannah Mills Creek and Cedar Point Creek may now be entering the latter stages of a tidal creek's life. Heckscher Dr. has constricted the circulation of water through the

creeks and has probably prevented some of the slumped bank sediment from being exported out of the creeks. If Heckscher Dr. remains in place, the creeks will probably fill up with sediment and become marsh. Clapboard Creek, adjacent to Cedar Point Creek, is spanned by a bridge and is thus not blocked. Its lack of mud may illustrate the effect Heckscher Dr has on sediment buildup in the closed Hannah Mills Creek and Cedar Point Creek. Perhaps they would be relatively devoid of mud as well if the road had not been installed. The comparison is not totally valid though. Clapboard creek is about 100 m wider than Hannah Mills Creek and Cedar Point Creek. Possibly, the greater width of Clapboard Creek is due to the open connection with the St. Johns River allowing greater current velocity and sediment export from the adjacent marsh than occurs in the blocked creeks. Also, Clapboard Creek has no bends in its course to slow the movement of water and cause greater sedimentation as do Hannah Mills Creek and Cedar Point Creek.

The embayment in the St. Johns River contains a large amount of sediment that may be eroded into the open river should Heckscher Dr. be removed. The middle section of the embayment would probably be subject to the greatest flow of water since the sides are enclosed by peninsulas.

If most of the sediment in the creeks was present before Heckscher Dr. was built then the effect Heckscher Dr. has on sediment accumulation may be small. If the current velocity in the reopened creeks remains less than or equal to the current velocity that existed before the road was built, the road may then be removed with little fear that the sediment will wash away.

CHAPTER 3 SEDIMENTATION RATE AND AGE-DEPTH RELATIONSHIP

3.1 Introduction

The sediment age and sedimentation rate was estimated to determine whether Heckscher Dr. caused the sediment accumulation or whether the sediment was already in the creeks or adjacent marshes at the time the road was built. By dating sediment cores over depth, sedimentation rates over a period of decades can be estimated. A sudden increase in sedimentation rate around 1920, the approximate time the road was built, would indicate blockage of sediment by the highway. If most of the sediment accumulated in Hannah Mills Creek and Cedar Point Creek is older than 80 years then the majority of it would have already been present in the marsh banks or the creek bottom at the time Heckscher Dr. was built. However, most of the sediment in the creeks may be old mud from the adjacent marsh banks. If this so, then sedimentation rates and sediment age will not indicate blockage of the old marsh mud.

3.2 Dating Sediment with Pb-210

Pb-210 is a member of the Uranium-238 decay series, shown in Fig. 3.1 on the next page. Because U-238 is ubiquitous in soils around the world, and because it has

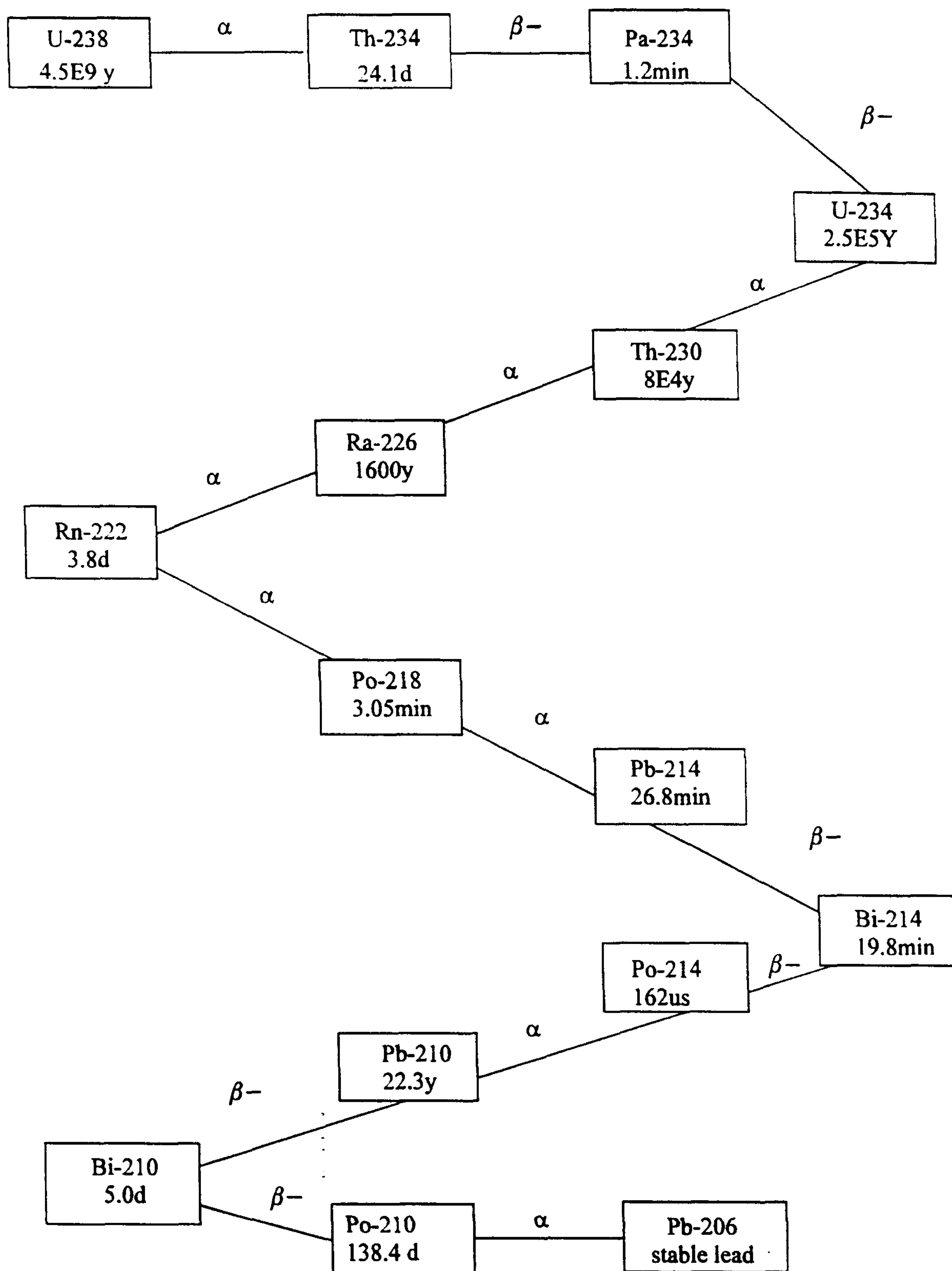


Fig. 3.1 Main path of the Uranium decay series

a long half life ($t_{1/2} = 4.5 \times 10^9$ years), constant emanation of its gaseous daughter radionuclide Rn-222 ($t_{1/2}=3.8$ d) takes place. Rn-222 decays into several short lived isotopes while in the atmosphere, which in turn produce Pb-210 ($t_{1/2}=22.3$ y), a solid, as illustrated in Fig. 3.2. It has a residence time of 10 days to a few weeks in the atmosphere, depending on precipitation amounts (Eakins and Morrison 1978). Pb-210 then attaches to solid aerosols and is deposited on land or water. Subsequently, Pb-210 deposits at the water-sediment interface.

Pb-210 is produced by Rn-222 trapped in the sediment as well, as illustrated by Fig. 3.2. This Pb-210 is called supported since its activity is maintained by its parent isotopes in the sediment. This Pb-210 derived from radon trapped in the soil must be subtracted from the total activity of Pb-210 in the sediment to obtain the Pb-210 derived from the atmosphere and runoff from land. The decay of the activity of the unsupported Pb-210 from the atmosphere is what is used to date sediments.

The dating model used in this study was the Constant Rate of Supply (CRS) model. It assumes a constant rate of supply of Pb-210 from the atmosphere to the sediments regardless of the sedimentation rate (Appleby and Oldfield 1978). Sediment can thus have varying concentrations of Pb-210, which can be used to measure varying sedimentation rates. If no variation in sedimentation rate occurs, Pb-210 does not move up or down within the sediment, and no bioturbation or other sediment mixing occurs, then the activity of the Pb-210 per gram of sediment should decrease exponentially over depth. However, sedimentation rates are not always constant over long periods of time. Since the rate of supply of Pb-210 is assumed to be constant, during periods of rapid sedimentation, less Pb-210 is sorbed per gram of sediment.

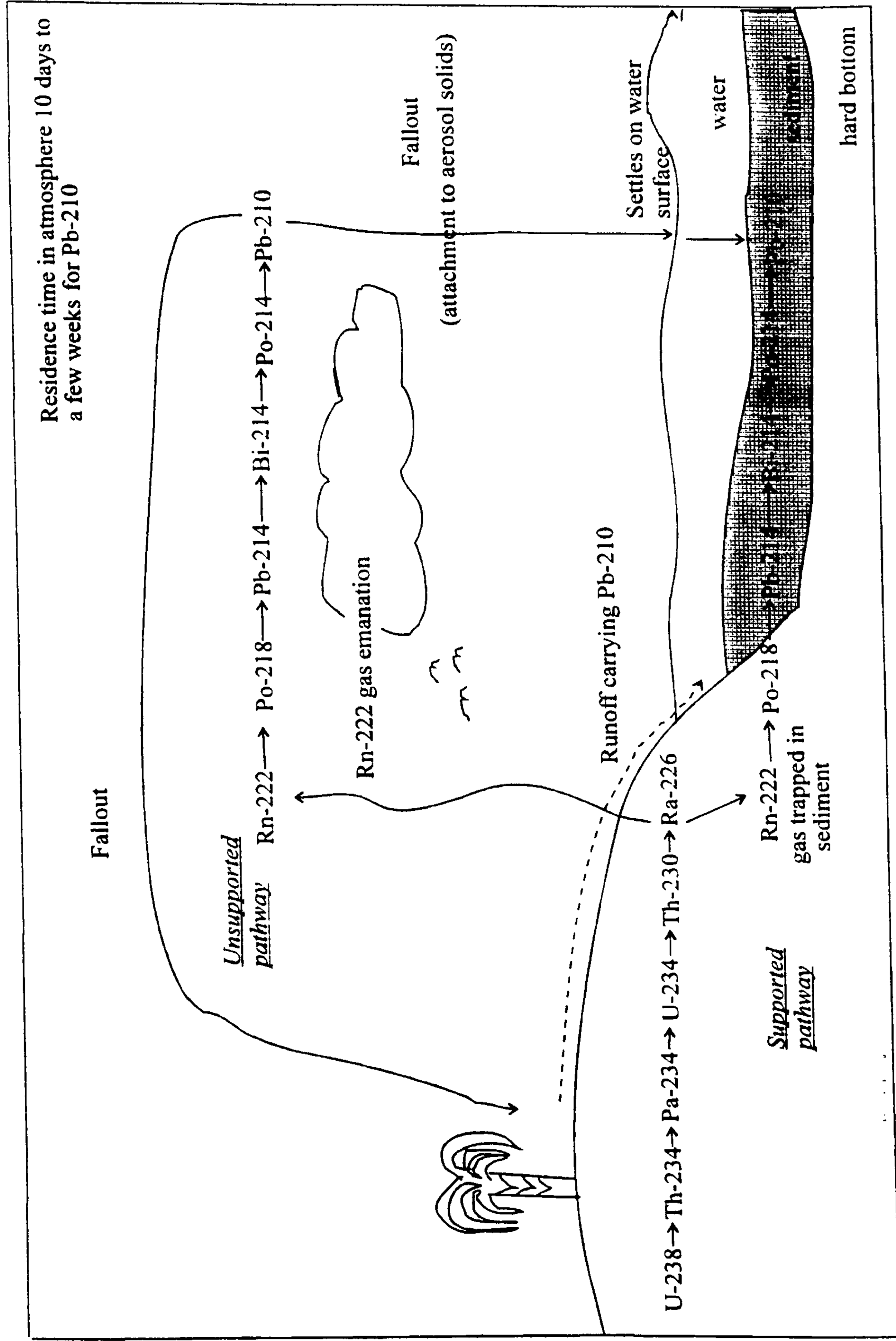


Fig.3.2 Pb-210 supported and unsupported pathways (adapted from J. Nagy 1988, and S. Fox and C. Montague 1996)

During periods of low sedimentation, more Pb-210 is sorbed per gram of sediment. The sediment, therefore, is deposited with varying initial concentrations of sorbed unsupported Pb-210.

Although the activity of unsupported Pb-210 per gram of sediment in this case may not decline exponentially with depth, cumulative activity over depth does decline exponentially. The total Pb-210 in the sediment below a given depth is always exponentially less than the total below a given shallower depth, whether the sedimentation rate is constant or varying. A core of mud can be taken and sectioned at regular intervals, each section representing a certain change of depth. The activity in each section is determined and added together to give a cumulative activity of the whole core in pCi/cm³. The cumulative activity of the core under sediment of age t changes according to the equation (Appleby and Oldfield 1983):

$$CU = TU * e^{-\lambda t}$$

where CU (pCi/cm³) is the cumulative activity of the core below sediment of depth z , TU (pCi/cm³) is the total unsupported activity of the entire core, and λ is the decay constant of Pb-210 (This can be converted to pCi/cm² by multiplying each section of the core by the difference of the depth of the top section of the section of the core and the depth where unsupported Pb-210 activity is consistently zero (Fox and Montague 1996)). The core activity declines exponentially with depth. One can solve for age t at any depth in the core:

$$t = 1/\lambda * \ln(TU/CU)$$

The following equation can be used to estimate the sedimentation rate:

$$r = CU\lambda/C$$

where r (pCi/cm²/y) is the sedimentation rate, λ is the decay constant of Pb-210, and C (pCi/g) is the concentration of unsupported Pb-210 in the sediment of depth z (Appleby and Oldfield 1978).

Pb-210 radiation can be detected in several ways. Gamma radiation was used in this study. Using a gamma ray spectrometer, one can measure gamma radiation of several parent isotopes as well as of Cs-137, which was produced in abundance in atmospheric nuclear bomb tests in 1962 and the nuclear power plant explosion in Chernobyl in 1986. Cs-137 can be an important supplemental dating isotope, whose largest peak in the sediment occurs in sediment laid down in 1963 (Kada and Meit 1992).

3.3 Materials and Methods

Sediment cores from two creeks, Cedar Point Creek and Hannah Mills Creek, and a third creek with unrestricted tidal flow, labeled “backdoor creek” were taken using 4 cm diameter tubes (Fig. 3.3). Cores were taken in the middle (equidistant from each bank) of the creek, where bank slumping is less likely to occur than near the creek banks. Slumping of the bank causes mixing of sediment of different ages, rendering a core undatable by the Constant Rate of Supply dating model. The core sites in Hannah Mills Creek and Cedar Point Creek had a mud depth of 1.5-3 m. They were manually inserted into the creek bed as far as possible. A test plug was used to create a vacuum which allowed retrieval of the mud during extraction of the tube from the sediment bed. The plug was attached to a string that ran through the tube and

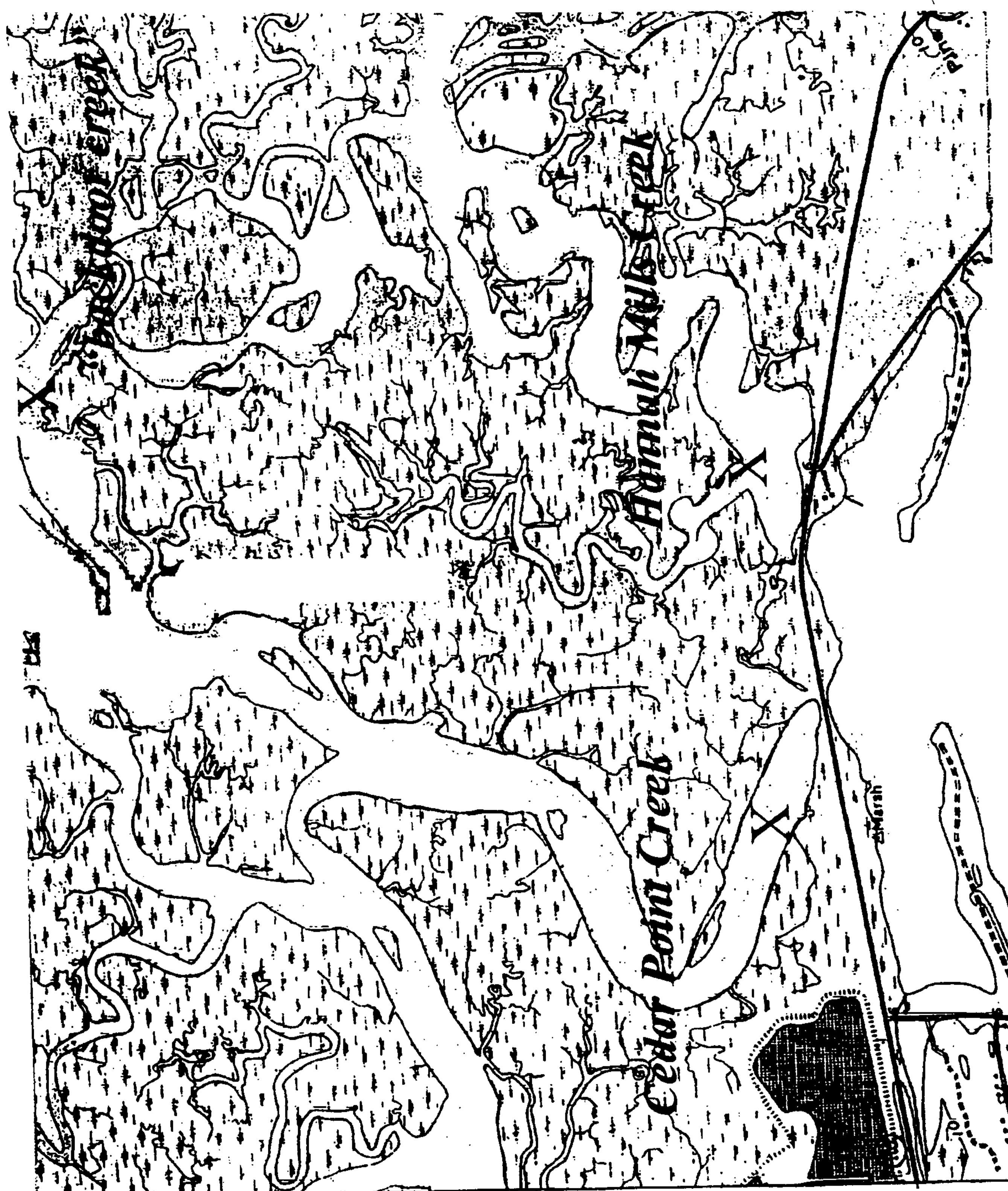


Fig. 3.3 Map showing approximate sites where Pb-210 cores were taken. X marks the spot.

extended out the top end. The tube was then pushed down around the test plug at the bottom of the tube while the string was held; thus the plug remained more or less stationary, creating a vacuum in the tube. The core could then be withdrawn with less slippage of the mud from the tube. Rubber stoppers were placed at the ends of the coring tubes and taped with duct tape. The tubes were then transported in a vertical orientation to a cold room (4°C) and stored until they were sectioned into 2cm sections.

Two cubic centimeters of each slice of sediment was removed with a 10 cm³ syringe and weighed. The sections were then dried in an oven for 24 hours at 100°C. The dry density, dry mass/wet volume, was then calculated to determine the dry mass per unit volume used to measure the activity per unit of dry mass. The dried sediment was ground by mortar and pestle and poured into 50x9 mm plastic petri dish with a tight lid (brand name Falcon-1006). The lid was then sealed to the petri dish with plastic cement to prevent the escape of Rn-222 produced by decay of Ra-226 in the sediment. The sample was then set aside for at least 2 weeks to allow the Radon-222 to reach secular equilibrium with its daughter isotopes, the immediate precursors of the supported Pb-210 in the sample (Turner 1986). The activity of supported Pb-210, calculated as the average of the activity of Pb-214 (at 295keV and 352keV) and Bi-214 (at 609keV) would then be identical to the activity of Ra-226, which is in secular equilibrium with Rn-222. Thus the portion of the Pb-210 activity that is supported by the decay of Uranium-238 in the sediment can be measured.

A thin window (beryllium) standard coaxial N-type intrinsic germanium (crystal) detector (Princeton Gamma Tech) was used to measure the gamma radiation

produced by Pb-210 and its precursors as well as Cs-137 in each section. The sample was placed on top of the crystal as required in this type of detector; thus only downward radiation was detected. After the 2 week waiting period, each sample was counted for at least 12 hours. Each background sugar blank was counted for at least 12 hours.

Several negative sedimentation rates were obtained after subtracting the Pb-210 background radiation from the total Pb-210 (unsupported + supported) sample activity and plugging the negative unsupported Pb-210 concentration in the sedimentation rate equation above. Negative unsupported concentrations were also obtained when the supported Pb-210 activity exceeded the total Pb-210 sample activity. A different method from the sedimentation rate equation above was used to interpolate sedimentation rate in these cases. The dry mass of a section was divided by its wet volume. This was then divided by the difference in the age of the section and the one below it. Interpolation too is made inaccurate by the negative unsupported Pb-210 concentrations, since the age estimates for the sections are determined by integration of the unsupported Pb-210.

3.4 Results

Dry density profiles over depth used in the dating of the sediment cores are shown in Fig. 3.4-3.6. The average dry density for the cores was about 0.33 g/cm^3 .

Figure 3.7 shows a significant Cs-137 peak in the Hannah Mills Creek core at a depth of about 25 cm in the Hannah Mills Creek core. The concentration of unsupported and supported Pb-210 over depth used to date the sediment is shown in Fig. 3.8. Notice the higher concentration in the sediment at the top of the core. The

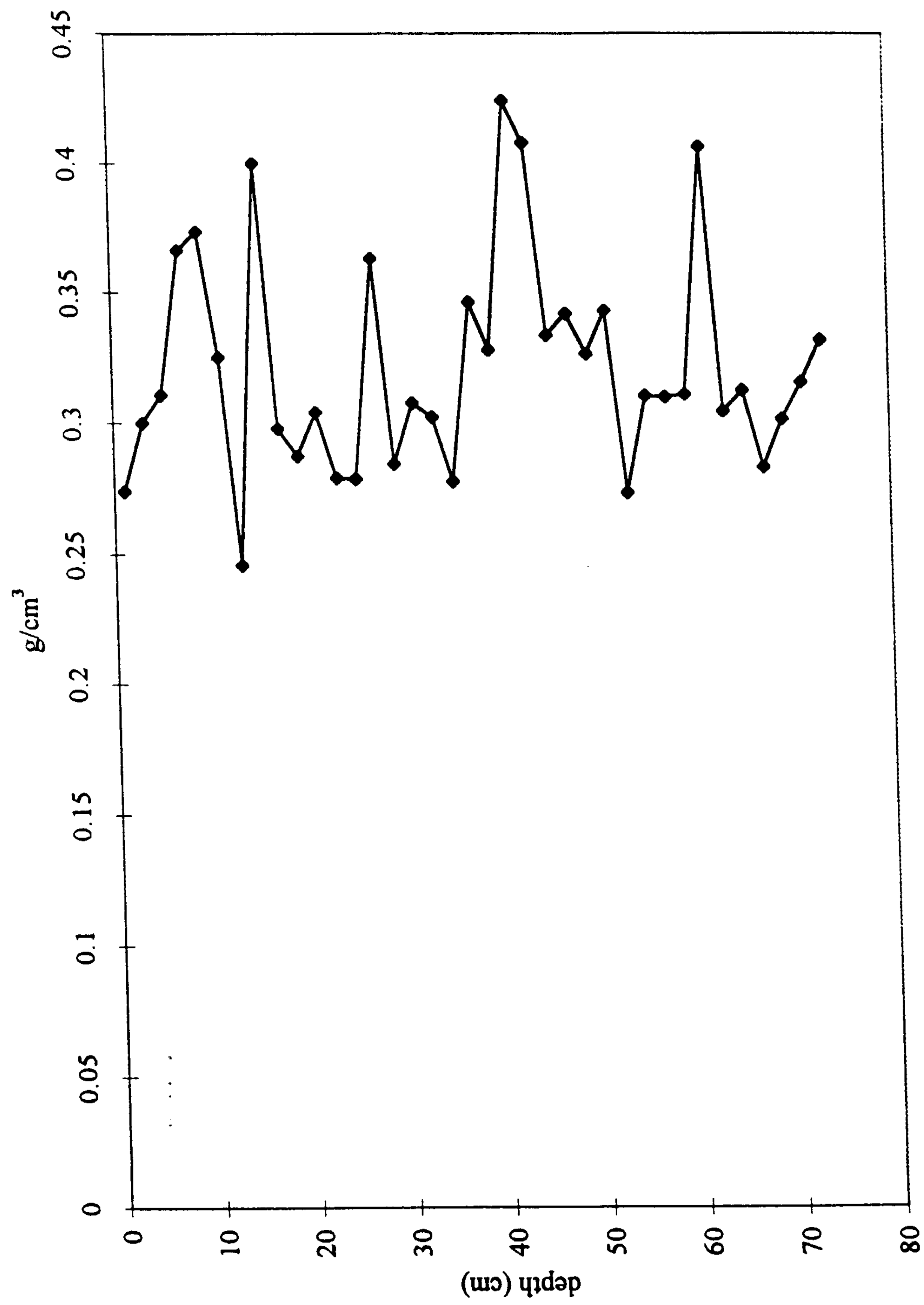


Fig. 3.4 Hannah Mills Creek dry density

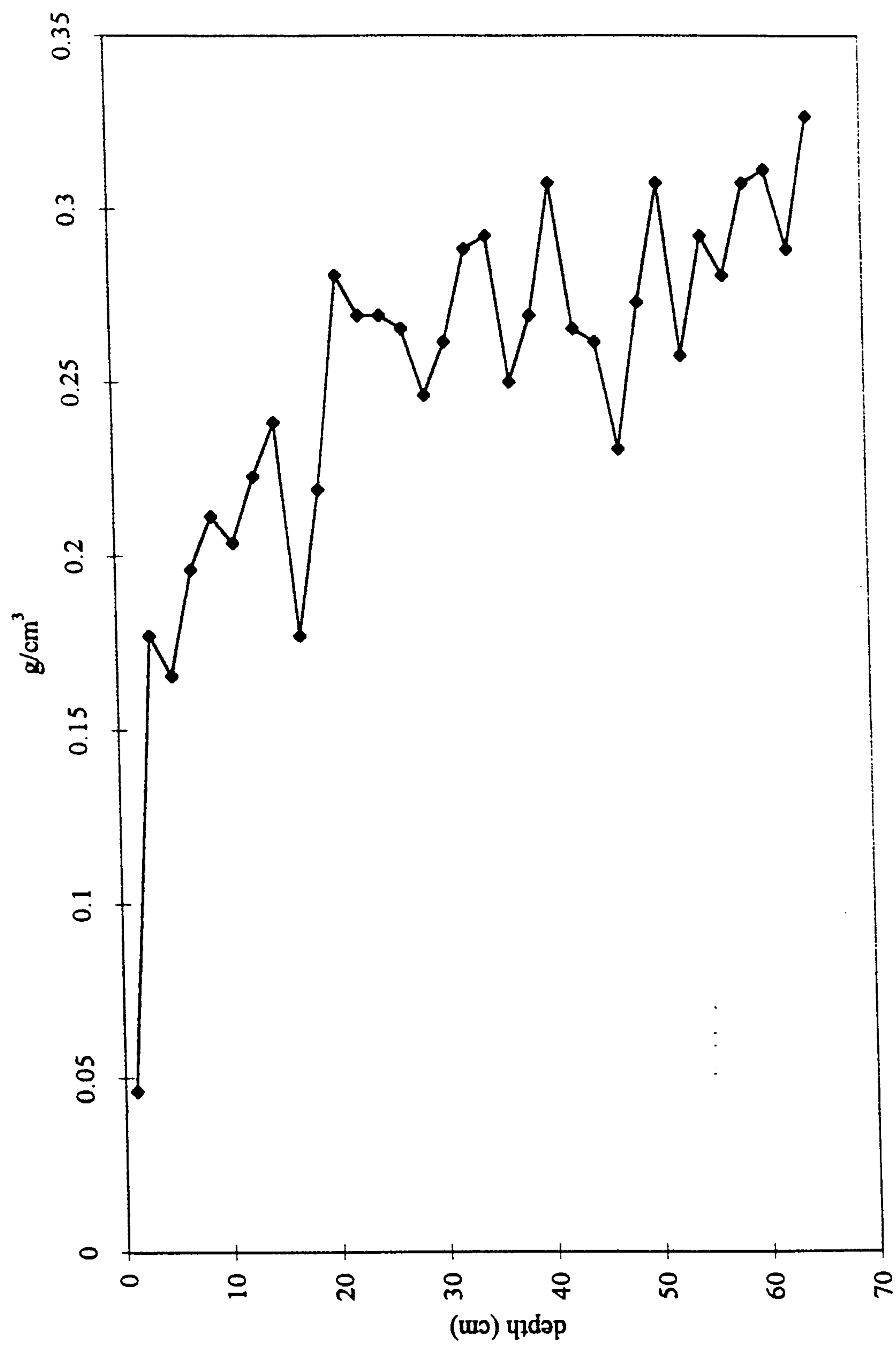


Fig. 3.5 Cedar Point Creek dry density

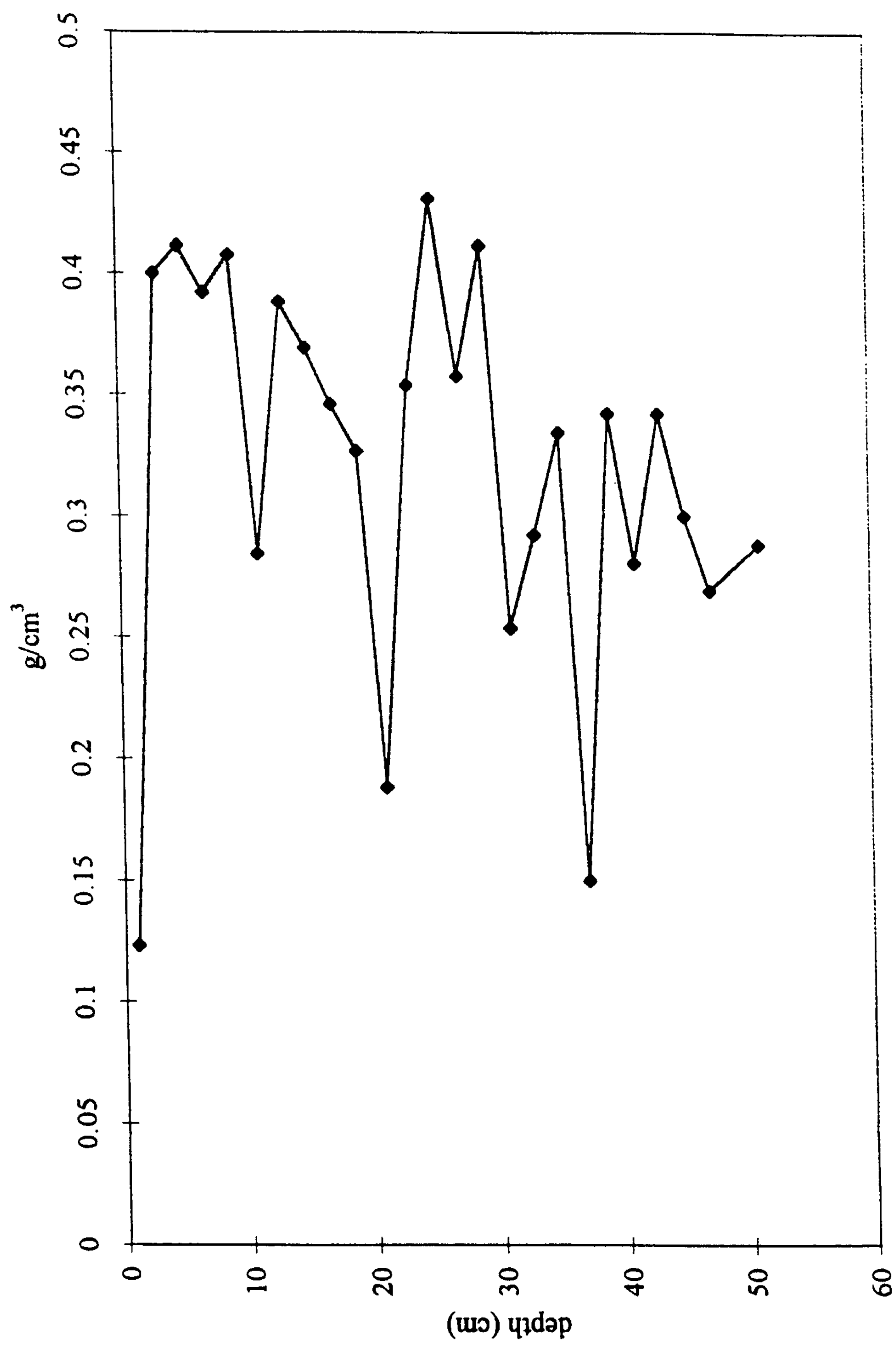


Fig. 3.6 "Backdoor creek" dry density

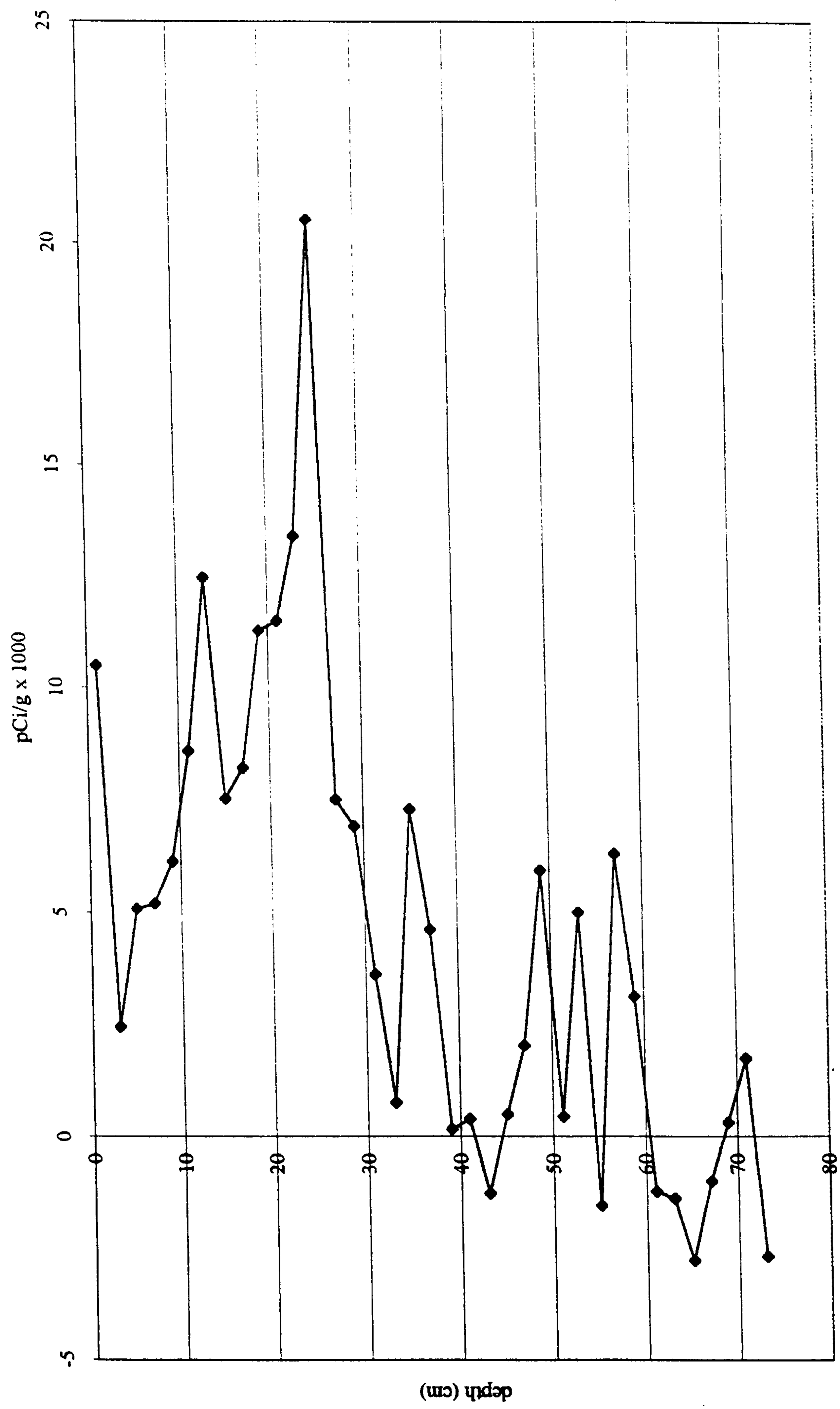


Fig. 3.7 Hannah Mills Creek Cs-137 concentration

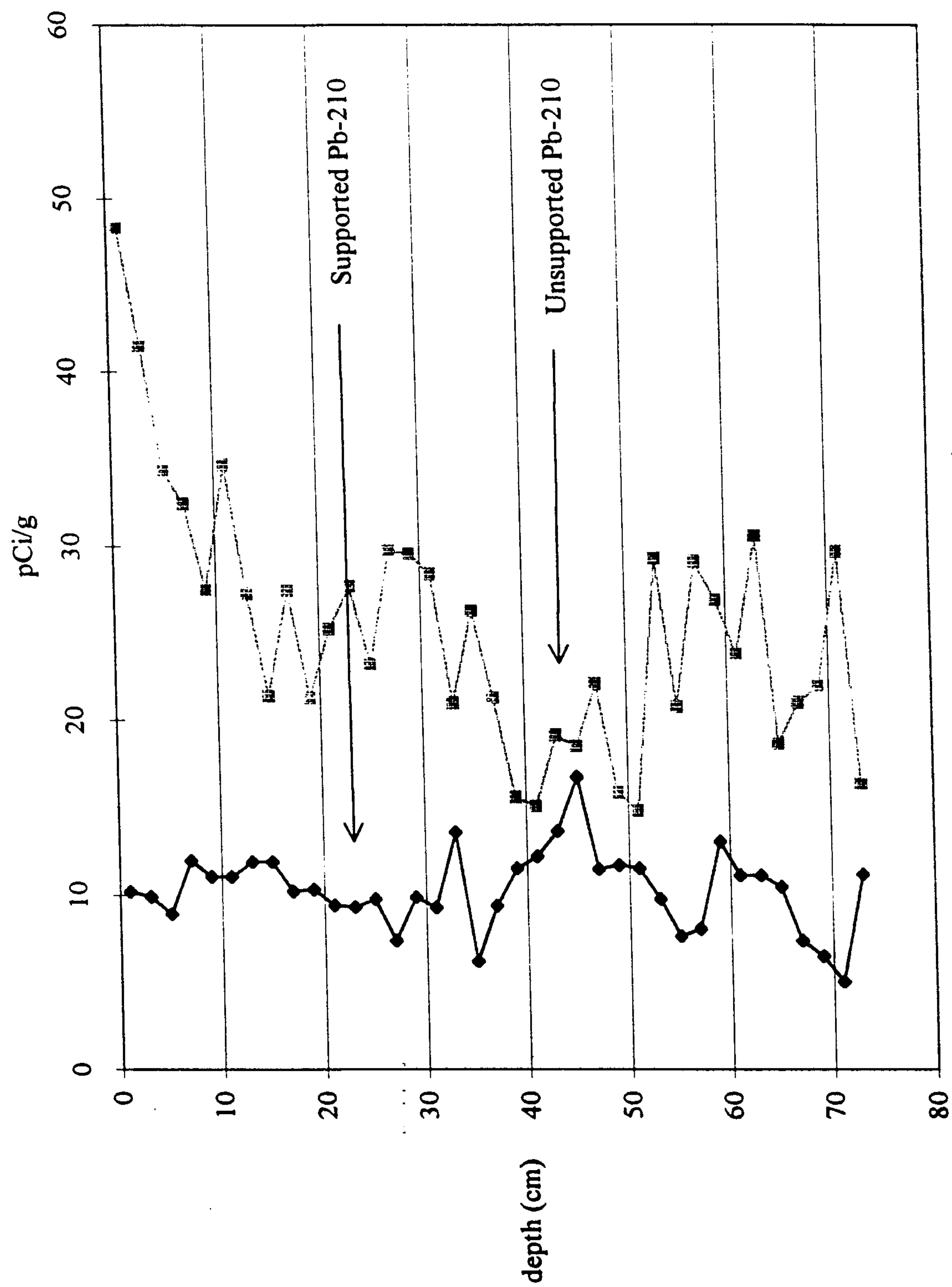


Fig. 3.8 Hannah Mills Creek Pb-210 activity vs. depth

depth at which the activity of unsupported Pb-210 is consistently zero was not reached. Age vs. depth estimates for Hannah Mills Creek sediment are displayed in Fig. 3.9. The age determined for the sediment at a depth of 71 cm is two centuries older than that determined for the top of the core. Finally, estimated sedimentation rate vs. estimated sediment age is shown in Fig. 3.10. The sedimentation rate in the creek has apparently increased significantly since the road was installed, from $\sim 4.44 \text{ g/cm}^2/\text{y}$ in 1925 to $\sim 15 \text{ g/cm}^2/\text{y}$ over the last decade or so

The results from the Cedar Point Creek core are shown in Fig. 3.11-3.14. There was no Cs-137 peak in this core (Fig. 3.11). The total concentration of Cs-137 in the core is actually higher in this core than in the Hannah Mills Creek core, $334.8 \text{ pCi/g} \times 1000$ and $167.8 \text{ pCi/g} \times 1000$ respectively. The bottom of the core has a higher concentration of Cs-137 than does the top. The Pb-210 derived age for the depth of 62 cm, the depth of the highest concentration of Cs-137, is ca. 1800. The sediment concentration of supported and unsupported Pb-210 is charted in Fig. 3.12. The depth at which the activity of unsupported Pb-210 is consistently zero again was not reached. Age vs. depth estimates are illustrated in Fig. 3.13. The dates computed from the Pb-210 profile in the Cedar Point core were similar to that of the Hannah Mills Creek core. If these dates are assumed to be accurate, at least half of the sediment in Cedar Point Creek and Hannah Mills Creek was present, perhaps in creek banks, before Heckscher Dr. was constructed.

Sedimentation rate estimates for Cedar Point Creek are shown in Fig. 3.14. The sedimentation rate in Cedar Point Creek was lower on average than that in Hannah Mills Creek. The extremely high value of $114.7 \text{ g/cm}^2/\text{y}$ near the top of the

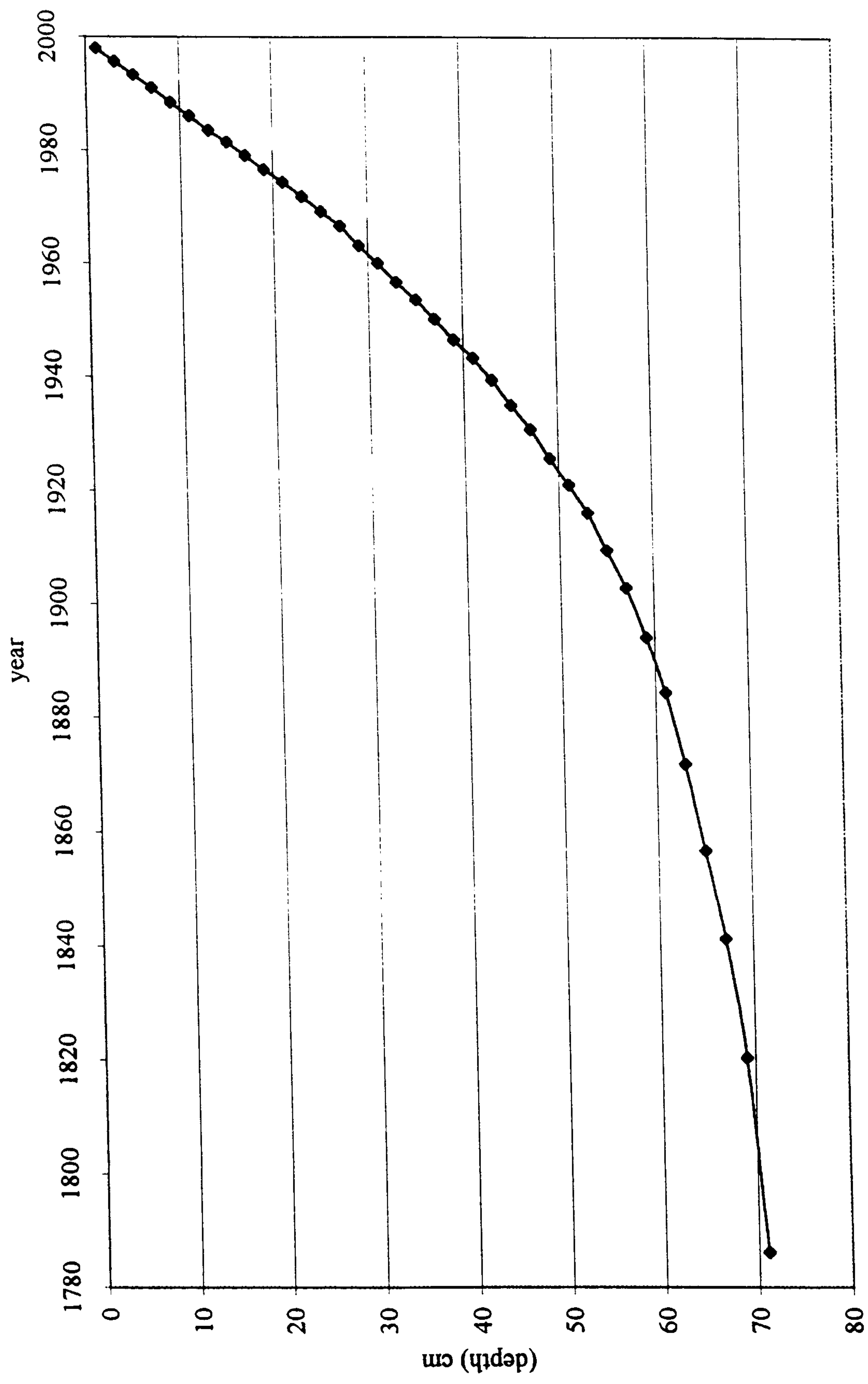


Fig. 3.9 Hannah Mills Creek sediment age vs. depth

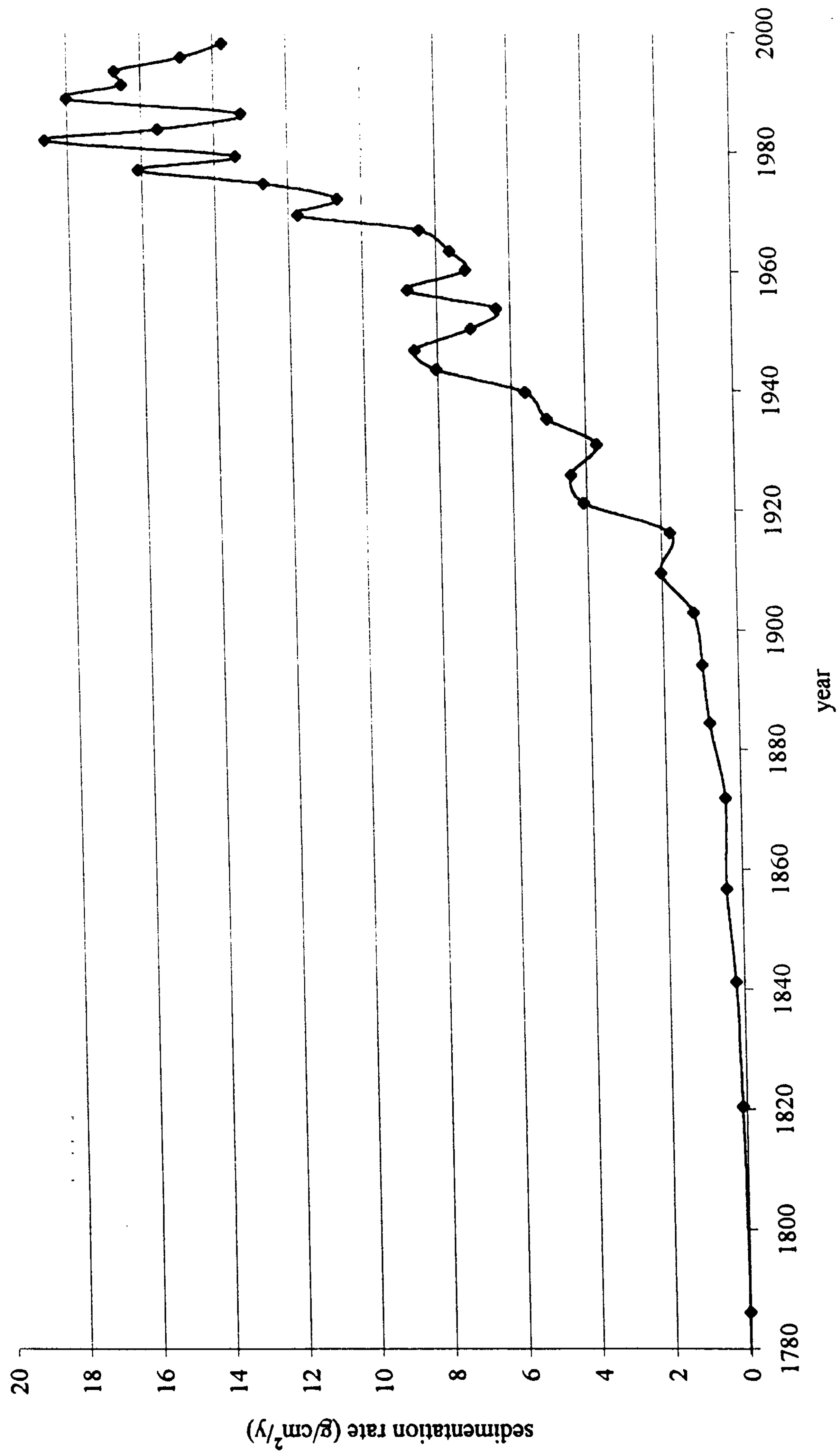


Fig. 3.10 Hannah Mills Creek sedimentation rate

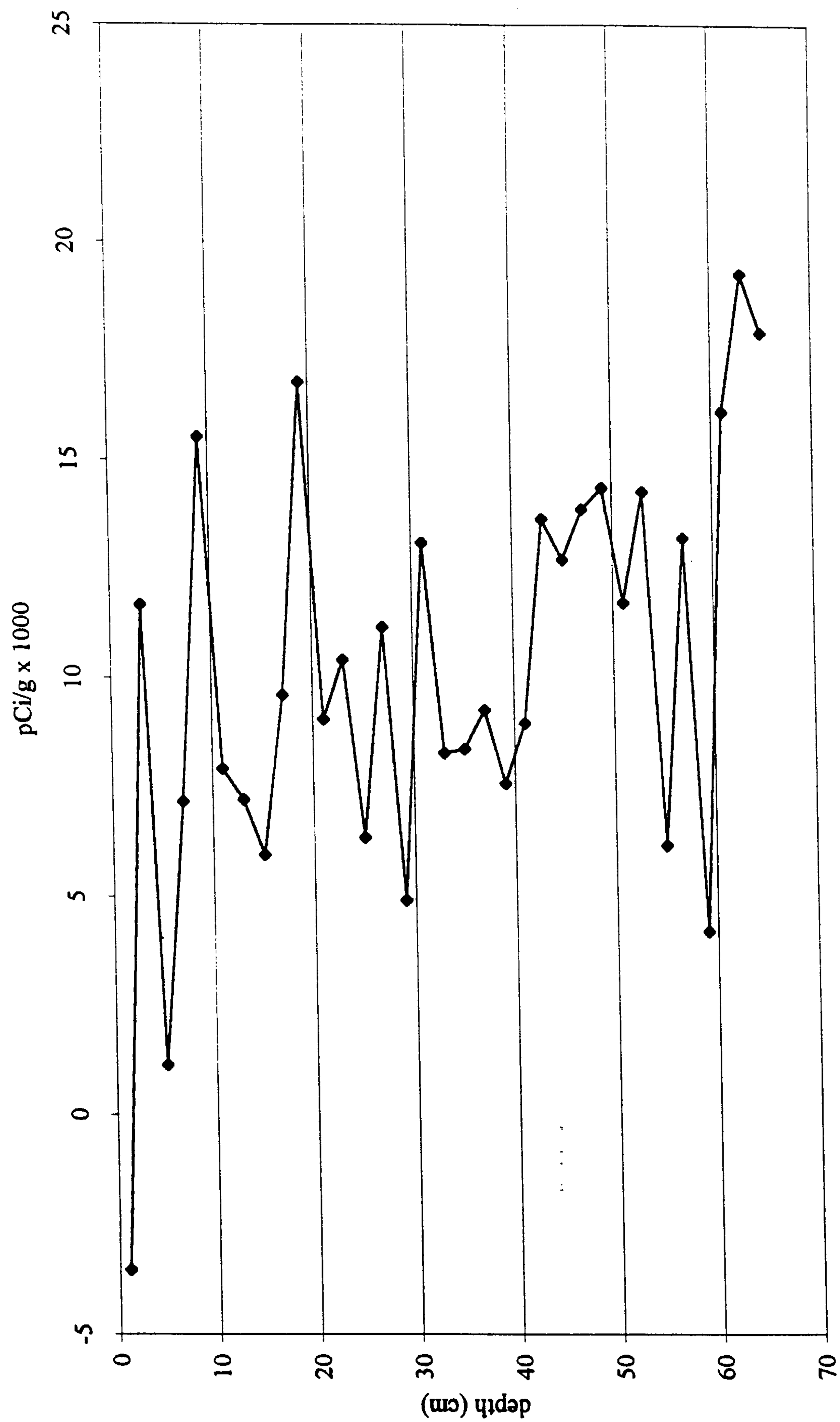


Fig. 3.11 Cedar Point Creek Cs-137 activity vs. depth

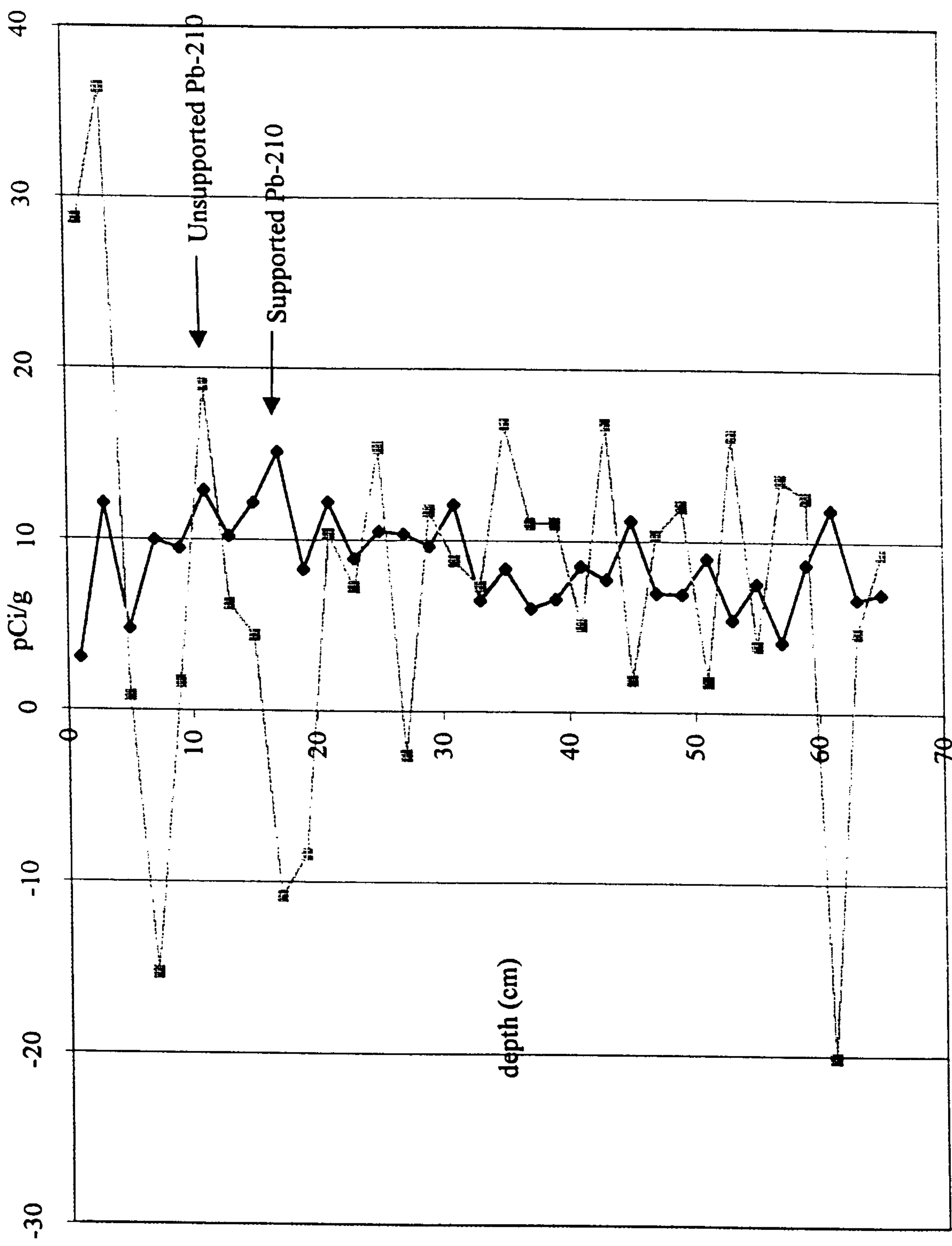


Fig. 3.12 Cedar Point Creek Pb-210 sediment concentration

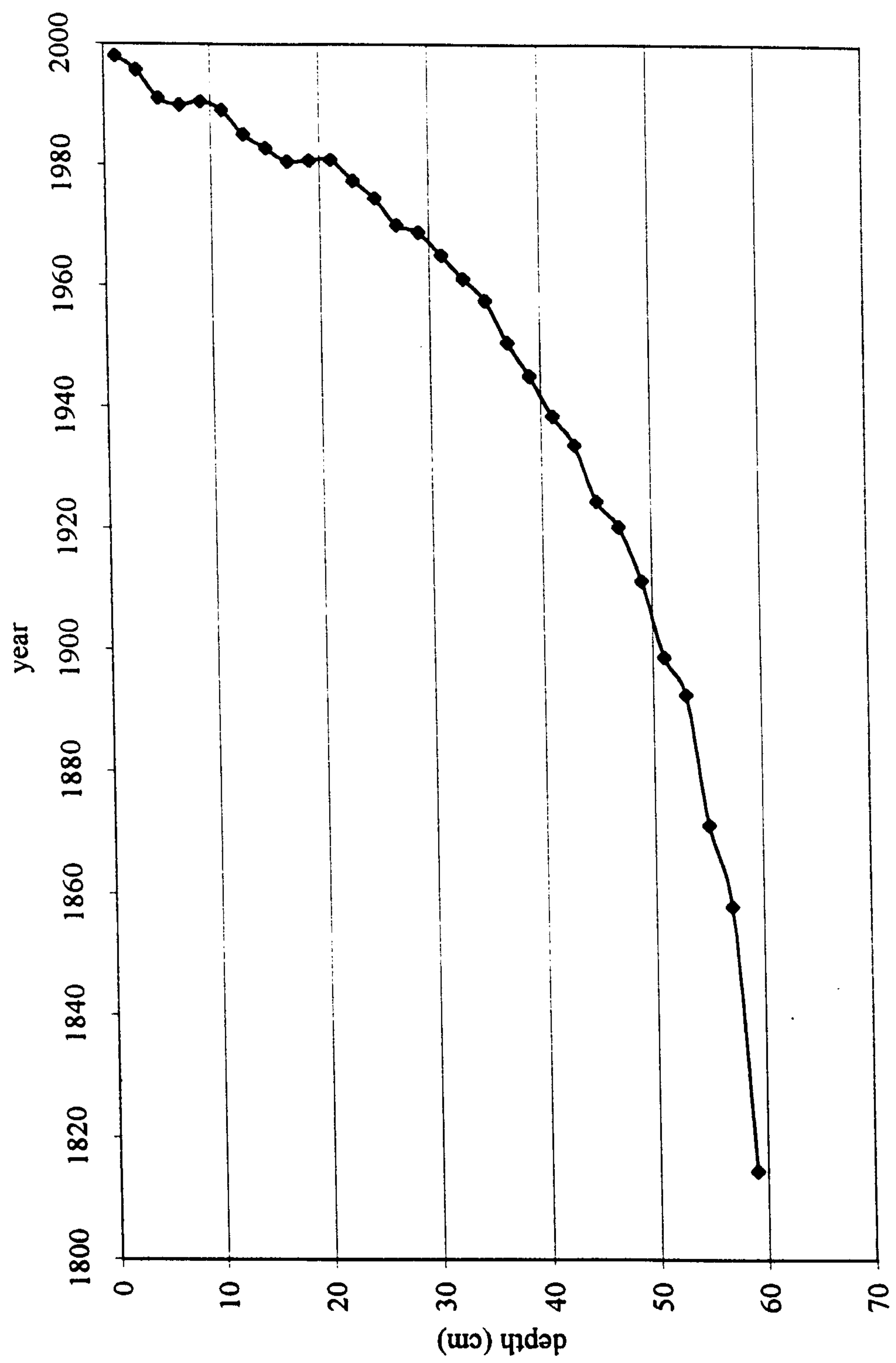


Fig. 3.13 Cedar Point Creek sediment age vs. depth

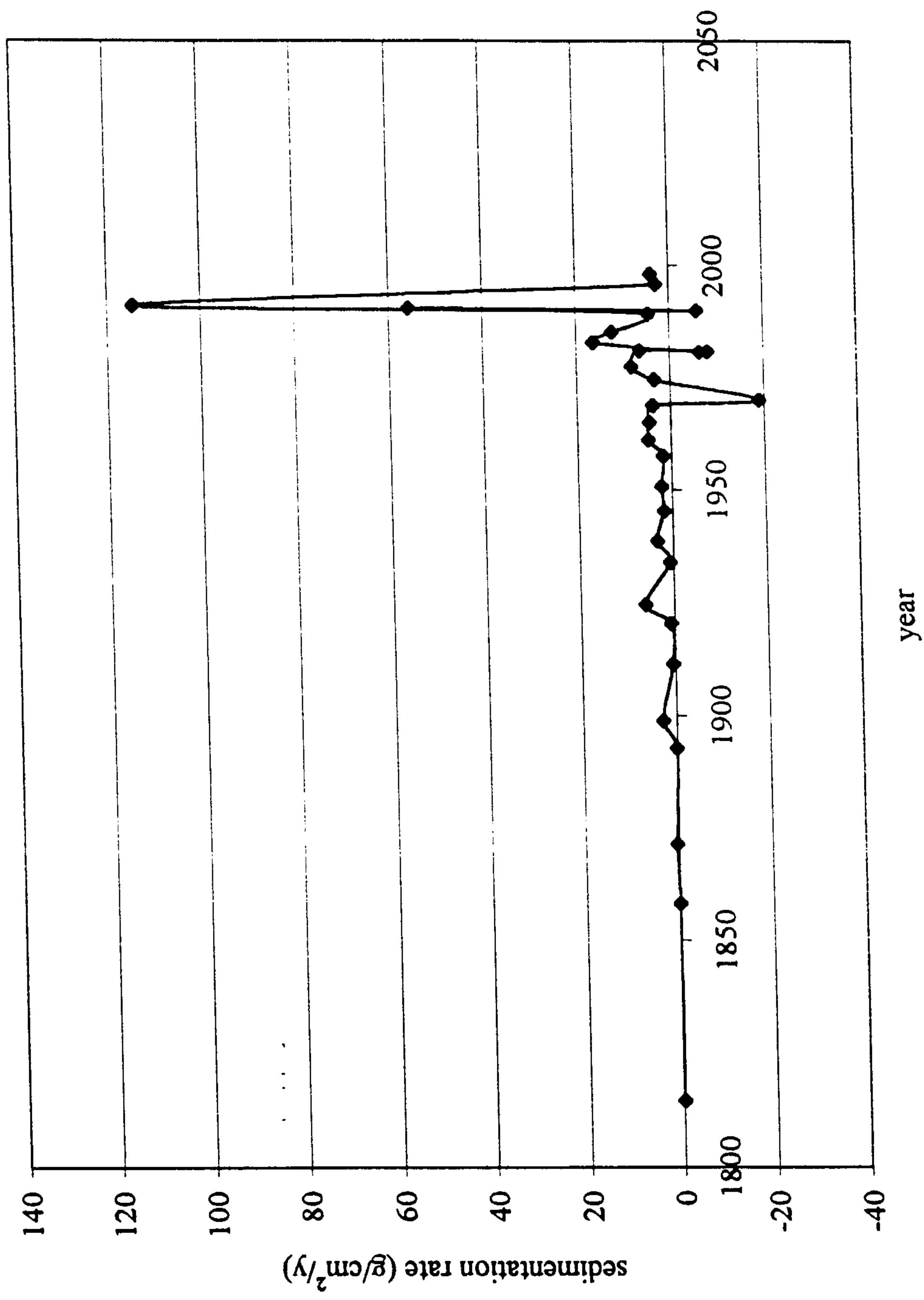


Fig. 3.14 Cedar Point Creek sedimentation rate

core may be the result of subtracting an average background that was higher than actually present on the day that the sample was counted, which created a very small number that when placed in the denominator of the rate equation yielded an unusually high result. The sedimentation rate calculated for the sample run immediately after it was negative, which indicated that the background subtracted from that sample was higher than the actual background also. Neither of the other cores has a similar peak in sedimentation rate. The alternative method for estimating sedimentation rates was used for the following slices because the rate equation produced negative sedimentation rates for these slices. At the 6-8 cm section, $0.3 \text{ g/cm}^3/\text{y}$; at the 16-18 cm section, $1.35 \text{ g/cm}^3/\text{y}$; and at 16-20 cm was $2.3 \text{ g/cm}^3/\text{y}$.

The core from the "backdoor creek," like the Cedar Point Creek core, yielded no Cs-137 peak (Fig. 3.15). The total "backdoor" creek Cs-137 concentration, at $237.6 \text{ pCi/g} \times 1000$, was also greater than the Hannah Mills Creek core. The "backdoor creek's" unsupported Pb-210 activity declined sharply below the first few centimeters (Fig. 3.16), but did not reach the depth at which it was consistently zero. The unsupported Pb-210 activity of this core is also close to the lower limits of detection of the gamma ray spectrometer. Several negative values were obtained for unsupported Pb-210 activity when the background Pb-210 radiation or the supported Pb-210 activity was subtracted from the sample Pb-210 activity. The unsupported Pb-210 activity of the core below 10 cm is practically identical to supported levels. Age vs. depth relationship is shown in Fig. 3.17. The Hannah Mills Creek core has a date of 1960 at 30 cm depth, the Cedar Point Creek core at 30 cm depth is 1965, and the "backdoor creek" is 1915 at 30 cm deep. Estimates of the "backdoor creek"

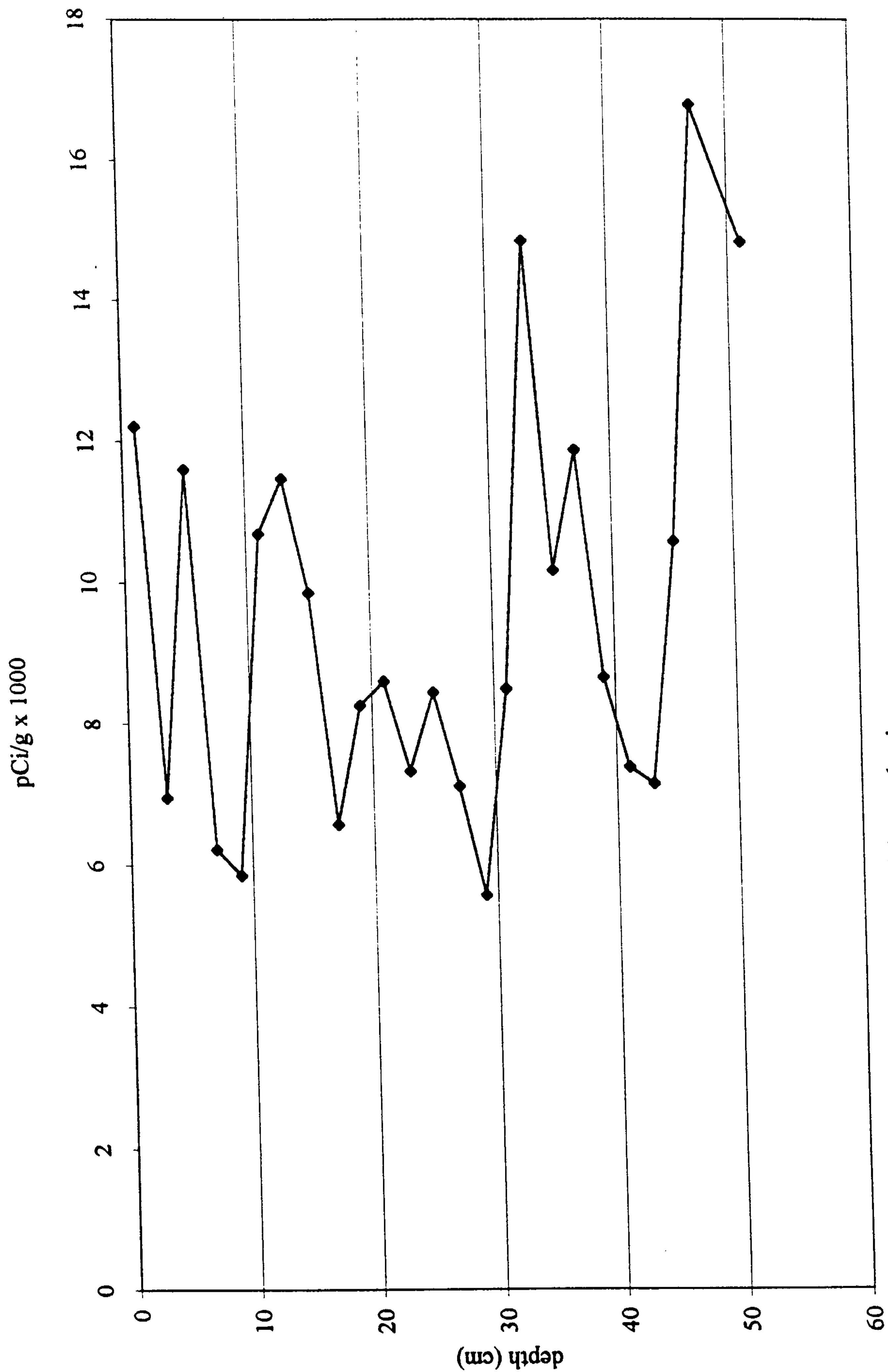


Fig. 3.15 "Backdoor creek" Cs-137 activity vs. depth

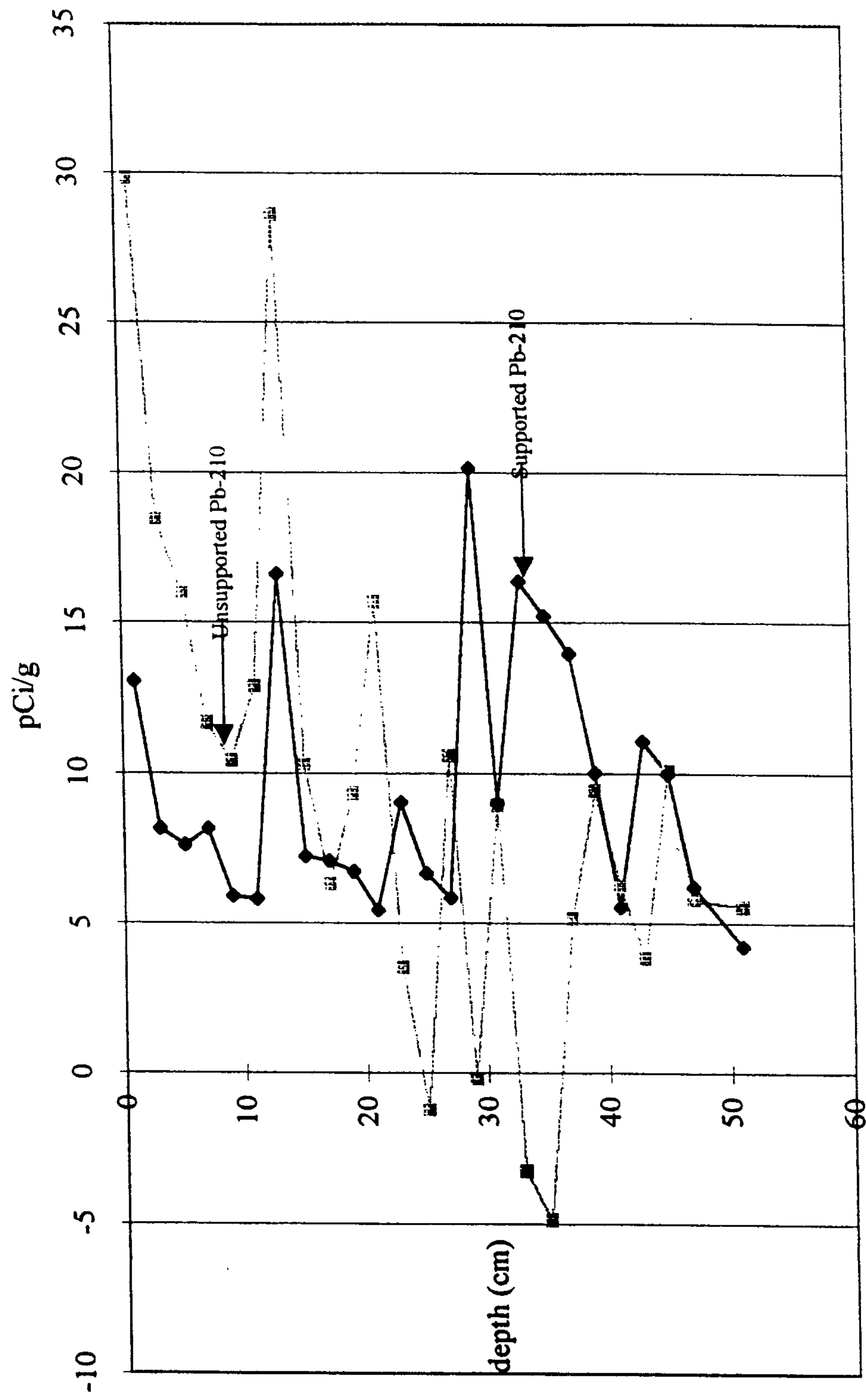


Fig. 3.16 "Backdoor creek" Pb-210 activity vs. depth



Fig. 3.17 "Backdoor creek" age vs. depth

sedimentation rate are shown in Fig. 3.18. They are similar to the sedimentation rates estimated for Cedar Point Creek, both cores being lower than the Hannah Mills Creek core. Sedimentation rates apparently increased slightly over the last few decades. Several negative sedimentation rates were also in the "backdoor creek" core. Using the interpolation method for determining sedimentation rate since the rate equation produced negative sedimentation rates, the following estimates were obtained: at 24-26 cm, 7.9 g/cm³/y; at 28-30 cm, 3.7 g/cm³/y; at 32-34 cm 8 g/cm³/y; and at 34-36 cm, 30 g/cm³/y.

The background of Pb-210 radiation varied substantially over the counting time of the cores. At the start of counting the Hannah Mills Core it was 0.018 cps (counts/sec), and at the time of counting the last slice of the "backdoor creek" core about 2.5 months later, it had declined to 0.006 cps. The average of the background over the counting time of the cores was 0.014892 cps, with a standard deviation of 0.0047 cps, and a relative error of about 32%. Some of the variation in the background was probably not detected since background sugar counts were counted only once every one to two weeks. Table 3.1 shows the Pb-210 background activity as a percentage of the sample activity. The background was a high proportion of the activity of the samples. Undetected variation in the background Pb-210 activity could have caused erroneous estimates of the sample activity when the background was subtracted, since the background activity in many cases was almost as great as that of the sample.

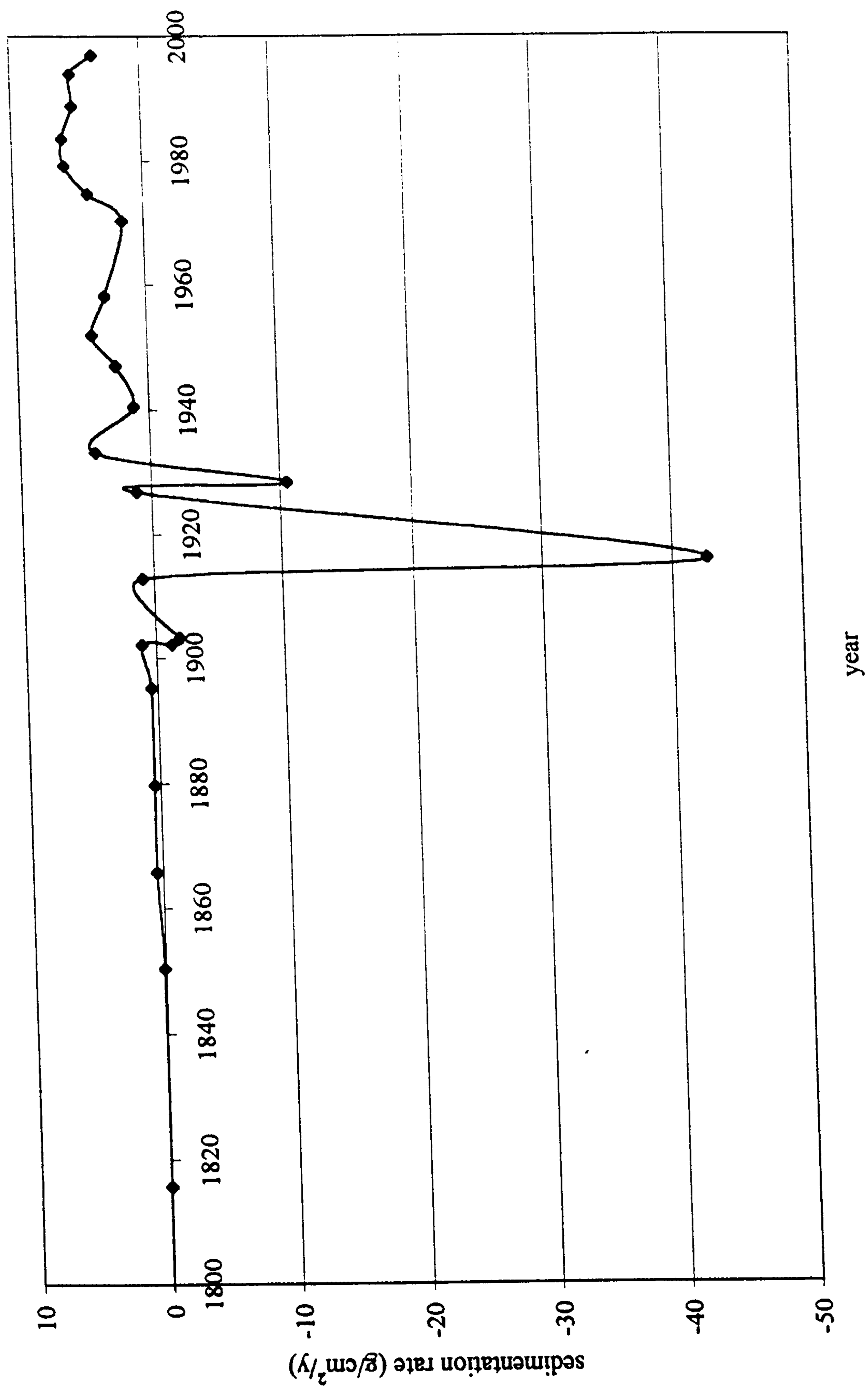


Fig. 3.18 "Backdoor creek" sedimentation rate

Table 3.1 Comparison of background and sample total Pb-210 activity

Core	Hannah Mills Creek	Cedar Point Creek	"backdoor creek"
most active slice	0-2 cm	2-4 cm	12-14 cm
sample activity (cps)	0.0258	0.0165	0.0085
relative error	2.1%	2.4%	2.1%
average background activity (cps)	0.0142	0.0108	0.0085
background/sample activity	55%	65%	39%
least active slice	66-68 cm	60-62 cm	50-52 cm
sample activity (cps)	0.200	0.009	0.01
relative error	4.3%	5%	4.7%
average background activity (cps)	0.0142	0.0108	0.0085
background/sample activity	72%	> 100%	85%

3.5 Discussion

The prominent Cs-137 peak in the Hannah Mills Creek core is probably derived from nuclear bomb testing that reached its peak in 1963 (Ritchie, et al. 1973). If the sediment at a depth of 25 cm is assumed to have been deposited in 1963, the average sedimentation rate over the last 35 years in Hannah Mills Creek is 0.7cm/y. The Pb-210 derived date for this depth is within 6 years of this estimate, at 1969. There is thus good agreement between the two dating markers.

The average sedimentation rate since the construction of Heckscher Dr. is about 11 g/cm²/y. Using the following equation, one can estimate the depth of mud deposited over 80 years at this sedimentation rate.

$$\frac{11 \text{ g}}{\text{cm}^2 \text{ y}} \times \frac{\text{cm}^3}{0.33 \text{ g}} \times 80 \text{ y} = 2.6 \text{ m}$$

This is close to the actual depth of mud found in the creek. Thus the road seems to have caused most if not all of the sediment accumulation. Assuming this sedimentation rate occurred in the whole creek, the amount of sediment that should have been deposited can be estimated using the following variables: 2.6 m (depth accumulated over 80 years at 11 g/cm²/y), 400 m (length of creek measured for sediment depth), 100 m (measured creek width), and 0.33 g/cm³ (average sediment dry density in Hannah Mills Creek). Plugging into the following equation yields: 2.6 m X 400 m X 100 m X 330 kg/m³ = 3.4x10⁷ kg. This is very close to 3.14x10⁷ kg, the sediment measured in Hannah Mills Creek. It is only about an 8% difference. Thus Heckscher Dr. probably caused the accumulation of sediment in the Hannah Mills Creek.

A possible explanation of the origin of the mud in Hannah Mills Creek and Cedar Point Creek is bank sloughing (Ch. 2) of the adjacent marshes. Old marsh bank mud may have slumped in large clumps into the creek and settled rapidly to the creek bottom. This mud would appear to have settled onto the creek bottom earlier than it actually did since its sorbed Pb-210 would have partially decayed. New sediment may have then overlaid it, producing a datable Pb-210 profile with higher unsupported Pb-210 concentrations at the top of the sediment bed. The sediment below the top meter is probably relatively unpolluted since it may have been deposited before the large scale use of pesticides and industrialization of the 20th century. The main industry in Jacksonville before this century was forestry. The port experienced its greatest period of growth in the 1920's (Wagman 1988). This does not necessarily imply an increase in marsh bank slumping caused by the installation of Heckscher Dr. but merely a blockage of export of the slumped mud from the creek. Another possibility is that the creek water expanded over the marsh when its mouth was closed by the road. This may have increased sloughing of the bank of the flooded marsh.

Sedimentation rates in some Virginia salt marshes were found to be 2g/cm²/month (Kastler and Wiberg 1996), lower than that found in the Hannah Mills Creek in recent years. The edges of marshes usually have a higher sedimentation rate than tidal creeks because of the effects of vegetation, namely trapping of sediment by plant roots and stalks (Morgan and Rickson 1995). The organic matter produced by plants also adds to the sediment in marshes. The creek has a relatively high sedimentation rate, even compared with marshes.

The reason for the increase in Cs-137 concentration down the core in the Cedar Point Creek and "backdoor creek" cores is unknown. Perhaps the higher Cs-137 was in marsh bank mud exposed to the atmosphere in 1963. Bank sloughing then may have added the marsh's Cs-137 a bit at a time to the creek sediment, thereby creating a smear. The concentrations in the Hannah Mills Creek and Cedar Point Creek core are similar at the top but where the Hannah Mills Creek core declines, the Cedar Point Creek core and "backdoor creek" core concentrations remain about the same and actually increase at the deepest section of the core. It seems improbable that this sediment was deposited around 1963, since this would be two centuries off the Pb-210 derived date. The old marsh bank's subsequent sloughing and being overlain with newer sediment might give the impression that it has been in the creek longer than it actually has. The profile of unsupported Pb-210 created thus may then be similar to profiles created by sediment derived solely from sediment settling out of the water over a long period of time. The dating model may then produce dates for the deposition of the sediment that are earlier than the true dates of deposition.

The sediment beneath the top few centimeters might have been mixed. This could account for the homogeneous concentration of unsupported Pb-210 down the core, where the higher concentration originally near the top of the core was reduced and the lower concentration at the bottom was increased. However, sediment may not mix thoroughly enough to make the activity uniform over depth. Wide fluctuation in the unsupported Pb-210 concentration over depth would be a reasonable consequence of mixing if sections of sediment originally at the top of the core merely exchanged places with sections of sediment originally lower in the core.

The lower sedimentation rate in Cedar Point Creek compared to Hannah Mills Creek may be due to the presence of a 1 m diameter culvert through which tidal water can move into and out of the creek under Heckscher Dr. The sediment might thus remain suspended in the faster current, reducing the accumulation of mud. The extremely high value of $114.7 \text{ g/cm}^2/\text{y}$ may have been the result of experimental error, namely, subtracting too high a background from the sample total Pb-210 activity. It also may have been caused by a storm increasing bank slumping into the creeks.

Subtraction of the total Pb-210 background activity created inaccurate negative sedimentation rates for Cedar Point and Hannah Mills Creek cores. However, these negative sedimentation rates may be no more inaccurate than the positive ones. If the background that was subtracted from the sample activity was the true background, then the sample activity was below the level of detection of the detector. The decline in the total Pb-210 background activity over the course of counting the cores caused a tendency to subtract too high a background from the samples as the study progressed. Daily background checks are recommended to adequately track variation in the background so that sufficiently accurate determinations of the true activity of the samples can be made.

Assuming the Pb-210 derived age of the sediment in Hannah Mills Creek and Cedar Point Creek is accurate, at least 50-60 cm of the sediment has accumulated since the road was built. If some of the sediment was sloughed from old marsh banks after the construction of the road, then more than 50-60 cm has accumulated in the creeks since the road was built. The origin of the sediment cannot be proved by its age. Whether it was derived from suspended solids or from marsh bank sloughing is

CHAPTER 4 CREEK MUD PROPERTIES

4.1 Introduction

The potential for the sediment in the Cedar Point Creek and Hannah Mills Creek to pose a contaminant risk to the St. Johns River estuary if Heckscher Dr. is removed was assessed. Properties of the creek sediment that would increase its capacity to sorb contaminants are small particle size and high organic matter content. Properties that increase the sediment's potential to move to other areas of the St. Johns River estuary are high erodibility and small particle size. A combination of all these traits would maximize the contaminant risk the sediment poses to the St. Johns River ecosystem.

Predictions about whether the sediment will move out of the creeks into the St. Johns River if Heckscher Dr. is removed were made by comparing the shear stress necessary to suspend the sediment in overlying water to the shear stresses expected in the creeks after Heckscher Dr. is removed. If the shear stresses in the creeks are of sufficient force, then the sediment will move out of the creeks. The direction of movement, away from the adjacent marsh or toward it, will depend on which tide is dominant, the ebb or flood.

4.1.1 Grain Size

Small particles have a higher surface area per unit mass and volume than do larger particles. The surface area of spherical particles, $4\pi r^2$, increases with the square of the

particle radius, whereas the volume, $(4/3)\pi r^3$ and mass increases with the cube of the particle radius. For a spherical particle of 1 mm diameter the surface area is 3.14 mm^2 and the volume 0.524 mm^3 . For a spherical particle of 2 mm the surface area is 12.6 mm^2 and the volume 4.19 mm^3 . The ratio of surface area to volume for the 1 mm particle is 6.00 and for the 2 mm particle is 3.00. Thus smaller particles have greater area for adsorption per unit volume and mass. The same volume can be divided into 8 particles of 1 mm diameter or 1 particle of 2 mm diameter. The 1 mm particles would have a total surface area of 25.1 mm^2 vs. a surface area of 4.19 mm^2 for the 2 mm particle. Most particles in the environment are flatter than perfect spheres; clay particles in the form of platelets have a much greater surface area per unit mass and volume than spherical particles. Thus more surface area for adsorption of contaminants is available on smaller flatter particles per unit mass and volume.

The electrochemical forces acting on small particles in the size range of clay, usually defined as $< 2 \text{ }\mu\text{m}$, are much greater than the force of gravity acting on them; they thus have low settling velocities. Clay can remain suspended in water for long periods of time as a result. This enables sorbed contaminants to be transported over great distances. Contaminants from a heavily polluted site can then travel to relatively pristine locations and threaten organisms there.

Clays are essentially negatively charged hydrous aluminum silicates with magnesium or iron substituting for aluminum in some minerals. This negative charge can attract positively charged contaminants. Cations adsorb to the surface of clays to neutralize this negative charge. The high cation exchange capacity of clays, the number of positive charges from sorbed cations required to neutralize a particle's negative charge,

makes fine sediment a major sorber of positively charged contaminants in the aquatic environment. The tendency of sorbed cations to diffuse into the surrounding water and reach equilibrium with the cations in the water is balanced by the electrostatic attraction of a clay particle; another layer of cations (per m^3) of lower concentration is formed above the one adsorbed (per m^2) to the particle surface. The concentration of this second layer is lower because the attractive charge of the clay particle is smaller at the greater distance from the clay surface. This double layer influences how clay particles interact with each other. If the cation concentration in the water in which clay is suspended increases, the thickness of the double layer would decrease; cations diffuse to areas of lower concentration than where they are, so when the concentration of cations in the water increases, the tendency to diffuse into the water would decrease. Clay particles can then approach each other more closely to form clusters called flocs (Parchure, 1984). Upon deposition, adsorbed water molecules and cations create links between clay and silt particles, making a cohesive mass that can resist erosion. This would reduce the probability that the sediment and any sorbed contaminants would move to other locations to threaten organisms.

Most particles in the aquatic environment are in the form of flocs. The formation of flocs affects sediment surface area exposed to contaminants and settling velocity. Microflocs, (10-20 μm in diameter) composed of smaller particles having higher surface area than macroflocs, usually dominate pollutant flux. Medium flocs would be 20-1000 μm . Macroflocs (> 1 mm), aggregates of microflocs, may dominate mass flux. They are thought to constitute a larger share of the sediment in the environment than microflocs (Dyer, 1989). A background of primary clay particles that only intermittently form flocs

probably exists in the aquatic environment. These primary particles can be important carriers of pollutants because of their high cation exchange capacity, low settling velocity, and high surface area per unit mass (Dyer, 1989).

The settling velocity of flocs determines how long sorbed contaminants can remain in suspension. The lower the settling velocity, the longer the sediment can remain suspended and thus expose areas of the ecosystem to contaminants. The important characteristic governing settling velocity of flocs toward the sediment bed is not the mass concentration of the constituent particles, but the volume concentration of the aggregate (Dyer 1989). Sand does not form flocs, so sand percent composition can be estimated using Stokes' Law and the density of quartz, 2.65 g/cm^3 . Flocs have an internal volume filled with water, reducing the density of the particle from approximately 2.65 g/cm^3 of the particles which compose the floc, to approximately 1.2 g/cm^3 for microflocs (Mehta, A. J. personal communication). Figure 4.1 shows the relationship between volume concentration and floc diameter. Macroflocs have a density similar to the fluid in which they are suspended. At a diameter of 1 mm the difference approaches 0.001 g/cm^3 . Microflocs have a density difference from their carrier fluid of 0.1 g/cm^3 to around 0.5 g/cm^3 , making a volume concentration of 1.1 g/cm^3 to around 1.5 g/cm^3 if the carrier fluid is water. Microflocs are composed of smaller particles that are more densely packed than macroflocs, so can settle faster than macroflocs. Suspended sediment concentration affects floc formation and settling velocity of flocs. This is important when trying to estimate floc size and settling velocity. This effect can be divided into three categories, as illustrated in Fig. 4.2. Flocs are typically considered to fall independently of one another in concentrations up to C_1 , 0.1 kg/m^3 - 0.3 kg/m^3 (Mehta, 1988). Above this

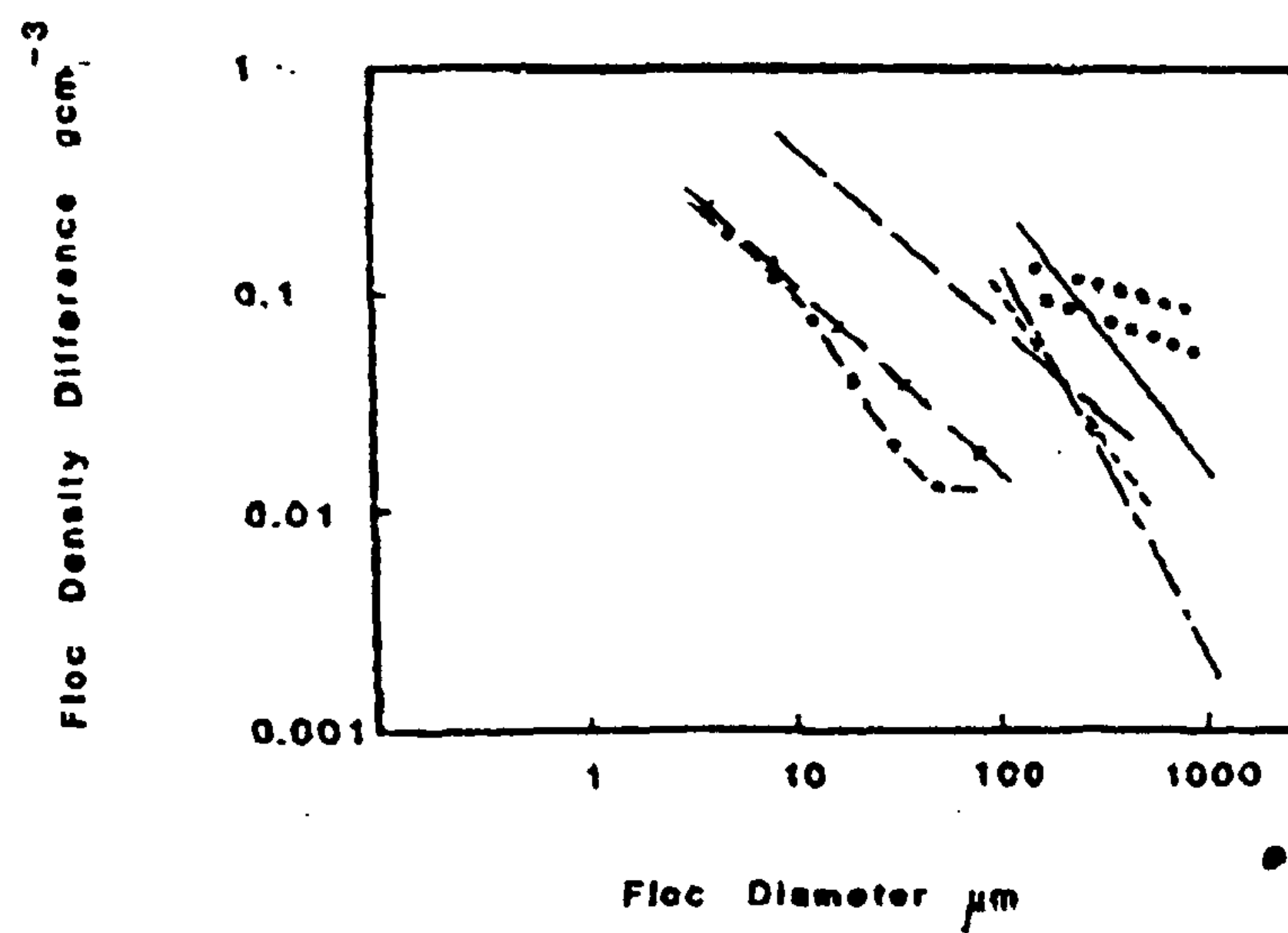


Fig 4.1 The variation of floc density difference (floc density minus fluid density)
(Taken from Dyer, K. 1989)

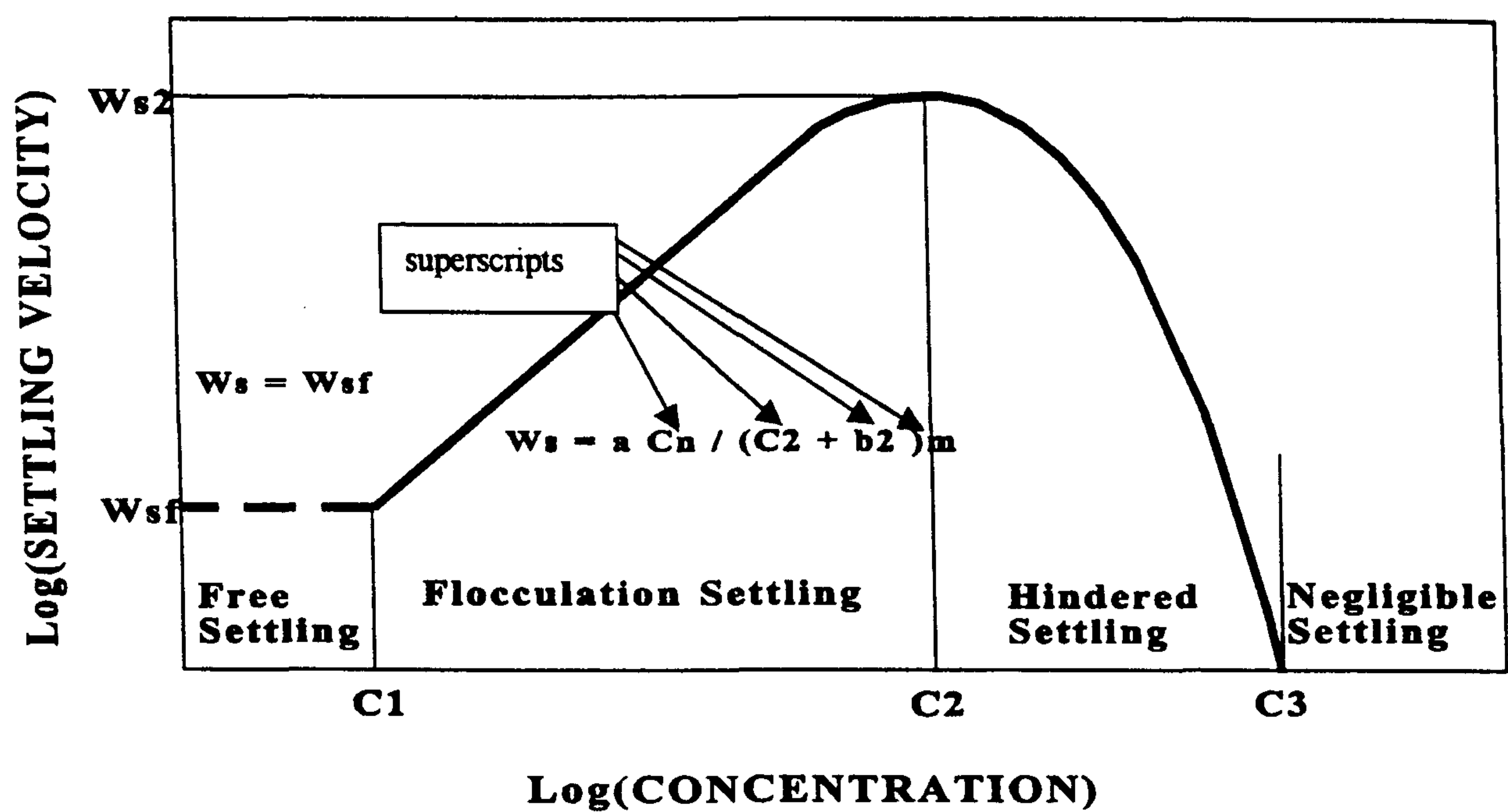


Fig. 4.2 Floc settling velocity vs. concentration, where a , b , n , and m are sediment dependent empirical coefficients (Taken from A. J. Mehta, OCP 6297 lecture notes).

concentration larger, denser flocs form by the increased number of collisions with other flocs; settling velocity increases. Finally, at above some concentration C_2 , nominally 6 kg/m³, formation of a network of flocs impedes the rising of floc displaced interstitial water. At some higher concentration C_3 and above, settling becomes negligible (A. J. Mehta, lecture OCP 6297 notes). If the sediment concentration is in the range up to C_1 , where the individual flocs fall independently of one another and do not form aggregations that increase or decrease settling velocity, floc size below that of macroflocs can be roughly estimated by a modified version of Stokes' law,

$$W_s = \frac{gd^2}{18\mu}(\rho_f - \rho_w)$$

where W_s is settling velocity, g is the acceleration due to gravity, μ is the molecular viscosity of water, ρ_f is the floc volume concentration, and ρ_w is the density of water, and d is the floc diameter. Using a volume concentration of 1.2 g/cm³ rather than a mass concentration, and measuring settling velocity, the equation can be used to solve for floc diameter. Sand does not form flocs. Therefore, the density of its constituent crystals, mainly quartz (2.65 g/cm³), is used to estimate sand settling velocity.

4.1.3 Organic Content

Some organic compounds are strongly electrically polar and can thus form chemical complexes with pollutants (Parchure, 1980). Organic compounds having carboxylic, phenolic, phosphatic and other functional groups form complexes with organic and metal pollutant. A high correlation between organic content of sediment and metal contamination has been found in Louisiana sediment (Feijtel et al. 1988). Organic matter also connects clay particles to form flocs and so influences settling velocity and floc size.

A specific kind of organic, mucopolysaccharide compounds strongly affect flocculation (Dyer, 1989). Organic exudates of benthic microbes have also been shown to stabilize sediment (Montague, et. al 1992).

4.1.4 Sediment Erodibility

Sediment in aquatic systems can be a significant sink for environmental pollutants since it provides sites for contaminant adsorption. As long as the sediment remains buried and unavailable to benthic organisms and leaching of contaminants does not occur, it poses no immediate problem. However, sediment particles can be brought out of storage and back into ecological circulation if sufficient force in the form of tides, waves and currents is applied to them. Hence, the sediment in the blocked creeks are a potential problem, for they may transport pollutants to the St. Johns River estuary and expose them to organisms there.

The erodibility of the sediment can be defined by the critical shear stress necessary for sediment to become suspended in overlying water. Organic matter generally has a low shear strength (resistance to fluid stress), so if sediment is mostly organic, it would be highly erodible (Parchure, 1984). Also, bubble formation by biological activity in the sediment can reduce bed shear strength (Montague, 1986). Bulk and dry density when measured over depth indicate the variation of shear strength as one goes deeper into the

bed. Bulk density, ($\rho = \frac{M}{V}$, where M is the wet mass of the sediment and V is volume),

and dry density, ($\rho_D = \frac{M_D}{V}$, where M_D is M oven dried at 100°C) correlate with bed

shear strength, τ_s , the ability of the bed to resist fluid stress (Table 4.1). With higher water

Table 4.1 Sediment shear strength and dry density relationship for sediment from various aquatic systems

Mud type	Sand %	Organic %	τ_c = critical bed shear stress (N/m ²), c is dry density in kg/m ³				
			$c = 100$	$c=150$	$c=200$	$c=250$	$c=300$
kaolinite (saline water)	0	0	-	0.05-0.10	0.30-0.40	-	-
kaolinite (distilled water)	0	0	-	0.05-0.10	0.15-0.20	0.20-0.25	-
Hollands Diep 1 (lake)	9	10	0.15-0.25	0.30-0.40	0.40-0.50	0.60-0.80	-
Hollands Diep 2 (lake)	23	9	0.15-0.25	0.30-0.40	0.40-0.50	0.80-1.00	-
Ketelmeer (lake)	7	12	0.10-0.20	0.20-0.25	0.25-0.35	0.50-0.70	-
Blesbosch (lake)	8	8	0.20-0.25	0.25-0.30	0.30-0.35	0.50-0.70	-
Mass (river)	36	8	0.15-0.30	0.30-0.40	0.40-0.50	0.80-1.00	-
Breskens Harbour (estuary)	27	5	0.15-0.25	0.25-0.35	0.35-0.45	0.60-0.80	-
Deltzigil Harbour (estuary)	60	2	0.05-0.15	0.15-0.20	0.20-0.25	0.40-0.60	-
Loswal ord (sea)	69	2	0.20-0.30	0.30-0.35	0.35-0.45	0.60-0.80	-
Brisbane, Grangemouth, Belzwan	0	-	0.20-0.30	0.40-0.60	0.80-1.00	-	-
Loire	-	-	0.10-0.15	0.15-0.20	0.20-0.30	0.30-0.40	0.80-1.20
Cardiff Bay	-	-	0.20-0.30	0.40-0.50	0.60-0.70	0.70-0.90	-

Adapted from Goodwin et. al (1995)

content the bed shear strength decreases (Postma 1967). The density of deposited beds in the laboratory increases with depth. This is caused by three factors: reorganization of clay particles to a more parallel orientation to each other, the crushing of floc structure by the weight of overlying sediment squeezing out the water, and faster settling of smaller particles forming denser flocs in the lower layers of the bed (Parchure, 1984). Many exceptions exist in nature, caused by deposition of different sediment types over time, producing layers of varying shear strength. A layer of sand could be deposited during a storm surge, then a layer of silt over another period of time, then plant mass, etc. The greater the sediment erodibility, the less force required to move the sediment and the more likely it will be transported to other parts of the ecosystem and become biologically available.

4.2. Materials and Methods

Three cores of sediment were obtained from Hannah Mills Creek and Cedar Point Creek, totaling six cores (Fig. 4.3). The cores were about 4 cm in diameter and about 0.75 m in depth. Each core was sectioned into four parts: 0 - 15 cm, 15-30 cm, and the remaining core depth halved across the core. The bulk density of each section was measured by weighing 2 cm³ of mud that had been withdrawn with a 10 cm³ syringe. The volume of mud was determined using a 10 cm³ syringe. Sections having similar bulk densities were then combined into 4 separate composites; Composite 1 was the most fluid, coming primarily from the top 15 cm of the sediment bed. Grain size, organic content, and erodibility were measured for each composite.

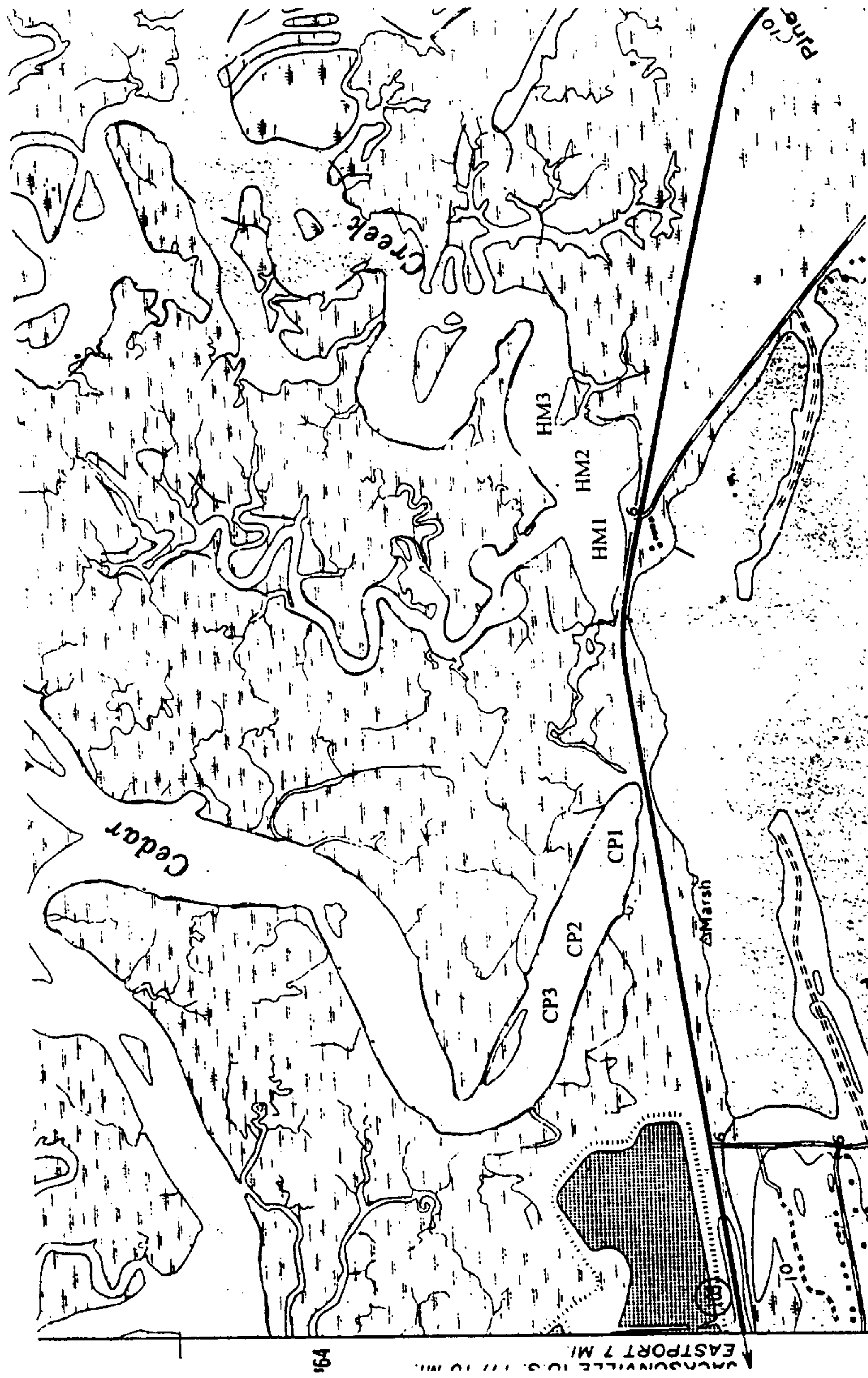


Fig.4.3 Sites of cores for grain size, organic content and erodibility analysis ,
 CP is Cedar Point Creek and HM is Hannah Mills Creek

4.2.1 Grain Size

Floc size distribution and settling velocity of suspended fine sediment were estimated by the bottom withdrawal method using a settling tube (Vanoni 1975). The 1 m long 570 ml tube was divided into ten 10 cm sections. The sections were used to measure the fall height of the sediment in the water. About one gram or less (wet weight) of sediment from each composite was transferred to the tube and evenly distributed by tilting. The tube was then placed in a vertical position which marked the beginning of the settling test. At subsequent time intervals (30 sec, 1 min, 2 min, 8 min, 20 min, 40 min, 1 hr, 20 min, 2 hr., 2 hr. 30 min), the bottom 10 cm section (57 ml) of the water column was withdrawn from the tube and the dry mass of the aliquot measured. The sediment fall height was as follows: 0.9 m for the first aliquot, 0.8 m for the second, etc. After each aliquot was removed, the fall height was reduced by 10 cm for the next aliquot taken. The aliquots were filtered using preweighed 934-AH 47 mm glass microfiber filters and a vacuum pump. The filters were then dried in an oven at 100 °C for 24 hours. They were then reweighed to determine the mass of the dry sediment on the filters. It was assumed that 100% of the sediment from the tube was retrieved and weighed. The sediment concentration in the settling tube did not exceed 0.02 kg/m³, well below the concentration at which flocs no longer settle freely due to floc aggregation. The time required for the sediment in an aliquot to settle 1 m was estimated by the following equation:

$$\text{time to settle 1 m} = \text{time elapsed since start of settling (s)} / \text{fall height of aliquot (m)}$$

where time is in minutes, fall height is the distance (in meters) the sediment in the 10 cm aliquot settled at the time of aliquot withdrawal. The percentage of sediment still in suspension after the aliquot was withdrawn was determined by the following equation:

$$\% \text{ in suspension} = (m_2 / \text{total sediment mass}) * (1 \text{ m} / \text{fall height of sediment in aliquot})$$

where m_2 is the sediment mass still in the settling tube after the aliquot was withdrawn and before the next aliquot is withdrawn. The length of the tube is divided by the fall height to determine how much sediment with the measured settling velocity of the aliquot was present in the tube at the start of the test. The time required for the particles to settle 1 m was plotted against the percentage by weight of the sample still in suspension after the aliquot was withdrawn. An Oden curve was then drawn connecting the points on the graph (Fig. 4.4). The times t_1 and t_2 are two different times along the curve. W_1 and W_2 represent the percentage by weight finer than the sizes corresponding to times t_1 and t_2 as determined by the modified version of Stokes' law.

Settling velocity vs. percent of sample still in solution was plotted. The median settling velocity was defined as the settling velocity below which 50% of the sample experienced. The modified Stokes' Law was then used to estimate the median floc size. Particles having a settling velocity greater than that predicted by the unmodified Stokes' Law for 59 μm spherical quartz particles were defined as sand. Particles smaller than 59 μm were defined as silt and clay in the form of flocs. A weighted average density of the sand and the flocs was used in the modified Stokes' Law equation to estimate the median particle size. If 16% of the sample was sand and 84% was flocs then the average would be as follows:

$$0.16 * (2.65 \text{ g/cm}^3) + 0.84 * (1.2 \text{ g/cm}^3) = 1.43 \text{ g/cm}^3.$$

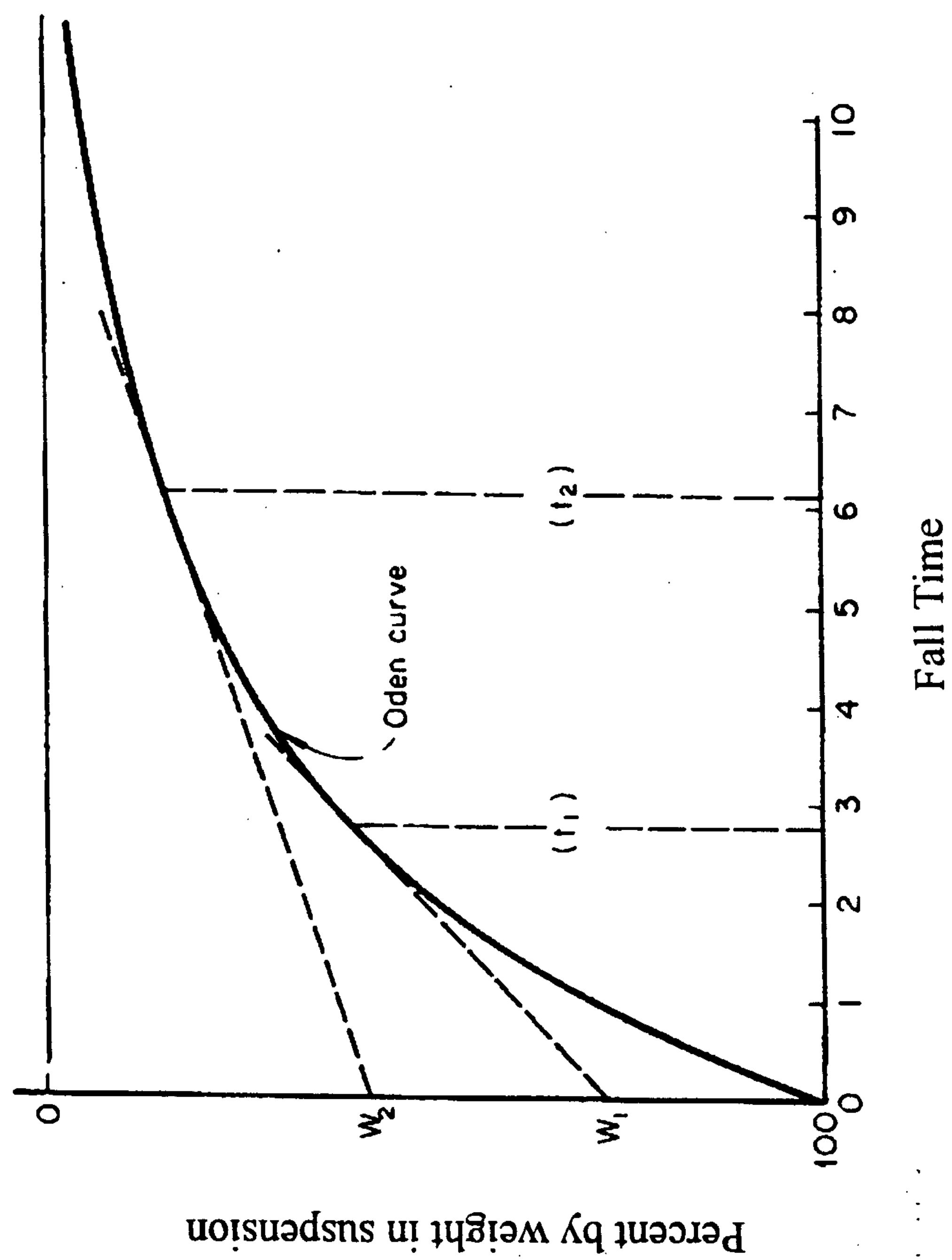


Fig. 4.4 Oden curve showing relative amount of sediment remaining in suspension with time; intersection of tangent to curve with ordinate represents percentage by weight in suspension in time.

A soil texture unit (LaMotte code 1067) was also used to estimate the sand, silt, and clay fractions of the sediment. The sediment was air dried and then ground into small particles. It was then poured into a graduated settling tube to the 15ml mark. One ml of the dispersing reagent, (two percent sodium pyrophosphate 10-hydrate) and 30 ml of deionized water was added to the sediment. The tube was capped, shaken for 2 minutes and then allowed to stand for 30 seconds to allow the sand to settle. The fluid portion was decanted, and the level of the sand recorded. It was then allowed to stand for 30 minutes for the silt to settle out. The fluid portion was again decanted. The fractions were determined as follows:

$$\text{sand \%} = \text{level of sand} / 15 \text{ ml},$$

$$\text{silt \%} = \text{level of silt} / 15 \text{ ml},$$

$$\text{clay \%} = (15 \text{ ml} - \text{level of sand} - \text{level of silt}) / 15 \text{ ml}$$

4.2.2 Organic Content

The fraction of organic matter in sediment was estimated by percent weight loss upon ignition. The sediment was first dried at 100°C for 24 hours. It was then placed in a combustion furnace and heated at 450°C for 24 hours. After the sample was combusted, it was then placed in a dessicator to cool. The sample was then weighed and the percentage of organic matter determined by the following equation:

$$\text{OC} = \frac{M_D - M_A}{M_D} \times 100\%$$

where OC is organic content, M_D is the dry weight of the sample, and M_A is the mass of the ash. The sample was not rehydrated after ignition. Four composite samples and one

entire core from both Hannah Mills Creek and Cedar Point Creek were analyzed for organic content.

4.2.3 Sediment Erodibility

Sections from the six cores with similar bulk density, some from different depths, were combined in four composites and mixed with a robber spatula to yield enough sediment to use in the particle erosion simulator (Table 4.2). Each composite was tested in the particle erosion simulator. Bulk density has been correlated with shear strength in previous studies, so combining the sections would not significantly reduce the information about sediment erodibility in the creeks.

A particle erosion simulator was used to measure critical shear stress (Tsai and Lick, 1986). It consists of a cylindrical chamber inside of which a horizontal grid oscillates vertically (Fig. 4.5). The composited sediment was placed at the bottom and overlain by water. The grid creates turbulence that generates a fluid stress at the bed surface. The period of oscillation of the grid can be increased by increasing the rotation speed of the disk to which the grid is attached by a hinged rod, increasing the force of the fluid stress. The particle erosion simulator was calibrated to a circular flume, an apparatus in which shear stress can be measured (Tsai and Lick 1986). By comparison of the sediment suspended in the circular flume at a known shear stress and suspended sediment concentrations in the particle erosion simulator at a given oscillation speed, equivalent shear stresses of the particle erosion simulator were determined. The shear stress created by the different grid oscillation frequencies was estimated to be about $0.000583 \text{ Pa/RPM} \times \text{RPM used in experiment} = \text{Pa}$ (Tsai and Lick 1986). When the stress exceeds the shear strength of the mud, sediment is suspended. During the test, 50 ml samples of water were

Table 4.2 Sediment properties of composites and composite origin

Composite	texture kit % sand	texture kit %silt + clay	% organic	median size (10^{-6} m)	median settling velocity(10^{-5} m/s)	density (kg/m ³)	dry density (kg/m ³)	M (g/N/s)	Ts (Pa)
1	12.8	70.7	16.5	24.3	6.2	1001	234.6	0.493	0.079
2	11.6	68.9	19.5	8.78	2.8	1080	263.3	-	-
3	2.2	85.3	12.5	11.5	3.2	1170	380	-	-
4	5.55	79.1	15.0	20.3	2.8	1230	340	-	> 0.175

Bulk densities of core sections from Cedar Point Creek and Hannah Mills Creek composing composites

HM is Hannah Mills Creek, CP is Cedar Point Creek

Composite 1 sections (cm)	bulk density (g/cm ³)	Composite 2 sections (cm)	bulk density (g/cm ³)	Composite 3 sections (cm)	bulk density (g/cm ³)	Composite 4 sections (cm)	bulk density (g/cm ³)
CP3 0-15.2	0.94	CP1 15.2-30.4	1.078	CP3 49.5-68.6	1.16	CP1 49.5-78.7	1.22
CP1 0-15.2	0.95	HM2 15.2-30.4	1.082	HM1 30.4-58.4	1.16	HM3 0-15.2	1.23
HM1 15.2-30.4	1.047	CP2 0-15.2	1.097	CP2 30.4-54.6	1.166	CP2 54.6-76.2	1.24
HM1 0-15.2	1.067						
average	1.001		1.086		1.162		1.23

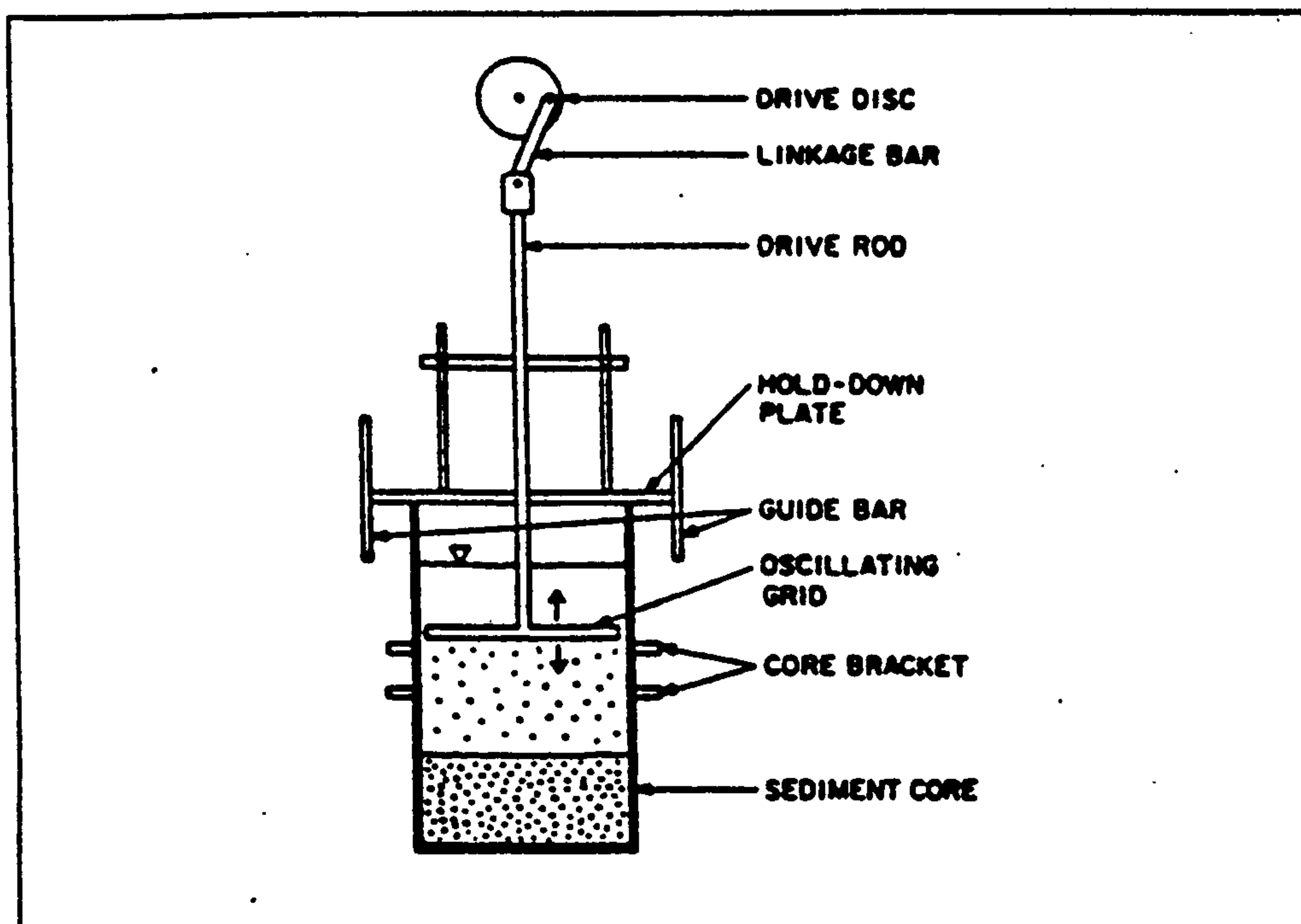


Fig. 4.5 Schematic of a vertical grid oscillator (from Tsai and Lick as reproduced by Lee and Mehta 1994)

withdrawn (50 ml of water were then added to replace the water withdrawn) and the suspended sediment concentration determined. Samples were taken every five minutes for the first 15 minutes at a specified frequency of oscillation, and then every 10 minutes thereafter until the completion of the test (45 minutes). For each test the grid oscillation began at about 100 RPM to erode any superficial sediment layer and establish a background suspended sediment concentration produced under very low shear stress. The background was subtracted from all other sediment concentrations measured. The RPM was increased at each step by an increment of 30 to 50 RPM (Table 4.3). The erosion rate was estimated using the following equation (adapted from Rodriguez, H. N. et al. 1997):

$$\frac{\Delta m}{\Delta t} = h \frac{\Delta C}{\Delta t} = M(\tau_b - \tau_c); \tau_b > \tau_c$$

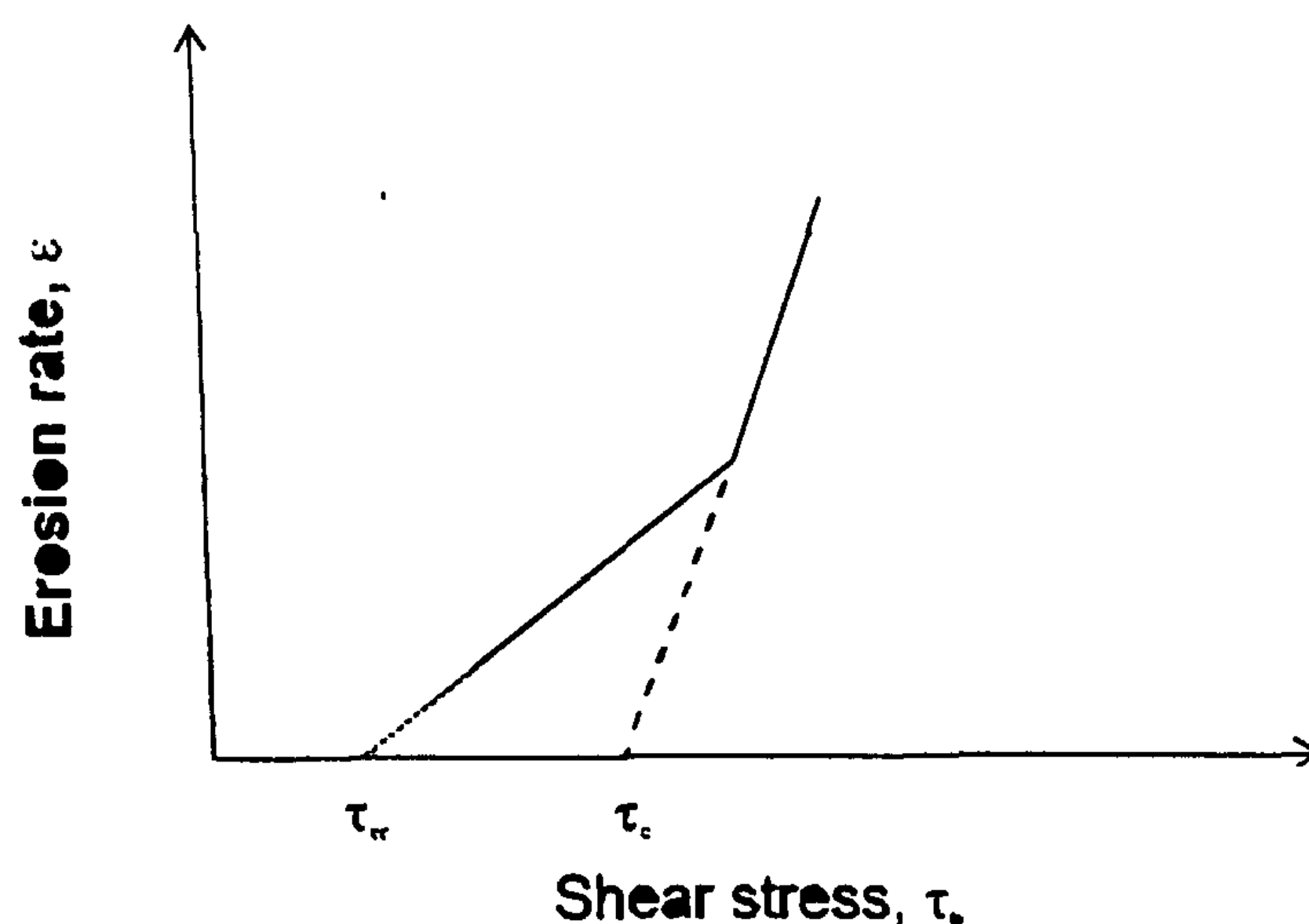
where m = the mass of the eroded sediment per unit bed area (g/m^2), t is time (s), h = depth (m) of water in the particle erosion simulator, C = measured sediment concentration (g/m^3) at the end of a period of a constant applied stress (τ_b (Pa)), M is the erosion rate constant, (g/N/s), τ_c (Pa) is the critical shear strength, and h = depth of water. The change in mass per unit time ($\Delta m/\Delta t$) is thus in units of $\text{g/m}^2/\text{s}$. The average erosion rate over a 45 minute period ($\Delta t = 2700$ s) was determined, where, ΔC is the difference in the concentration at the beginning of the 45 minute period of applied stress and the end of the period of applied stress. Forty-five minutes was the length of time beyond which no more sediment was suspended at a given oscillation frequency. The intermediate points were monitored to determine this for each oscillation frequency. The erosion rate at the end of the 45 minute period for each grid oscillation frequency is then plotted against the

Table 4.3 RPM used in particle erosion simulator tests

Composite	initial background	first step	second step	third step	fourth step
1	101	178	231	271	309
2	98	194	234	264	293
3	95	180	210	258	311
4	99	202	232	263	297

estimated bed shear stress and a best fit line drawn. The intercept of the best fit line with the x axis is assumed to be the critical shear stress necessary for erosion to begin.

The lower value, τ_{cr} , in the Fig.4.6, is the shear stress at which erosion begins at the very top surface of the sediment. This very top surface layer is extremely flocculent and requires very little force to suspend. It is the same layer that is eroded by the background run at 100 RPM. Designing channels to eliminate this erosion would be impractical; therefore, Partheniades and Paaswall (1970) suggest using τ_c as the magnitude of the critical shear stress. The shear stress at τ_c was used as the critical shear stress for the sediment in the blocked creeks.

Fig. 4.6 Definition of τ_{cr} and τ_c (adapted from Parchure, T. 1984)

4.3. Results

4.3.1 Grain Size

The median settling velocity obtained was 6.2×10^{-5} m/s (about 0.2 days/m) for Composite 1, 2.8×10^{-5} m/s for Composite 2 (about 0.4 days/m), 3.2×10^{-5} m/s (about 0.36 days/m) for Composite 3, and 2.8×10^{-5} m/s (about 0.36 days/m) for Composite 4. Settling velocity distributions for the four composites are shown in Fig. 4.7-4.10. Sand percentage by weight ($\phi > 59 \mu\text{m}$) was also estimated at about 12% for Composite 1, 8% for Composite 2, 16% for Composite 3, and 18% for Composite 4. Using an average density of the sand at 2.65 g/cm^3 and 1.2 g/cm^3 of the flocs (silt and clay), and the median settling velocity, the median particle size was estimated for four composites. The median particle size obtained from the modified Stokes' law was $24.3 \mu\text{m}$ for Composite 1, $8.78 \mu\text{m}$ for Composite 2, $11.5 \mu\text{m}$ for Composite 3, and $20.3 \mu\text{m}$ for Composite 4 (Table 4.2). Sand, silt, clay fractions determined by the soil texture unit method for the composites are shown in Table 4.2. The sediment in the creeks is mainly silt and clay. Over 30% by mass of the sediment in each composite would remain in suspension in still water for over 24 hours. There is fairly good agreement between the sand, silt, and clay fraction estimates made with the two methods.

4.3.2 Organic Content

Organic matter content estimated for the composites is shown in Table 4.2. The composites differ very little in organic content. Composite 1 has practically the same organic matter content as mud from a depth of about 0.75 m. For comparison, organic matter content of a core (not composite) from Hannah Mills Creek and one from Cedar Point Creek (Fig. 4.11) is shown. Organic matter content is quite variable, with a low of

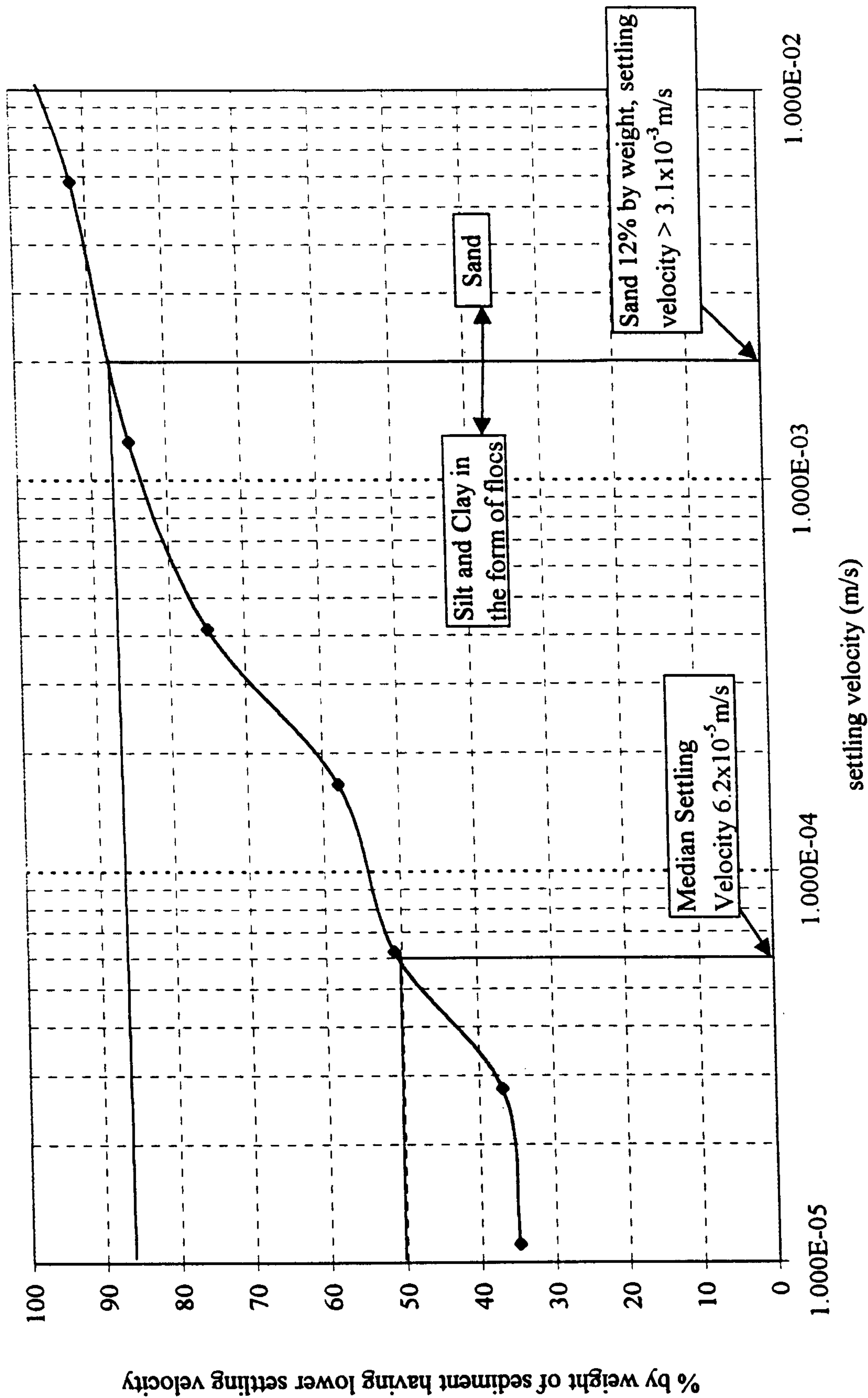


Fig. 4.7 Composite 1 flocc and sand settling velocity distribution

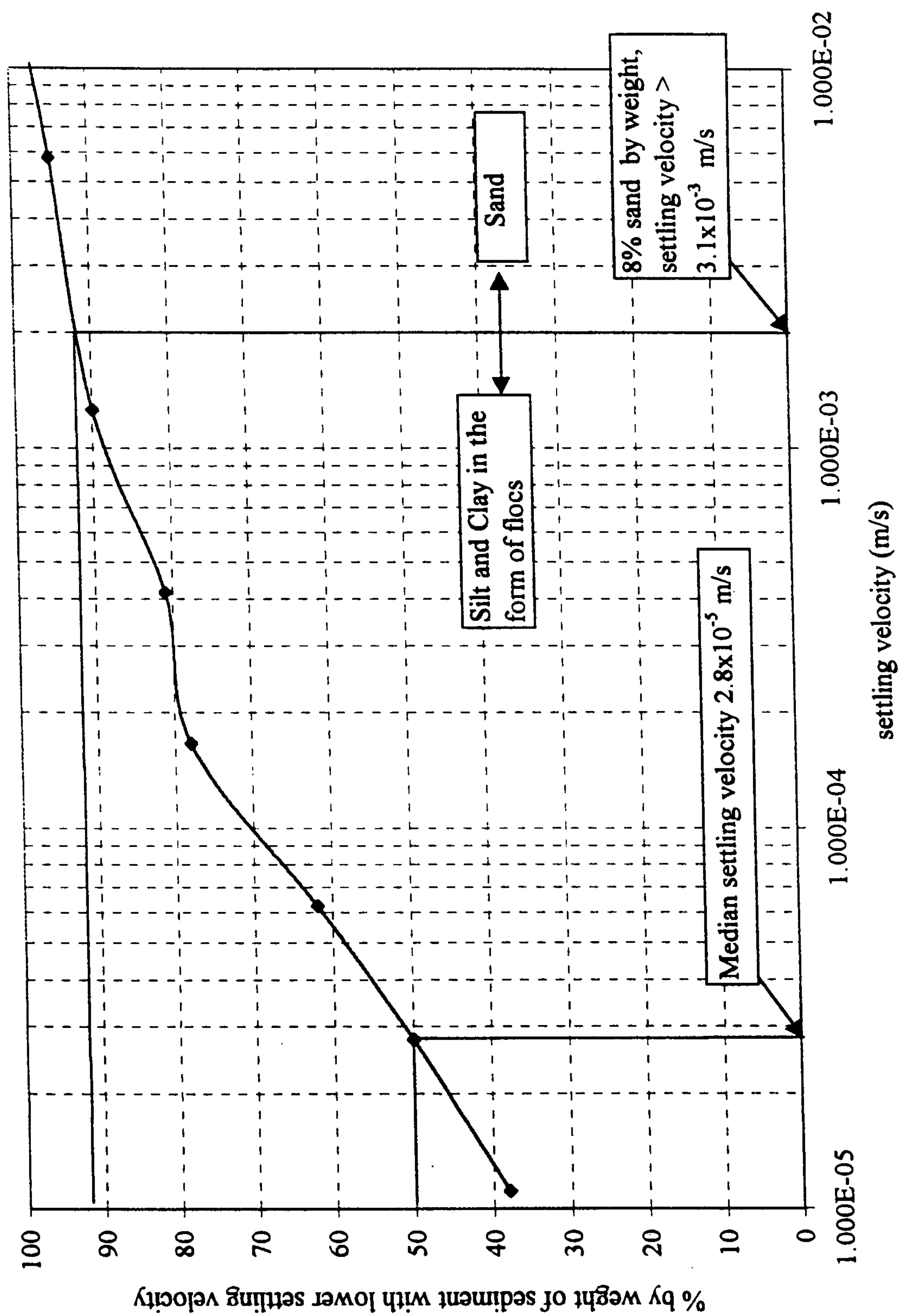


Fig. 4.8 Composite 2 floc settling velocity distribution

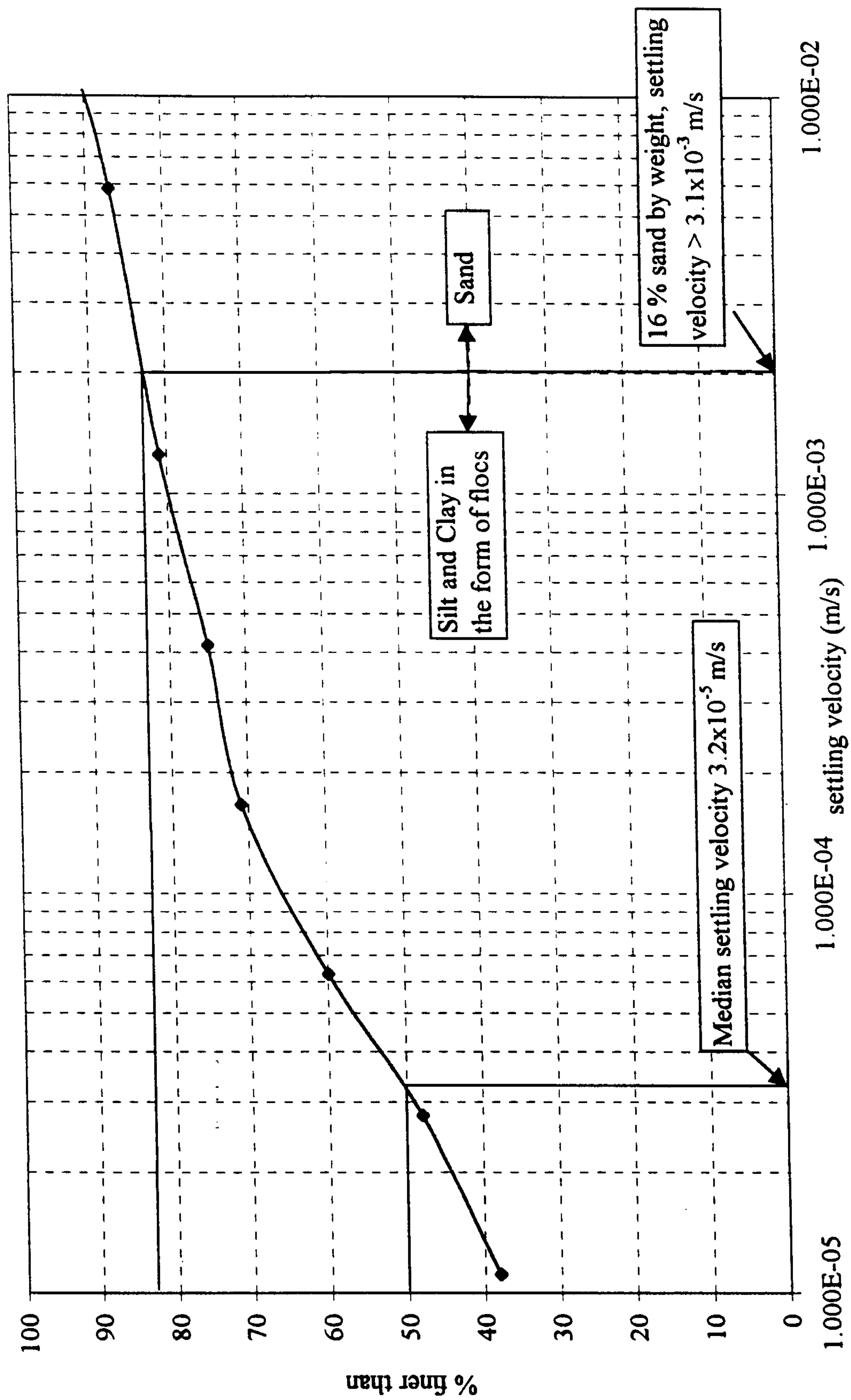


Fig. 4.9 Composite 3 settling velocity distribution

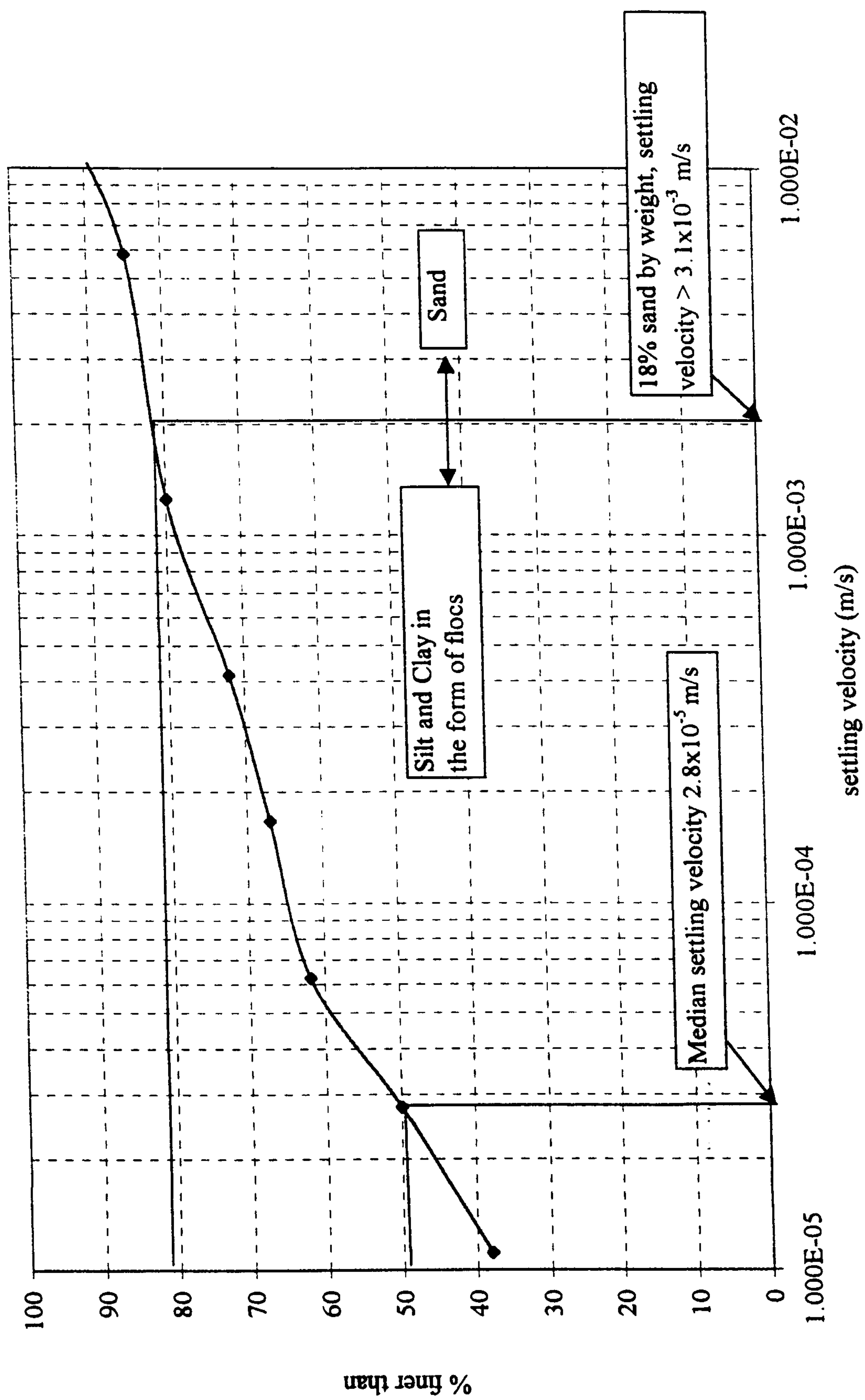


Fig. 4.10 Composite 4 settling velocity distribution

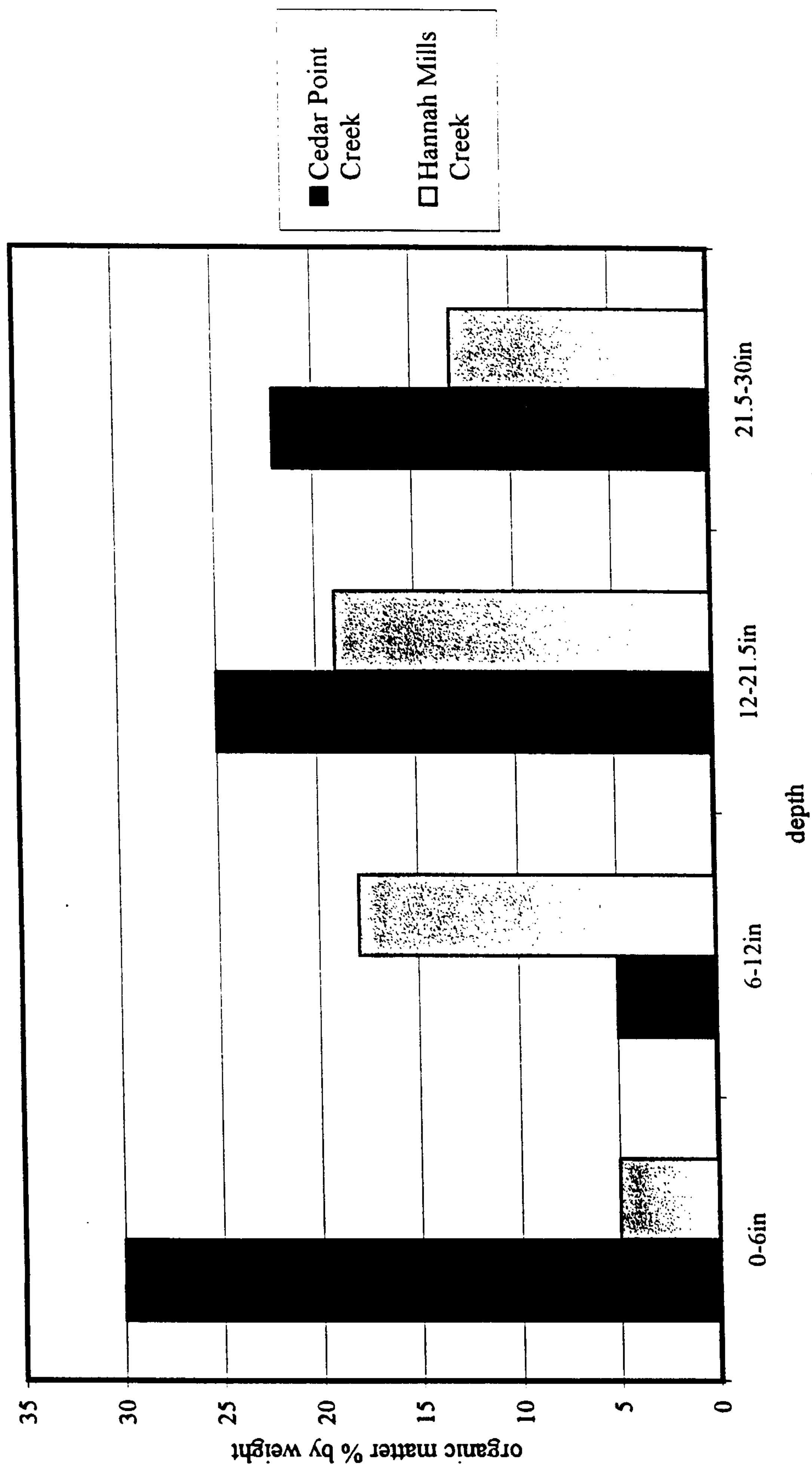


Fig. 4.11 Organic matter content of two cores (not composites) from Hannah Mills Creek and Cedar Point Creek

about 5% in each core and a high of 30% in the Cedar Point Creek core. Organic content for the composites is shown in Fig. 4.12. The composite is close to an average of the extremes in the cores. An abundance of leaf matter was seen floating in the settling tube during the settling velocity test as well.

4.3.3 Erodibility

The bulk density of the composites is shown in Table 4.2. Also see dry densities for the Pb-210 cores Fig. 3.4-3.6 in results section 3.4. These cores taken for Pb-210 dating are from the same general area of the creeks and thus give more information about the sediment shear strength in the creeks.

Forty-five minutes was usually sufficient for the sediment to reach saturation in the water column at a given oscillation frequency. The RPM's were given in Table 4.3. Sediment concentration in the water column above Composite 1 increased in a stepwise fashion with increased grid oscillation frequency (Fig. 4.13). Figure 4.14 of Composite 2 shows there was only a very slight increase in sediment concentration in the water column with increasing bed shear stress. Figure 4.15 illustrates the seemingly random scatter of increase and decrease in sediment concentration of Composite 3. Composite 4 (Fig. 4.16) was eroded very little; the superficial layer eroded during the initial background run was the great majority of sediment eroded in Composite 4. Only 0.002 g/50 ml more sediment was eroded in Composite 4 at the highest shear stress applied. The background run for Composite 4 produced a concentration of 0.0246 g/50 ml compared to 0.06 g/50 ml for the highest oscillation frequency for Composite 1, the most erodible composite. Table 4.4 lists the mass measured from the initial background runs for each composite.

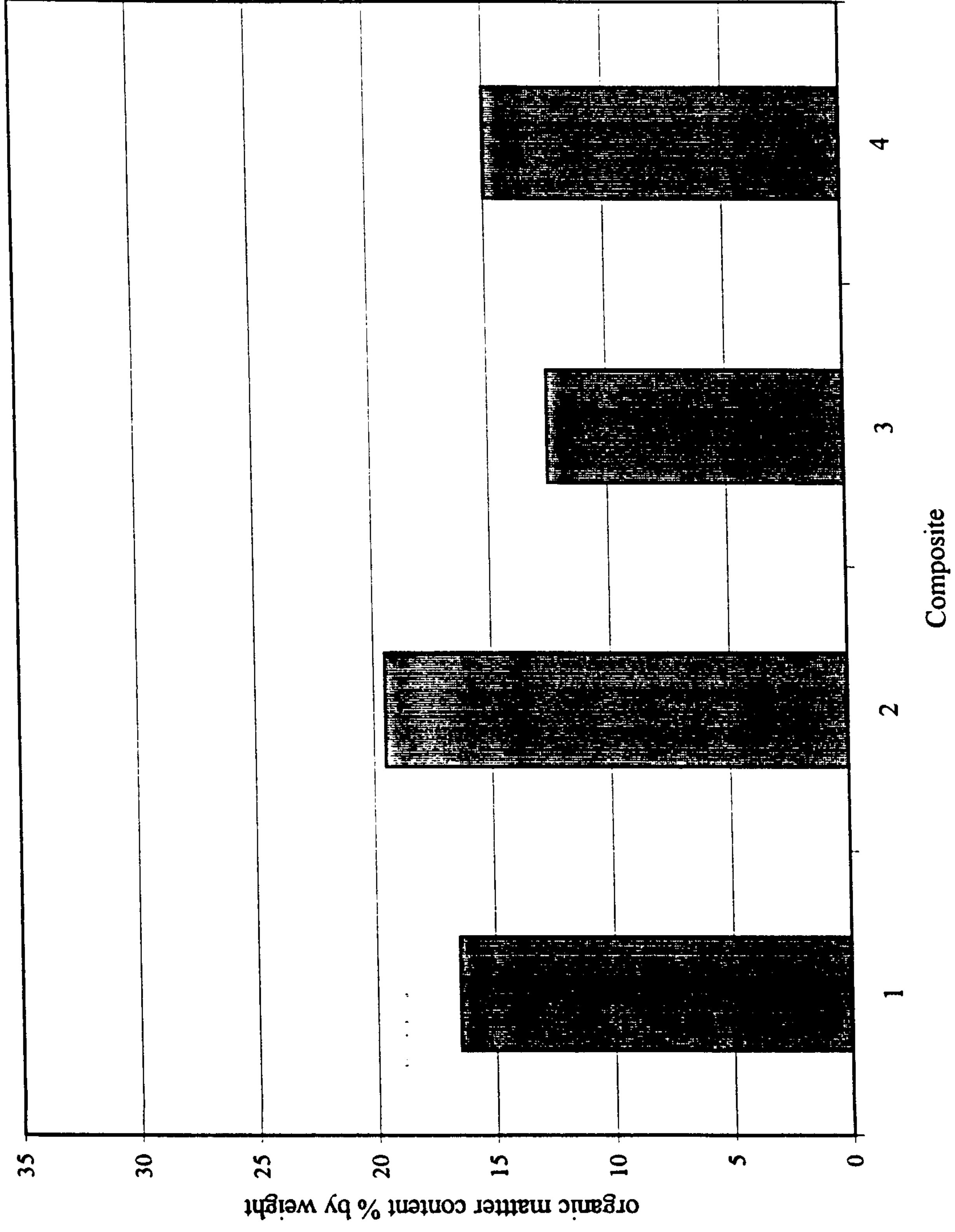


Fig. 4.12 Organic matter content of composites

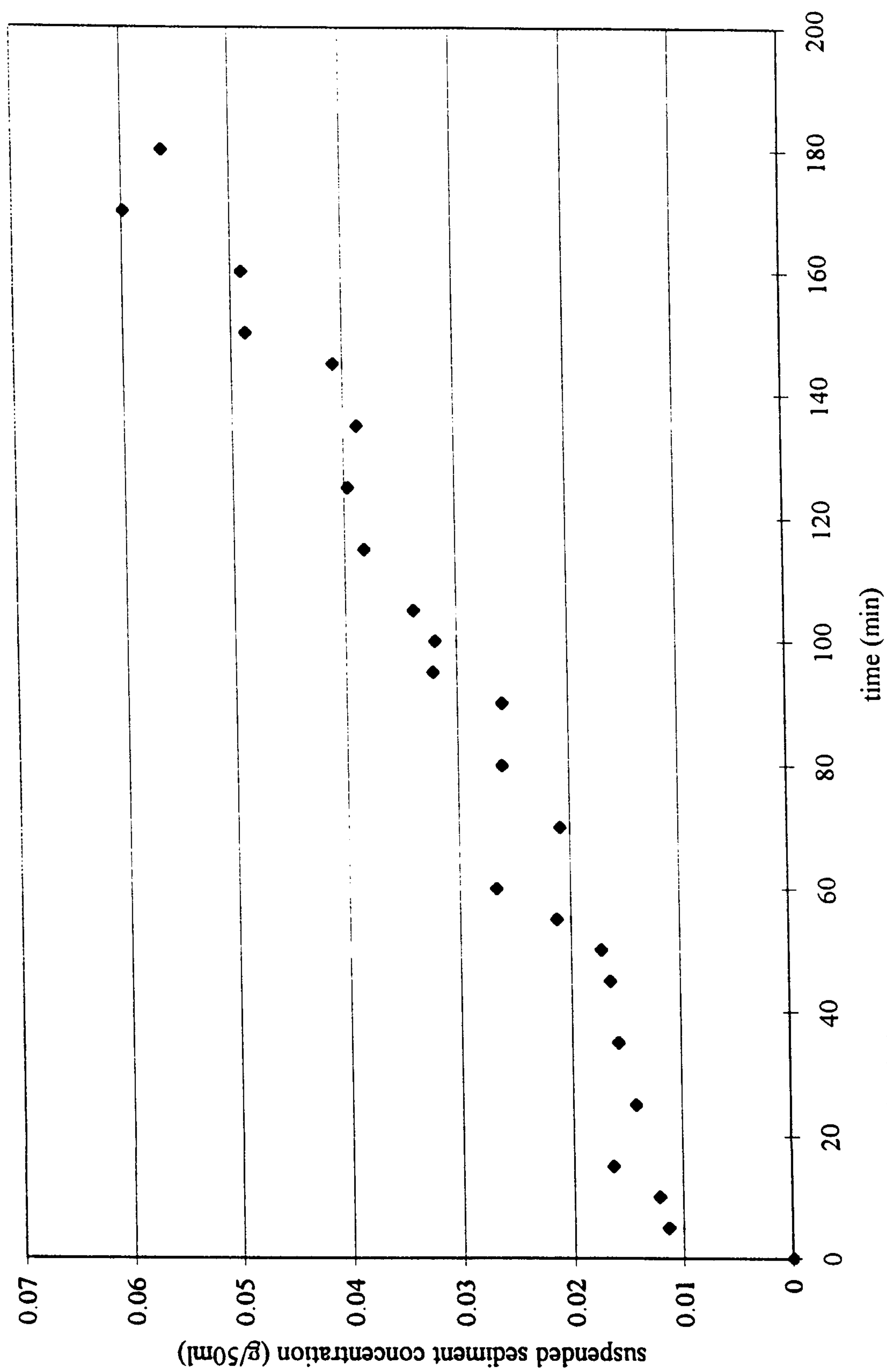


Fig. 4.13 Composite 1 time vs. suspended sediment concentration in particle erosion simulator test

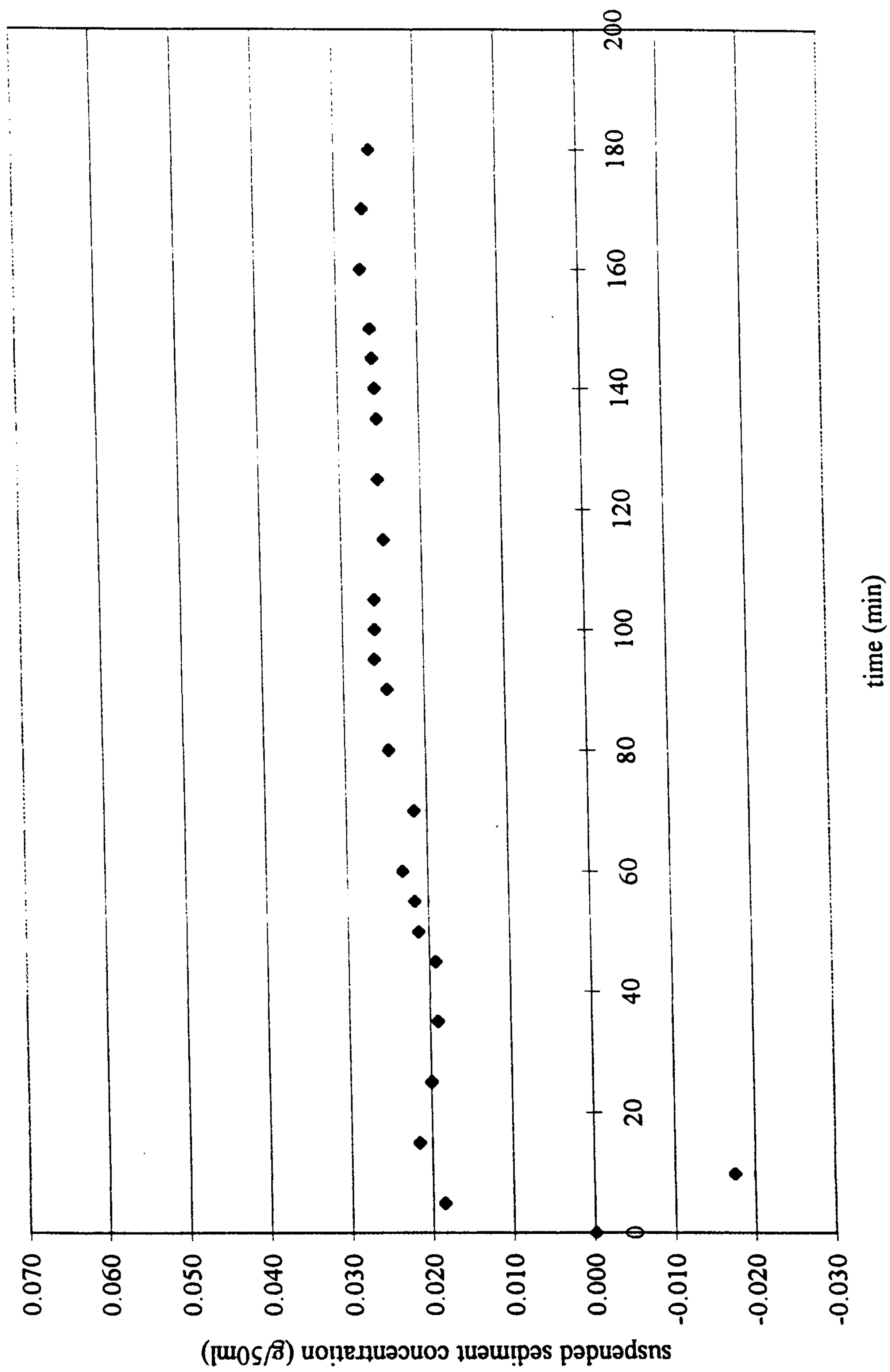


Fig. 4.14 Composite 2 time vs. suspended sediment concentrationmass for particle erosion simulator test

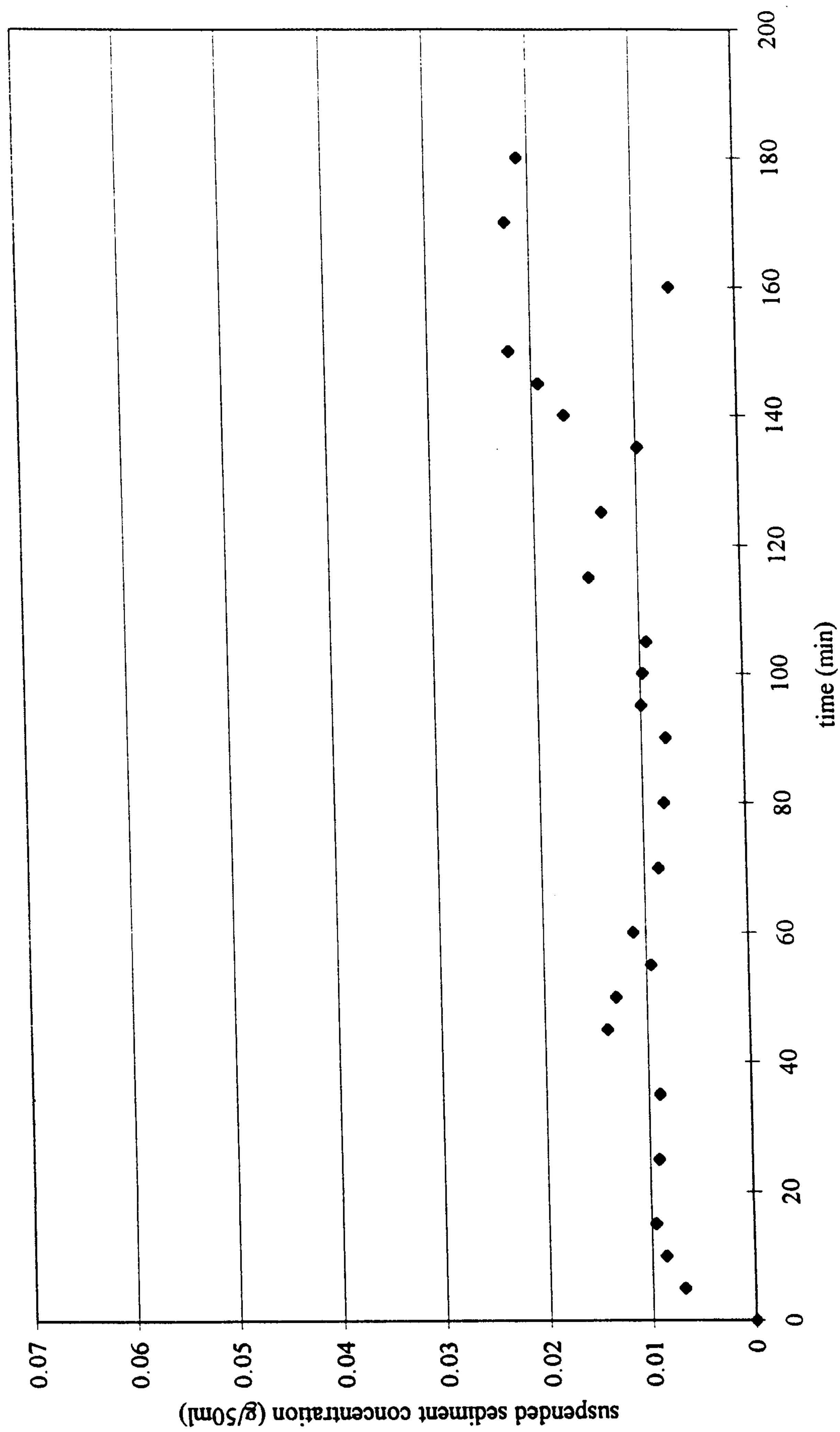


Fig. 4.15 Composite 3 time vs. suspended sediment concentration during particle erosion simulator test

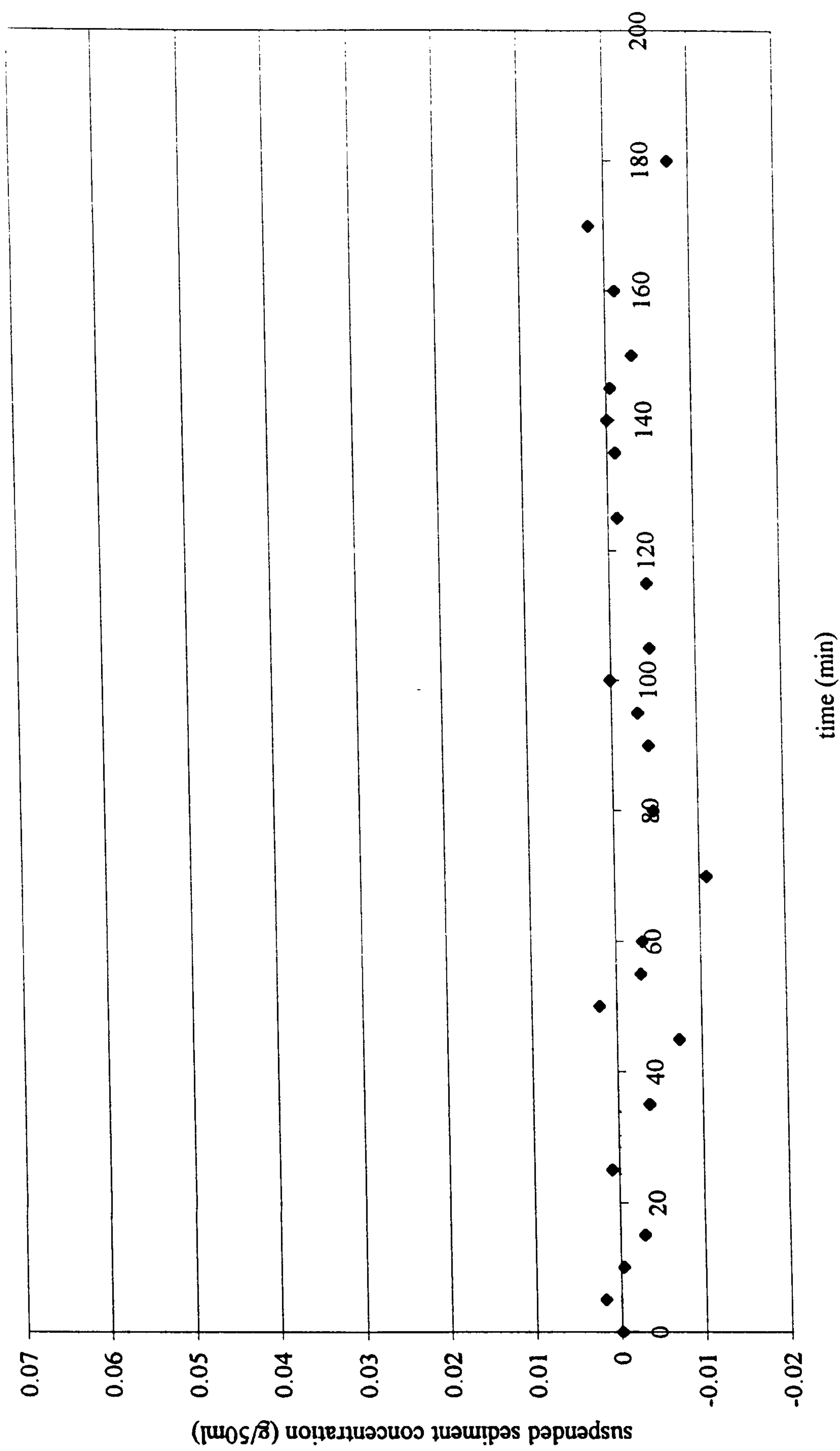


Fig. 4.16 Composite 4 time vs. suspended sediment concentration in particle erosion simulator test

Table 4.4 Initial background sediment mass/50 ml of water for particle erosion simulator test

Composite	RPM	Pa	Mass (g)
1	101	0.0599	0.0162
2	98.2	0.0583	0.0195
3	95.0	0.0564	0.0100
4	98.8	0.0587	0.0246

A best fit line through the erosion rate vs. shear stress plot (Fig. 4.17) of Composite 1 shows a linear relationship between erosion rate and shear stress, with a correlation coefficient of $R^2 = 0.95$. The estimated critical shear stress, τ_c , is 0.078 Pa. Composite 1 followed the dotted line in Fig. 4.6 to give an estimate of τ_c . The most fluid-like mud (bulk density $< 1200 \text{ kg/m}^3$) of Composite 1 has a higher estimated τ_c value than either of the other composites having higher bulk density. An examination of the mass eroded vs. time (Fig. 4.13-4.16) shows that about 3 times as much sediment of Composite 1 was suspended at the highest shear stress applied as compared to Composite 2 and 3.

A best fit line through the erosion rate vs. shear stress plot for Composite 2 (Fig. 4.18) produces a negative value for the critical shear stress with an $R^2 = 0.80$. A best fit line drawn in erosion rate vs. shear stress plot (Fig. 4.19) of Composite 3 again produces a very low estimate of critical shear stress with an $R^2 = 0.36$. Composites 2 and 3 followed the solid line in Fig. 4.6 to give an estimate of τ_{cr} . The τ_c values estimated for Composites 2 and 3 are less than the stress applied by the background runs at 100 RPM (0.06 Pa) for Composite 2 and 3. Composite 3 and 4 were the least erodible. The linear relationship between erosion and grid oscillation frequency was poor for Composites 3 and nonexistent for Composite 4.

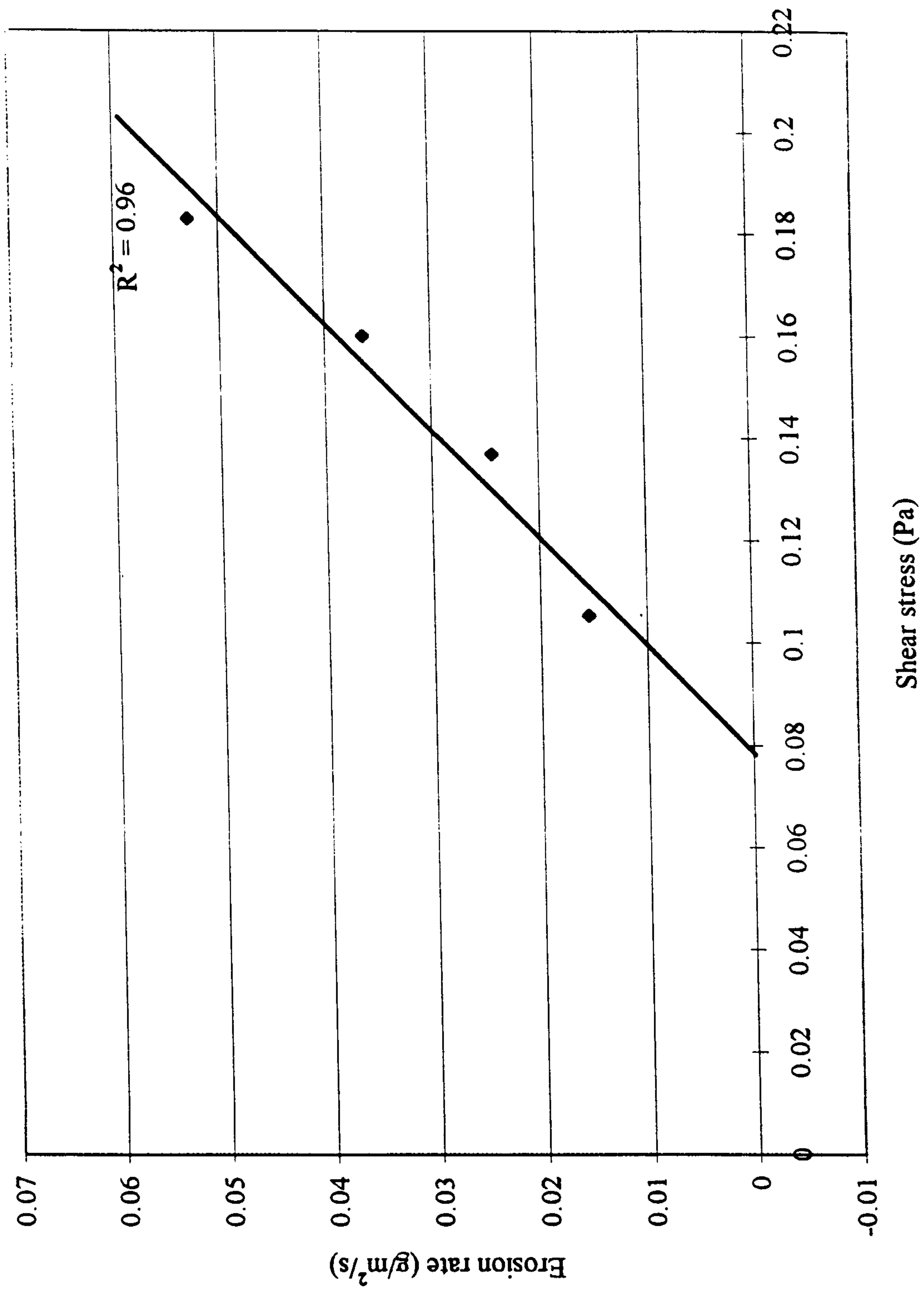


Fig. 4.17 Composite 1 shear stress vs. erosion rate

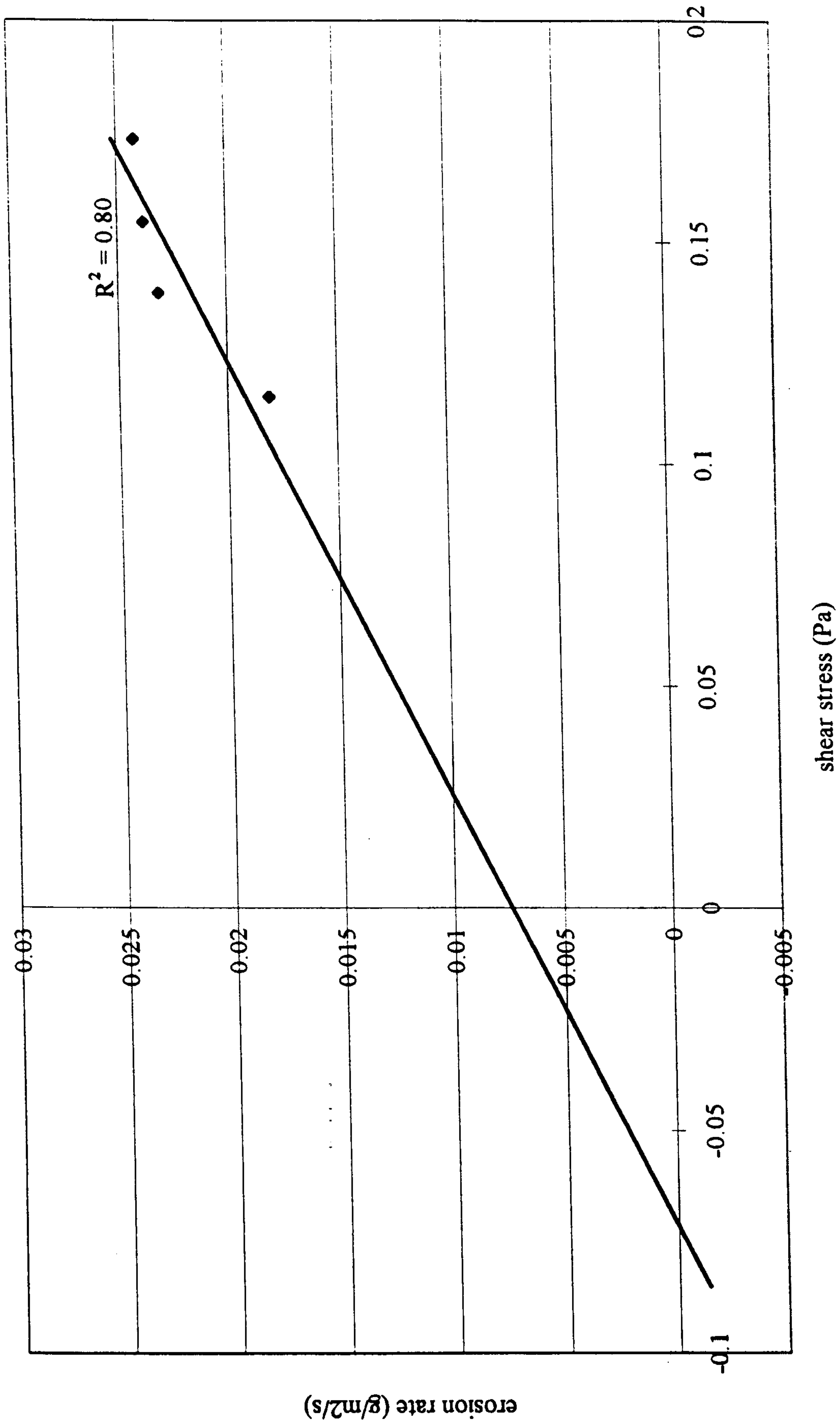


Fig. 4.18 Composite 2 shear stress vs. erosion rate for particle erosion simulator test

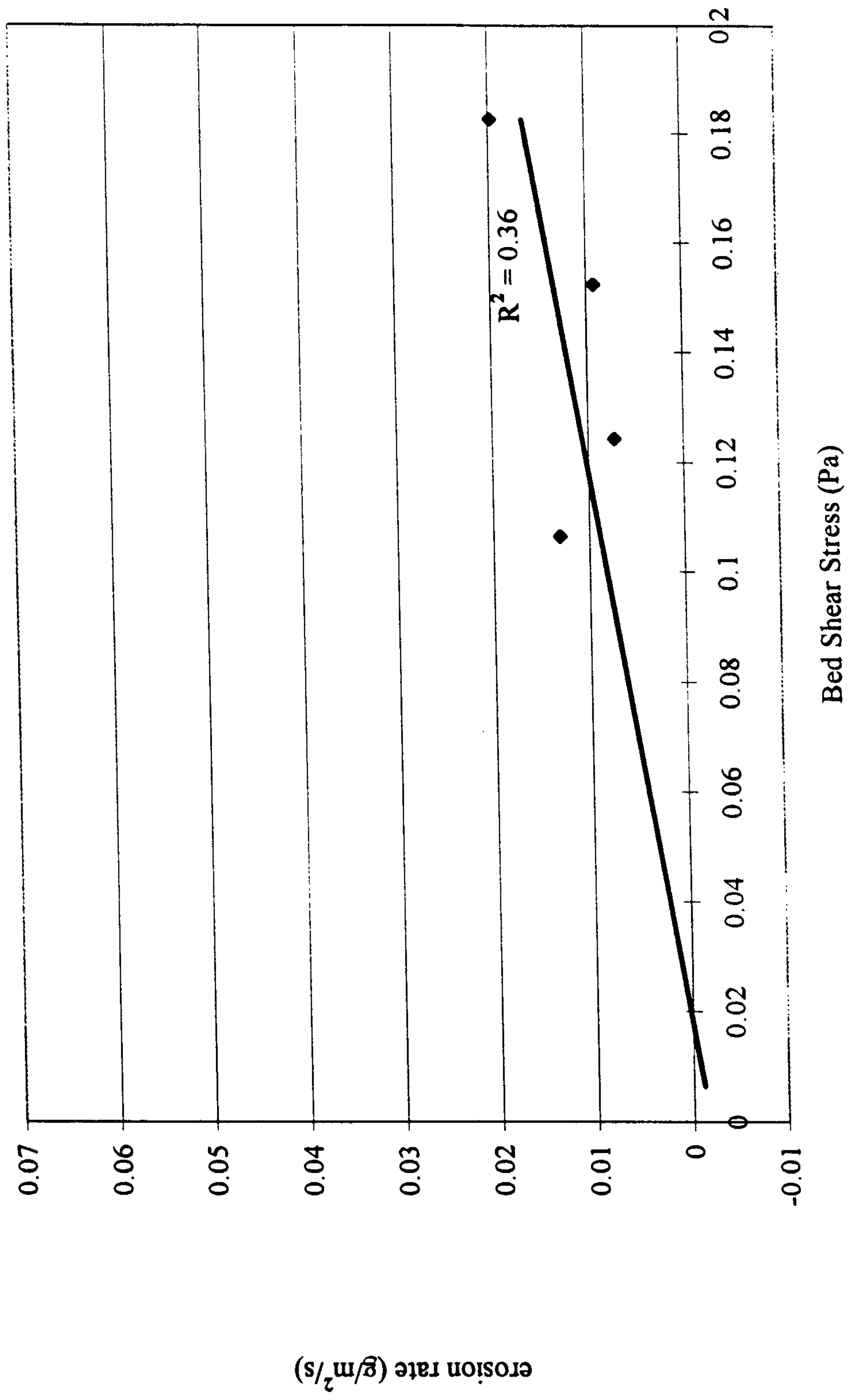


Fig. 4.19 Composite 3 shear stress vs. erosion rate for particle erosion simulator test

4.4 Discussion

4.4.1 Grain Size

Microflocs are the predominant type of sediment found in the composites. If tidal flow to the blocked creeks is restored by the removal of Hecksher Dr. the microflocs could resuspend. Any sorbed contaminants could then be carried to other parts of the St. Johns estuary. Sediment in the creeks has a high potential for contaminant sorption because of the high surface area to mass ratio of most of the sediment. The long residence time (about 40% of the composites by weight had a settling ≥ 1 day/m) also increases the potential for the sediment and its sorbed pollution to be transported to other locations of the St. Johns River estuary.

4.4.2 Organic Content

The high organic content (up to about 30% for the uncomposited Hannah Mills Creek core) of the Hannah Mills Creek and Cedar Point Creek composited sediment suggest a high potential for contaminant adsorption (sections 4.1.1 and 4.1.2). In addition, sub-sediment-surface bubbles may form with high organic matter (Montague 1986). Bubbles can reduce the shear strength of sediment, increasing the likelihood that any sorbed contaminants on the sediment could threaten organisms in the St. Johns River. Organic content estimated in Hannah Mills and Cedar Point Creek sediment is similar to that found for salt marshes in southern New England. Salt marshes of the tidal Rowley River in the estuary of Plum Island Sound, Massachusetts, had an average sediment organic content minus root mass (estimated by weight loss upon ignition without rehydration and subsequent drying) of 23% in the *Spartina alterniflora* sites and 31% in the *Spartina patens* sites (Schmitt, C. 1998). This is similar to some of the values

estimated for Hannah Mills and Cedar Point Creek sediment. At another salt marsh in New England, organic content (estimated by weight loss upon ignition without rehydration and subsequent drying) was found to be c. 25% (Orson et al. , 1998). At a salt marsh in South Carolina, an organic content of 20% was found (Vogel 1997). These observations of high organic content in salt marsh sediment lend support to similar findings in the blocked creeks of this study.

Given the fairly high organic content, the sediment in the creeks has a high potential for contaminant sorption and chelation. Six to eight percent of Pb entering an experimentally enriched salt marsh in the southeastern United States was taken up by *Spartina alterniflora* (Banus et al. 1975). The leaf matter seen in the settling tube reported in section 4.3.2 may have contained metals as well. A high correlation between organic content and metal contamination in Louisiana sediment was found, while no correlation was found between the silt and clay fraction of the sediment and metal contamination (Feijtel, et. al. 1988). If the sediment in Hannah Mills Creek and Cedar Point Creek is released into the St. Johns River it is likely to sorb contaminants in the river and expose them to sediment consumers.

4.4.3 Erodibility

The estimated τ_c values for Composites 2 and 3 are closer to what one would expect for τ_{cr} , the shear stress that begins to erode the superficial layer of the background. Mainly the superficial layer of flocculent, unconsolidated material at the surface of Composites 2, 3, and 4 was eroded. It is the erodibility of the more consolidated sediment that is of interest. Including the eroded superficial layer of Composites 2 and 3 in the graph of eroded sediment mass/50 ml vs. shear stress (Fig. 4.14 and 4.15) caused a

departure from the linear relationship between the bed sediment erosion rate and the applied shear stress. This resulted in an estimate of τ_c for Composites 2 and 3 smaller than the estimate of τ_c for the fluid mud layer of Composite 1. The shear stresses applied to Composites 2, 3 and 4 were not great enough to erode much more than was eroded in the background run at 0.06 Pa. The particle erosion simulator cannot produce high enough shear stresses to reproduce the dotted line in Fig. 4.6 to estimate τ_c for the more consolidated sediments of Composites 2, 3, and 4.

Mehta (1991) has proposed an equation for estimating shear strength for bay muds, expressed as:

$$\tau_s = 1.65 \phi \text{ (N/m}^2\text{)}$$

where the solids volume fraction $\phi = \rho_D(\text{g/cm}^3) / g_d(\text{g/cm}^3)$, where ρ_D is dry density (oven dried (100°C) mass of sediment/wet volume), and g_d is the equivalent quartz crystal density of the sediment. Assuming a dry density of Composite 1, 0.235 g/cm³, and g_d equals that of quartz, 2.65 g/cm³, the estimated τ_s is 0.15 Pa., close to that of 0.078 Pa estimated with the particle erosion simulator. Assuming the dry density, ρ_D , is 0.370 g/cm³, ϕ would be 0.14 and $\tau_s = 0.23$ Pa. The dry density of 0.370 g/cm³ is similar to the dry density of Composites 3 and 4; thus these composites are likely to have shear strengths of around 0.23 Pa. This estimate supports the finding that the critical shear strength of Composites 3 and 4 is greater than could be estimated by the particle erosion simulator because it could not generate high enough shear stresses to erode the sediment in these composites.

A comparable situation to that of the creeks blocked by Heckscher Dr. occurred near San Francisco Bay. Breaching of the Sonoma Baylands Pilot Unit levee, which separated a tidal wetland from a channel connected to the San Francisco Bay, was considered. Figure 4.20 shows the bed shear stresses determined by a model that predicted tidal inlet velocity. Shear strength of the mud was estimated using Mehta's (1991) relation between sediment density and shear strength. Figure 4.21 shows depths over which erosion is likely to occur in the Pilot Unit (Goodwin, P et al. 1995). A channel is likely to form at the breach of the levee, where the shear stresses are highest. A similar pattern of erosion may occur in the creeks if their barrier, Heckscher Dr., is removed. The wet bulk density of the mud in the Pilot Unit wetland ranged from 1.06 at the bed surface to 1.45 kg/l at a depth of 1m whereas the mud of Cedar Point Creek and Hannah Mills Creek ranged from 1.0 at the creek bed surface to only 1.22 kg/l at a depth of 0.75 m. Thus if Heckscher Dr. is removed, the creeks may erode to greater depths than the Pilot Unit if shear stresses similar to those shown in Fig. 4.20 are applied.

The shear forces that will act on the creek sediment if Heckscher Dr. is removed are not known. The shear forces depend on current velocity, and wave motion (A. J. Mehta and Y. Li, lecture notes):

$$\tau_b = \begin{cases} \frac{1}{2} f_w \rho u_b^2 & \text{(for wave motion)} \\ \frac{1}{2} f_c \rho U^2 & \text{(for current)} \end{cases}$$

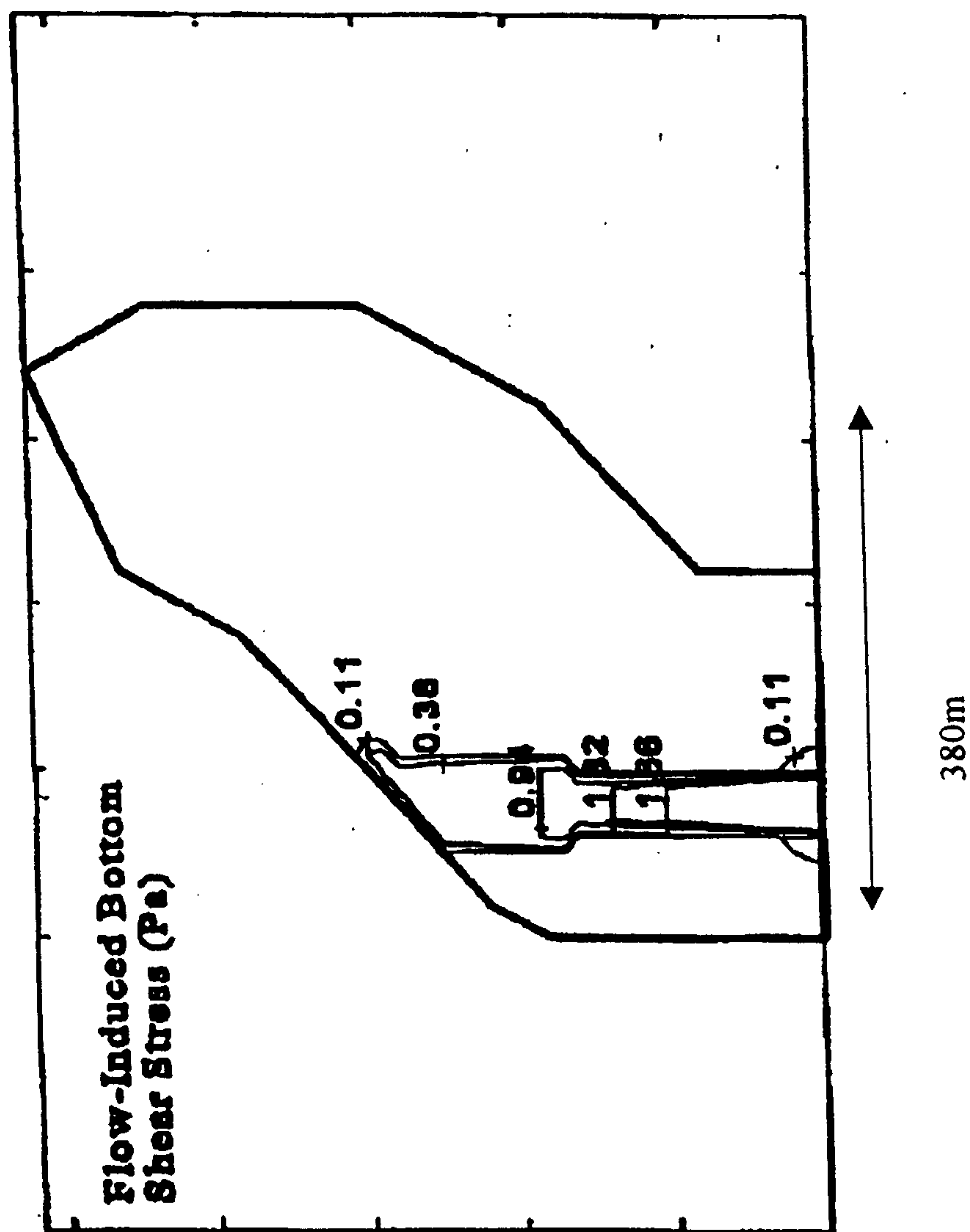


Fig. 4.20 Simplified version of bed shear stress distribution in the Pilot Unit with no pesninsulas (Adapted from Goodwin, P. et al. 1995)

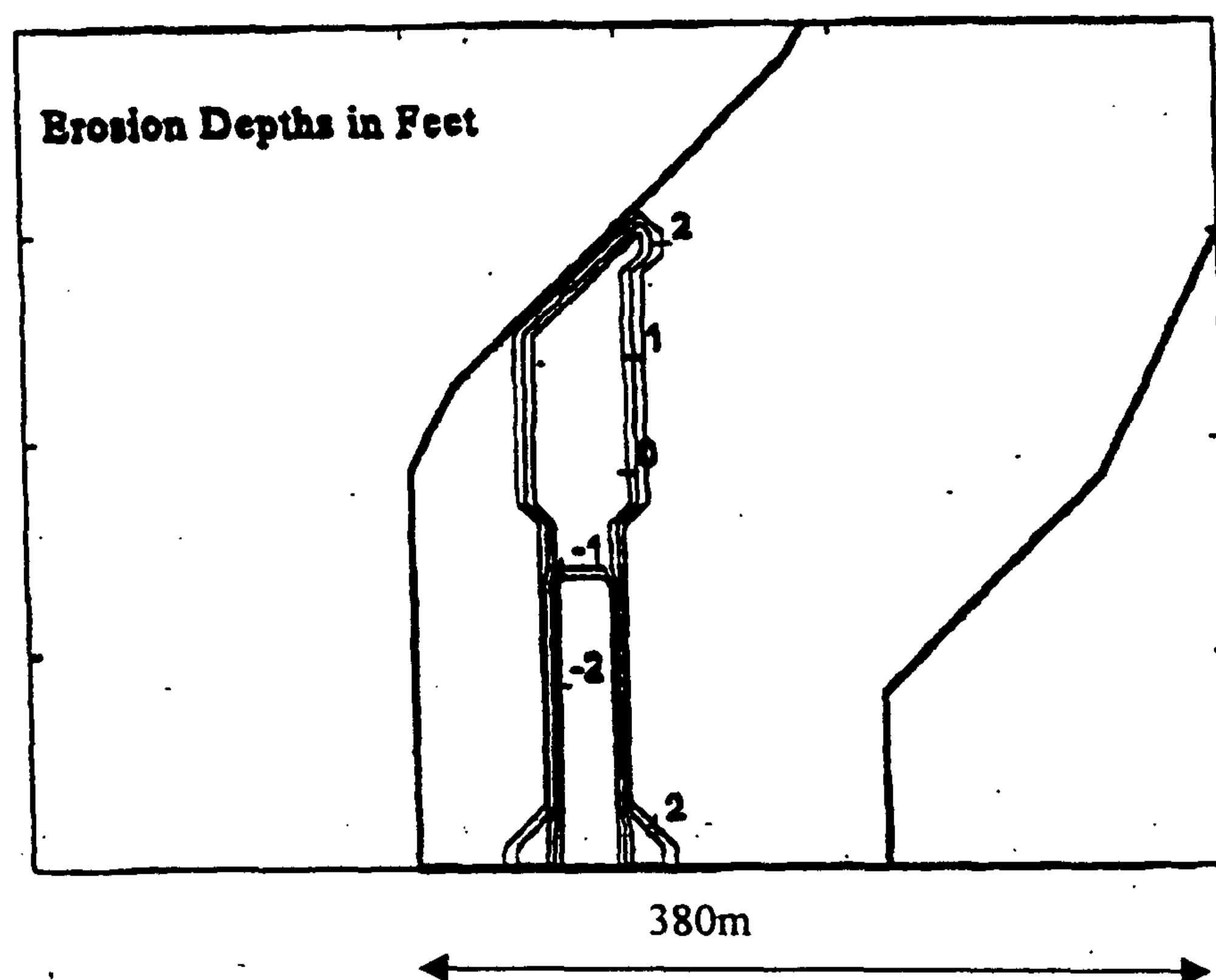


Fig. 4.21 Simplified analysis of bed erosion depth distribution in the Pilot Unit with no peninsulas. (Taken from Goodwin, P. et al. 1995)

where u_b is the amplitude of the bottom horizontal velocity under wave motion, f_w is the wave friction coefficient (Johnson, 1966), U is the depth averaged current velocity, ρ is the fluid density, f_c is the current friction coefficient, which is expressed as (Vanoni, 1975):

$$f_c = 2g \frac{n^2}{h^{1/3}}$$

where n is the Manning's bed resistance coefficient, and h is the water depth.

An estimate of the possible shear forces in the creek after removal of Heckscher Dr. can be made with these equations. Taking h to be 3 m, f_w to be 0.015, the water density to be 1030 kg/m³, and u_b of waves with a period of 6 seconds and a height of 0.3 m to be 1 m/s, the shear stress caused by waves is approximately 0.3 Pa. Current velocities greater than 0.3 m/s are not common in Florida (A. J. Mehta, personal communication). The shear stress from the current, taking n to be 0.02, U to be 0.3 m/s, and f_c to be 0.05, is about 0.25 Pa. Combined, the wave and current shear stress will create 0.55 Pa. This represents conditions likely during a thunderstorm, possibly in addition to a high tide giving a slope to the water. This may be a bit conservative, since the water depth is only about 2.5 m deep during most high tides. In shallower water, waves would have a greater force on the sediment bed. It is likely that the sediment, with a probable shear strength around 0.2 Pa down to a depth of 0.75 m, will erode into the St. Johns River if reconnection is established.

4.4.4 Sediment Resuspension and Transport

Sediment resuspension is dependent on many variables: grain size, sediment particle density, settling velocity, wave height and frequency, current speed, shear strength of the sediment, among others. A. J. Mehta and Yigong Li have developed a one

dimensional vertical suspension transport model (Appendix C). The following argument may apply to the sediments in Hannah Mills Creek and Cedar Point Creek after Heckscher Dr. is removed: Assuming a bulk density of 1270 kg/m^3 , a particle grain density of 2.65 g/cm^3 , a median free settling velocity of $2.15 \times 10^{-5} \text{ m/s}$, a mean current velocity of 0.3 m/s , a wave height of 0.3 m , and a wave period of 6 seconds, the suspended sediment profile over water depth during a storm was simulated using Mehta and Li's transport model. Bulk densities between 1200 and 1300 kg/m^3 can be treated either as fluid mud or a sediment bed. Figure 4.22 shows the results of the fluid mud option of the program (critical solids volume fraction below which mud has a fluid like consistency (bulk density $< 1200 \text{ kg/m}^3$)). Notice the higher concentration close to the sediment bed. The lift force decreases rapidly in magnitude away from the bed as the velocity and pressure gradients become less (Knighton, 1998). Figure 4.23 shows the results of the bed option (bulk density $> 1200 \text{ kg/m}^3$). Notice the concentration is lower than in the fluid mud option.

The average concentration of suspended sediment over water depth, 40 mg/l , for the bed option is similar to that measured at the headwaters of a marsh in Georgia during a storm (Fig. 4.24). Note the sharp increase in suspended sediment concentration during the thunderstorm. In a marsh tidal channel in Kiawah Island, S. C., greater sediment concentrations were measured during summer, $10\text{-}200 \text{ mg/l}$ from July to August 1977, than in winter, March 1977, $6\text{-}50 \text{ mg/l}$. This was attributed to greater biological activity and more frequent storms during the summer. Waves and large tidal prisms combined were found to be required for maximum transport (Ward 1981). Wind induced waves, as in thunderstorms, are effective in scour and resuspension of clayey sediment which can then be removed by gentle tidal currents. Current velocities are usually slow in the

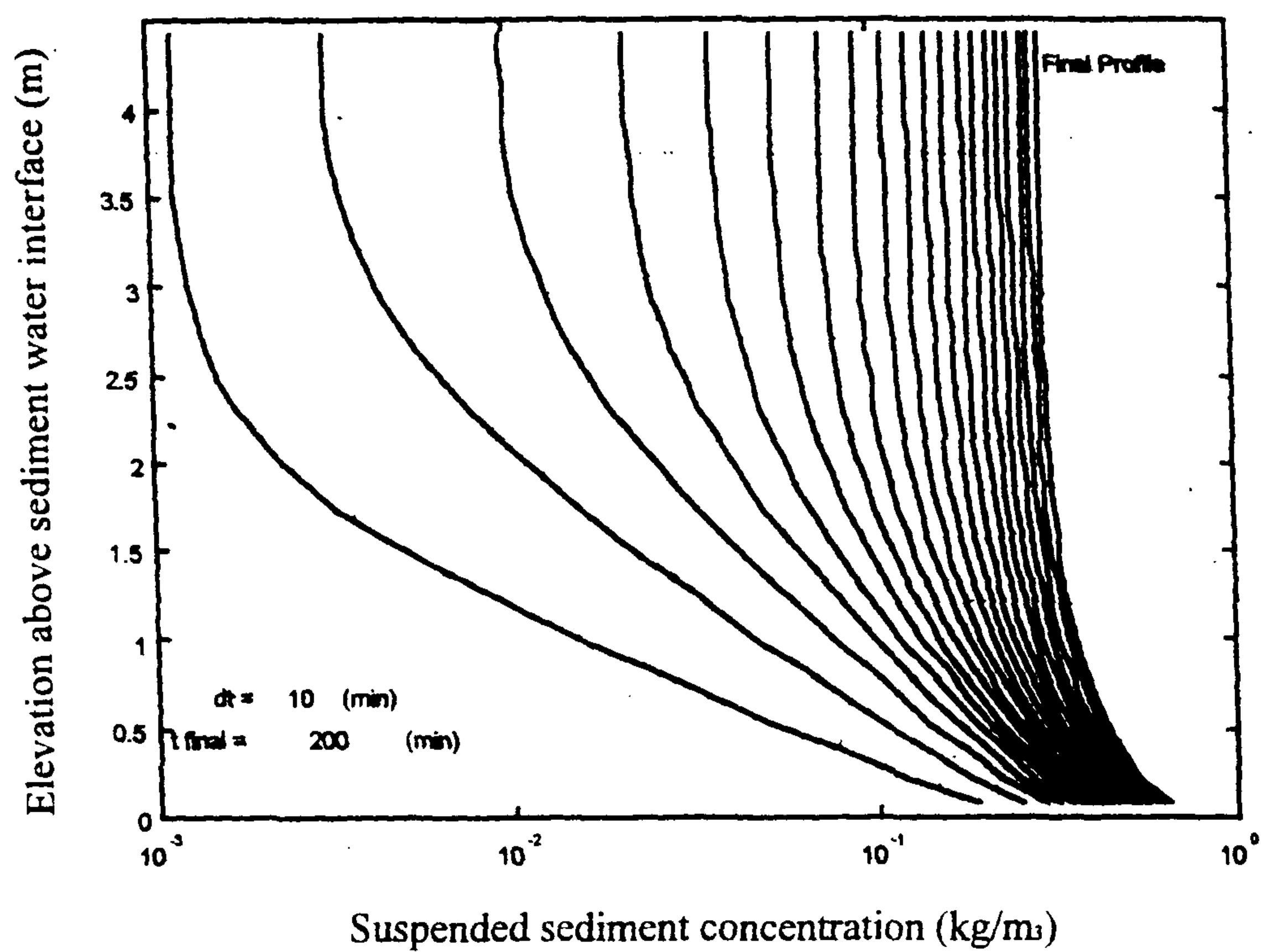


Fig. 4.22 Concentration profile evolution for fluid mud under waves plus a weak current. At $t=0$, the concentration in the water column is zero. The first curve on the left is for $t=10$ min. Curves of increasing concentrations are in 10 min increments.

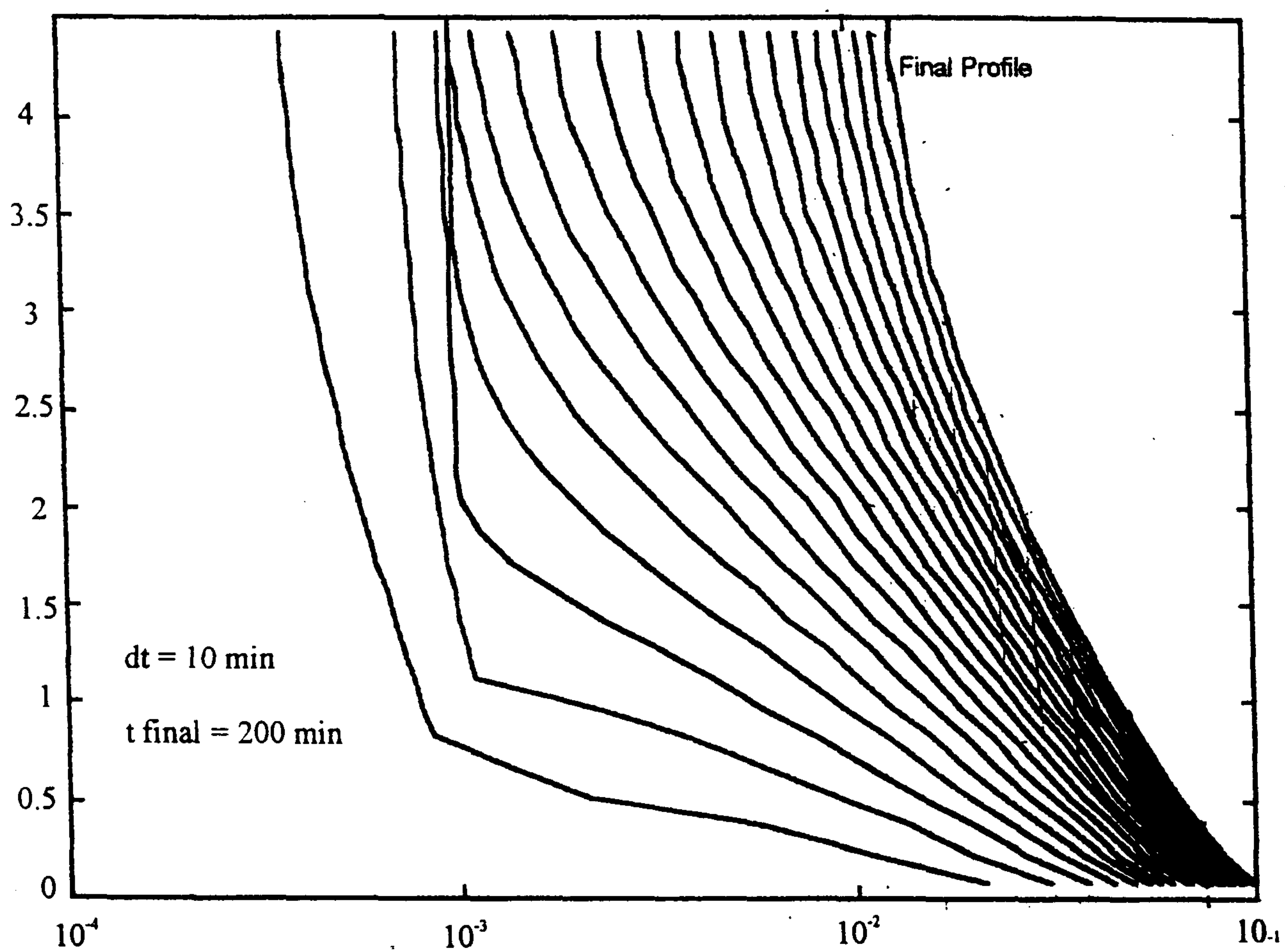


Fig. 4.23 Suspended sediment concentration profile evolution for bed sediment under waves plus a weak current. Suspended sediment concentration is zero at $t=0$. The first curve to the left is at $t=10$ min; each curve thereafter is at 10 minute increments.

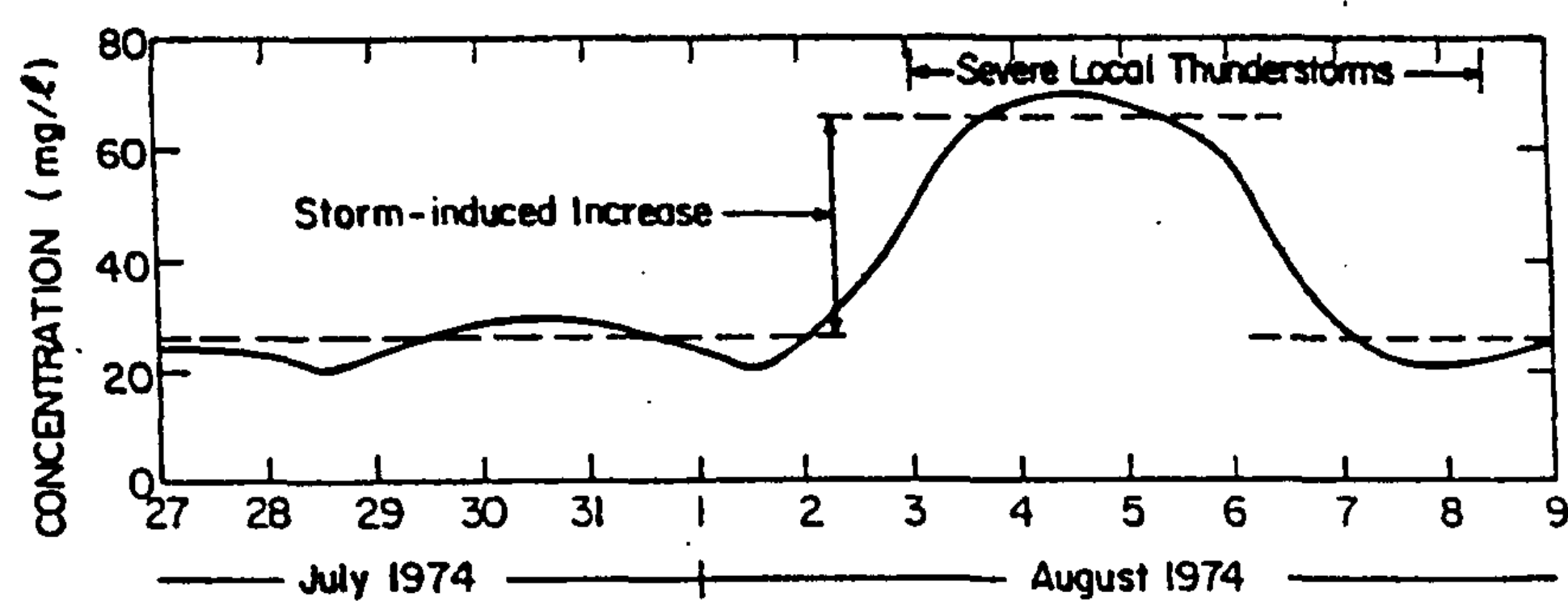


Fig. 4.24 Daily mean sediment concentrations near the headwaters of a tidal marsh at low tide (Taken from Oertel, 1976)

meandering marsh tidal creeks; they are more significant in terms of their competence for transporting clayey sediment suspended by wave action than for their ability to suspend sediment per se (Letzch, et al. 1980). A concentration profile similar to those measured above and that predicted by the model may occur in the creeks if Heckscher Dr. is removed. This can be used to predict export rates of sediment out of the creeks once Heckscher Dr. is removed.

Once the sediment is suspended in the creeks, its direction of transport depends on tidal currents. Sediment transport in tidal creeks depends not only upon the shear strength of the sediment, but also on the strength and direction of flow patterns resulting from the interaction of tidal stage and marsh topography. Tidal waves become asymmetrical in estuaries; the ebb and flood current velocities, duration of flow, and areas under the ebb and flood curves on a time-velocity graph are rarely equal (Trenhaile, 1997). This inequality in erosive force results in a net movement of sediment in one direction, either landward or seaward.

Tidal asymmetry can be expressed in terms of differences in peak ebb and flow current velocities and in the duration of the ebb and flood flows. When the tidal amplitude is a significant proportion of the mean water depth, the crest of the wave travels in deeper water than the trough. The crest tends to travel faster than the trough in front of it, because of bottom friction slowing the trough, and so overtakes it, producing an asymmetrical wave of reduced duration of flood with higher current velocities and lengthened duration of ebb with lower current velocities (Trenhaile, 1997). When the area submerged by water in an estuary increases non-linearly with tidal height due to large flat intertidal areas, e.g., low marsh and tidal flats, flood tide duration increases and ebb

current dominance may be produced (Lincoln, et al. 1988). The creeks in the Timucuan Ecological and Historic Preserve are probably ebb dominant because of the large area of low marsh in the area. Unequal ebb and flood current velocities also can be the result of mixing of river and ocean water, coriolis deflection, and flow separation into distinct channels.

Tidal asymmetry can be represented as the non-linear growth of harmonics of the principal ocean astronomical constituents. Harmonic growth is the result of amplitude effects entering through friction, non-linear advection, and interactions with channel geometry as the tide oscillates within the estuary (Aubrey and Speer, 1985). Most of the variance in shallow water tidal curves can be attributed to differences in the amplitude and phase of the M_2 and M_4 constituents (M denotes lunar origin, subscripts denote the number of daily oscillations) (Trenhaile 1997).

Some channels in salt marshes can be flood dominant and others ebb dominant due to complex changes in water elevation over the tidal cycles (Ashley, 1988). In some areas water still flows out after low water has passed; water in the incoming tide follows the path of least resistance, cutting channels not taken by the outgoing water. This creates a variety of mutually evasive ebb and flood dominant channels (Trenhaile 1997). It is thus difficult to predict whether a channel will be flood or ebb dominant, though there may be a general trend in an area.

The great majority of studied marshes in the southeastern United States are ebb tide dominant (Stevenson, 1988). Presumably the large area of low *S. alterniflora* salt marsh in the southeastern United States is the cause of this asymmetry. Thus Hannah Mills Creek and Cedar Point Creek are likely to be ebb dominant if Heckscher Dr. is

removed. If all tides over a year are considered, and maximum discharge and maximum current velocity are greater on average for the ebb tide, then the net annual movement of sediment in the creeks will be in the seaward direction.

The net sediment movement in a 50 m wide, ebb dominant creek in Kiawah Island, SC was estimated by Ward (1981). Sediment transport from this creek may be similar to that of Cedar Point Creek and Hannah Mills Creek if Heckscher Dr. is removed. The direction of flow in Hannah Mills Creek and Cedar Point Creek after the removal of Heckscher Dr. may initially be different from what it could later become, as the original network is restored. The two locations experience similar tidal ranges of 1.5-2 m (Trenhaile, 1997), so tidal velocities may be similar. At Kiawah Island over 7 spring tidal cycles in March, 1977, the average suspended concentration of sediment on the flood tide was 15 mg/l, and on the ebb tide was 15.6 mg/l. The net movement of sediment over the 7 spring tidal cycles was 2170 kg out of the marsh. The net sediment movement of 6 neap tidal cycles in March was 242 kg toward the marsh. Over 5 spring tidal cycles in July/August 1977, the average flood suspended sediment concentration was 58 mg/l and for the ebb was 76 mg/l. The net sediment movement over the 5 tidal cycles was 51300 kg out of the marsh. The net movement of sediment over 3 neap tidal cycles in August was 2730 kg out of the marsh.

Using the above measurements, the likely sediment export out of Hannah Mills Creek and Cedar Point Creek can be estimated. Averaging the spring and neap tidal cycle net sediment movement in March, 964 kg/tidal cycle are exported out of the marsh. Averaging the spring and neap tidal cycle in July/August, 27000 kg are exported out of the marsh. Finally, averaging the summer and winter averages, 14000 kg are exported per

tidal cycle. Net annual export out of the Kiawah Island creek would then be about 1.02×10^7 kg. The creek in Kiawah Island is about half as wide as Cedar Point Creek and Hannah Mills Creek, so perhaps they will each export 2×10^7 kg of sediment from the marsh annually. (Cedar Point Creek contains about 3.25×10^7 kg up to the bend; Hannah Mills Creek contains about 3.14×10^7 kg of sediment up to its bend (Ch. 2). Thus roughly estimated, it would take about a year and a half to erode all the sediment in the creeks if the creeks carry sediment only from the creek bottom. Catastrophic events such as hurricanes could significantly increase or decrease this rate of export.

The top meter of sediment in Hannah Mills Creek and Cedar Point has a shear strength that will likely be exceeded by shear stress from current flow and wave action if Heckscher Dr. is removed. The sediment is likely to move out into the St. Johns River if Heckscher Dr. is removed. Because of the sediment's small floc size, organic content, and long residence time in suspension, it could carry a substantial amount of sorbed pollutants long distances. The sediment may become a greater danger to organisms after it enters the St. Johns River, sorbing more contaminants as it moves along.

CHAPTER 5 CONCLUSIONS

The predominance of clay and silt in the Hannah Mills Creek and Cedar Point Creek, the high organic content, and the low shear strength of the surface sediment make it likely that it will erode into the St. Johns River if Heckscher Dr. is removed. The low settling velocity of fine-grained sediment also increases residence time in the water and thus the distance it will be transported in the water. Organic matter has low density and accumulations in sediment may reduce shear strength. Low shear strength of the surface sediment renders it easily eroded by low shear stresses, and thus easily transported to other areas of the estuary. Hence the sediment may be dispersed over long distances in the St. Johns River.

The accumulated sediment in the bottom of the two creeks may have come from bank sloughing of the marsh adjacent to the creeks. The Pb-210 derived dates indicate that most of the sediment is older than 1920, the approximate year of construction of Heckscher Dr. If velocities of 0.3 m/s occurred in the creeks prior to this date, as is likely, then the sediment was probably deposited in the creeks after the road was built. Rather, this old mud may be from the marsh, which possibly became flooded after the road was built. The banks of the flooded marsh could have collapsed and filled in the blocked creeks.

Removal of Heckscher Dr. will allow an export path for the sediment in Hannah Mills Creek and Cedar Point Creek into the St. Johns River. Current velocities will probably increase when tidal flow is restored. Shear stresses of 0.25 Pa at tidal current velocities of 0.3 m/s are likely. Storm events creating waves could deliver another 0.3 Pa or more of shear stress to the sediment. The estimated shear strength of the mud is approximately 0.1 Pa at the surface of the creek beds and probably about 0.23 Pa to a depth of 0.75 m. Thus the sediment will erode at least to this depth. The net movement of the creek sediment is dependent on which tidal direction, ebb or flood, has on average the higher velocities and thus higher suspended sediment concentration. This will likely be the ebb tide. Hence the sediment should erode seaward, into the St. Johns River estuary. Hence the sediment may expose organisms in the St. Johns River to sorbed contaminants. However, this exposure may not be significant compared to the high level of contamination of sediment found at several sites in the river (*Saint Johns River Sediment Quality: Physical and Chemical Characteristics* 1998).

Both the tidal current velocities and suspended sediment concentrations in the vicinity of the Timucuan Ecological and Historic Preserve should be measured to predict the likely tidal dominance and net sediment transport in the opened Hannah Mills Creek and Cedar Point Creek. The contamination of the sediment in the creeks should also be measured and compared to the sediment in the St. Johns River. If the creek sediment is relatively clean, then it would pose little more danger to the organisms already exposed to higher concentrations of contaminants in the St. Johns River; rather, Heckscher Dr. should remain closed in such a case to protect the marsh and creeks from the contaminants in the river.

APPENDIX A
SEDIMENT DEPTH MEASUREMENTS

Table A.1 Hannah Mills Creek sediment depth measurements

transect points	water depth (m)	mud depth (m)	cross sect (m ²)	volume between transects (m ³)	mass (kg)
Transect 1: 10 m from S edge to 10 m from N edge of creek					2.52E+06
1	1.2	2.4	78.255	6202.125	
2	1.3	2.3	45.7875		
3	1.25	0.45	7.4925		
4	1.25		Σ = 124.0245		
Transect 2: 50 m from transect 1, 10 m from N edge to 10 m from S edge of creek					2.41E+06
1	1.3	1.45	51.875	5937.5	
2	1.3	2.7	70.625		
3	1.3	2.95	48.125		
4	1.35	0.9	48.125		
5	1.3	2.95	Σ = 118.75		
Transect 3: 50 m from transect 2, 10 m from S edge to 10 m from N edge of creek					1.98E+06
1	1.3	1.2	46.25	4880	
2	1.4	1.85	41.75		
3	1.4	1.67	20.875		
4	1.4	0	13.125		
5	1.7	1.05	Σ = 122		
Transect 4: 50 m from transect 3, 10 m from N edge to 10 m S edge of creek					3.63E+06
1	1.8	1.1	10.02	8934.5	
2	1.9	0.1	25.05		
3	1.6	2.9	48.0125		
4	1.4	2.85	23.7975		
5	1.15	0	25.05		
6	2	3	46.76		
7	1.4	2.6	Σ = 178.69		
Transect 5: 50 m from transect 4, 10 m from S edge to 10 m from N edge of creek					1.05E+07
1	1.2	2.8	351.4014		
2	1.3	3.7	44.6725		

Table A.1 continued

transect points	water depth (m)	mud depth (m)	cross sect (m ²)	volume between transects (m ³)	mass (kg)
Transect 5: 3	1.35	1.65	16.7		1.05E+07
4	1.9	0.35	30.06		
5	2	3.25	49.6825		
6	1.8	2.7	26.3025		
7	1.35	0.45	$\Sigma = 518.8189$	25940.945	
Transect 6: 50 m from transect 5. 10 m from N edge to 10 m from S edge of creek					3.62E+06
1	1.3	1.4	16.875		
2	1.3	1.3	11.5625		
3	1.45	0.55	10.625		
4	2.35	1.15	19.6875		
5	2.8	2	18.125		
6	2.1	0.9	18.125		
7	1.3	2	38.75		
8	1.3	4.2	44.375		
9	1.1	2.9	$\Sigma = 178.125$	8906.25	
Transect 7: 50 m from transect 6. 10 m from S edge to 10 m from N edge of creek					3.57E+06
1	2.1	0.9	64.935		
2	2.1	3	74.925		
3	1.5	1.5	35.7975		
4	1.35	0.65	$\Sigma = 175.6575$	8782.875	
Transect 8: 50 m from transect 7. 10 m from N edge to 10 m from S edge of creek					2.18E+06
1	1.3	0	25		
2	2	2	33.75		
3	1.9	0.7	35.625		
4	3.35	2.15	38.125		
5	1.6	0.9	$\Sigma = 107.5$	5375	
Transect 9: 50 m from transect 9 and unmeasured transect 10					1.02E+06
1	1.1	2.65	34.375		
2	4	0.1	15		
3	3.9	1.1	21.25		
4	2.4	0.6	13.75		
5	2.5	0.5	$\Sigma = 50$	2500	

Hanna Mills Creek total volume (m³) 7.75x10⁴
Hanna Mills Creek total mass (kg) 3.14x10⁷

Table A.2 Cedar Point Creek sediment depth measurements (transects 50 m apart)

transect points	water depth (m)	mud depth (m)	cross sect (m ²)	volume between transects (m ³)	mass (kg)
Transect 1:	1	0.5	2.5	5375	1.77E+06
(between 1.2) 1.5	1.3	0	1.75		
(between 1.2) 1.75	1.3	0.7	7.25		
2	1.3	2.2	44		
3	1.4	2.2	37		
4	1.5	1.5	15		
5	1.4	0	0		
6	1.4	0	$\Sigma = 107.5$		
Transect 2:	1	0	12.5	6250	2.06E+06
2	1.6	1	25		
3	1.4	1	32.5		
3.5	1.5	1.6	25		
4	1.4	2.4	30		
5	1.3	0	$\Sigma = 125$		
Transect 3:	1	0.45	28.75	5218.75	1.72E+06
2	1.4	1.85	33.75		
3	1.4	0.85	26.25		
4	1.5	1.25	15.625		
5	1.3	0	$\Sigma = 104.375$		
Transect 4:	1	0	16.25	5.19E+03	1.71E+06
2	1.6	1.3	30		
3	1.5	1.1	31.25		
4	1.5	1.4	26.25		
5	1.4	0.7	$\Sigma = 103.75$		
Transect 5:	1	0.45	25.625	5031.25	1.66E+06
2	1.5	1.6	33.75		
3	1.5	1.1	27.5		
4	1.5	1.1	13.75		
5	1.3	0	$\Sigma = 100.625$		
Transect 6:	1	0.05	25.625	5781.25	1.91E+06
2	1.5	2	36.25		
3	1.6	0.9	25.625		
4	1.6	1.15	28.125		
5	1.4	1.1	$\Sigma = 115.625$		
Transect 7:	1	0.3	13.125	5843.75	1.93E+06
2	1.5	0.75	26.875		
3	1.6	1.4	25.3125		
3.5	1.6	2.65	26.875		
4	1.6	1.65	24.0625		
4.5	1.4	2.2	13.75		
5	1	0	$\Sigma = 116.875$		

Table A.2 continued

transect points	water depth (m)	mud depth (m)	cross sect (m ²)	volume between transects (m ³)	mass (kg)
Transect 8: 1	1	0.5	19	8250	2.72E+06
1.5	1.7	3.3	8.25		
1.75	1	0	0		
2	1.25	0	36.5		
3	1.6	3.65	20.75		
3.5	1.5	0.5	8.75		
4	1.2	1.25	47.5		
5	1.5	3.5	51.5		
6	1.6	1.65	$\Sigma = 165$		
Transect 9: 1	0.9	0	0	8906.25	2.94E+06
2	1	0	20		
3	1.4	1.6	34.375		
3.5	1.7	3.9	50.625		
4	1.4	4.2	73.125		
5	1.1	1.65	$\Sigma = 178.125$		
Transect 10: 1	1	0.2	39.375	6562.5	2.17E+06
2	1.8	2.95	64.375		
3	1.3	2.2	27.5		
4	0.7	0	0		
5	0.7	0	$\Sigma = 131.25$		
Transect 11: 1		0	8.75	6468.75	2.13E+06
2	1.4	0.7	30		
3	1.9	1.7	46.25		
4	2.1	2	44.375		
5	1.2	1.55	$\Sigma = 129.375$		
Transect 12: 1	1	0.2	38.75	7937.5	2.62E+06
2	2	2.9	53.125		
3	1.9	1.35	35.625		
4	1.1	1.5	31.25		
5	0.5	1	$\Sigma = 158.75$		
Transect 13 (elbow): 1	0.7	1.3	58.75	10062.5	3.32E+06
2	1.6	3.4	85		
3	2.1	3.4	25.9375		
3.5	2	0.75	5.3125		
3.75	0.7	0.55	11.25		
4	2.2	3.05	$\Sigma = 73.75$		
Transect 14: 1	1	2.6	75.625	11531.25	3.81E+06
2	1.7	3.45	82.5		
3	2.1	3.15	49.375		
4	1.7	0.8	23.125		
5	0.7	0.55	$\Sigma = 230.625$		
Total measured Cedar Point Creek volume (m ³)			98406.25		
Total measured Cedar Point Creek mass (kg)				3.25E+07	

Table A.3 Clapboard Creek sediment depth profile

Transect 1: parallel to bridge	total depth (m)	water (m)	mud (m)
1	4.6	4.6	0
2	5.5	5.5	0
3	5.5	5.5	0
4	6	6	0
5	> 6	> 6	?
6	> 6	> 6	?
7			0.2
Transect 2:	total depth (m)	water (m)	mud (m)
1	4.2	4	0.2
2	?	> 6	?
3	?	> 6	?
4	4.5	4.5	0
5	2.5	2.5	0
Transect 3:	total depth (m)	water (m)	mud (m)
1	2	0.65	1.35
2	2.25	0.7	1.55
3	2.5	1.8	0.7
4	3.75	3.55	0.2
5	5	4.25	0.75
6	?	> 6	?
7	5.25	5.25	0
8	1	0.7	0.3
Transect 4:	total depth (m)	water (m)	mud (m)
1	1	0.4	0.6
2	1.2	0.7	0.5
3	3.25	3.25	0
4	4	4	0
5	4	4	0
6	3.5	2.65	0.85
Transect 5:	total depth (m)	water (m)	mud (m)
1	1.5	1.1	0.4
2	3	2.5	0.5
3	3	3	0
4	1.8	1.8	0
Transect 6:	total depth (m)	water (m)	mud (m)
1	1.2	0.9	0.3
2	3.75	2.75	1
3	3.75	3.75	0
4	4.2	4.2	0
5	2.4	2.4	0

Table A.4 Saint Johns River embayment sediment profile

Transect 1: West Side of embayment			
transect points	total depth (m)	water (m)	mud (m)
1	2.25	1.3	0.95
2	1.75	1.3	0.45
3	1.75	1.3	0.45
4	3.75	1.3	2.45
5	5.75	1.3	4.45
6	5.75	1.3	4.45
7	6	1.1	4.9
Transect 2: East side of embayment			
transect points	total depth (m)	water (m)	mud (m)
1	5.75	1.7	4.05
2	5.8	1.7	4.1
3	5.75	1.8	3.95
4	5.5	2	3.5
5	5.2	1.7	3.5
6	4.6	1.3	3.3
Transect 3: SJR in front of Hannah Mills Creek mouth (east to west)			
transect points	total depth (m)	water (m)	mud (m)
1	2	1.4	0.6
2	3.3	1.5	1.8
3	3.75	1.5	2.25
4	3.5	1.5	2
5	2.25	1.6	0.65
Transect 4: SJR in front of Cedar Point creek mouth			
transect points	total depth (m)	water (m)	mud (m)
1	1.5	1.4	0.1
2	3.85	3.8	0.05
3	3.25	3.25	0
4	1.5	1.5	0
5	1.5	1.5	0
Transect 5: St. Johns River from west end of Cedar Point to the east end of Hannah Mills Creek mouth			
transect points	total depth (m)	water (m)	mud (m)
1	2.25	1.3	0.95
2	1.8	1.3	0.5
3	1.25	1.2	0.05
4	2.5	1.4	1.1
5	4.4	1.4	3
6	2	1.5	0.5
7	4.2	1.5	2.7
8	2.25	1.7	0.55
9	2.7	1.7	1
10	2.9	1.7	1.2

Table A.4 continued

transect points	total depth (m)	water (m)	mud (m)
11	2.3	1.7	0.6
12	2.4	1.7	0.7
13	3.6	1.7	1.9
14	5.5	1.8	3.7

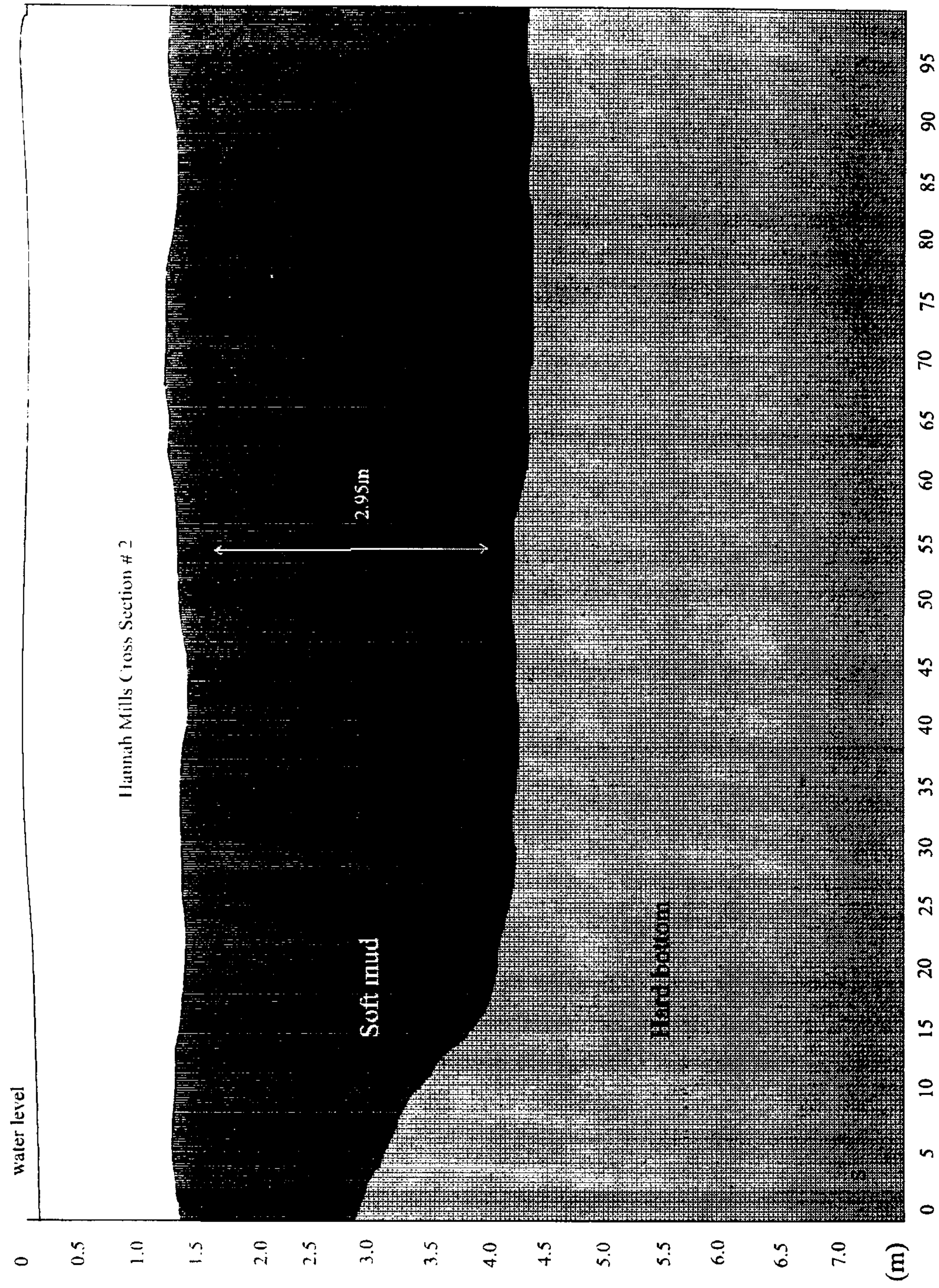


Fig. A.1 Hannah Mills Creek cross section #2 (hard bottom refers to siliceous sand)

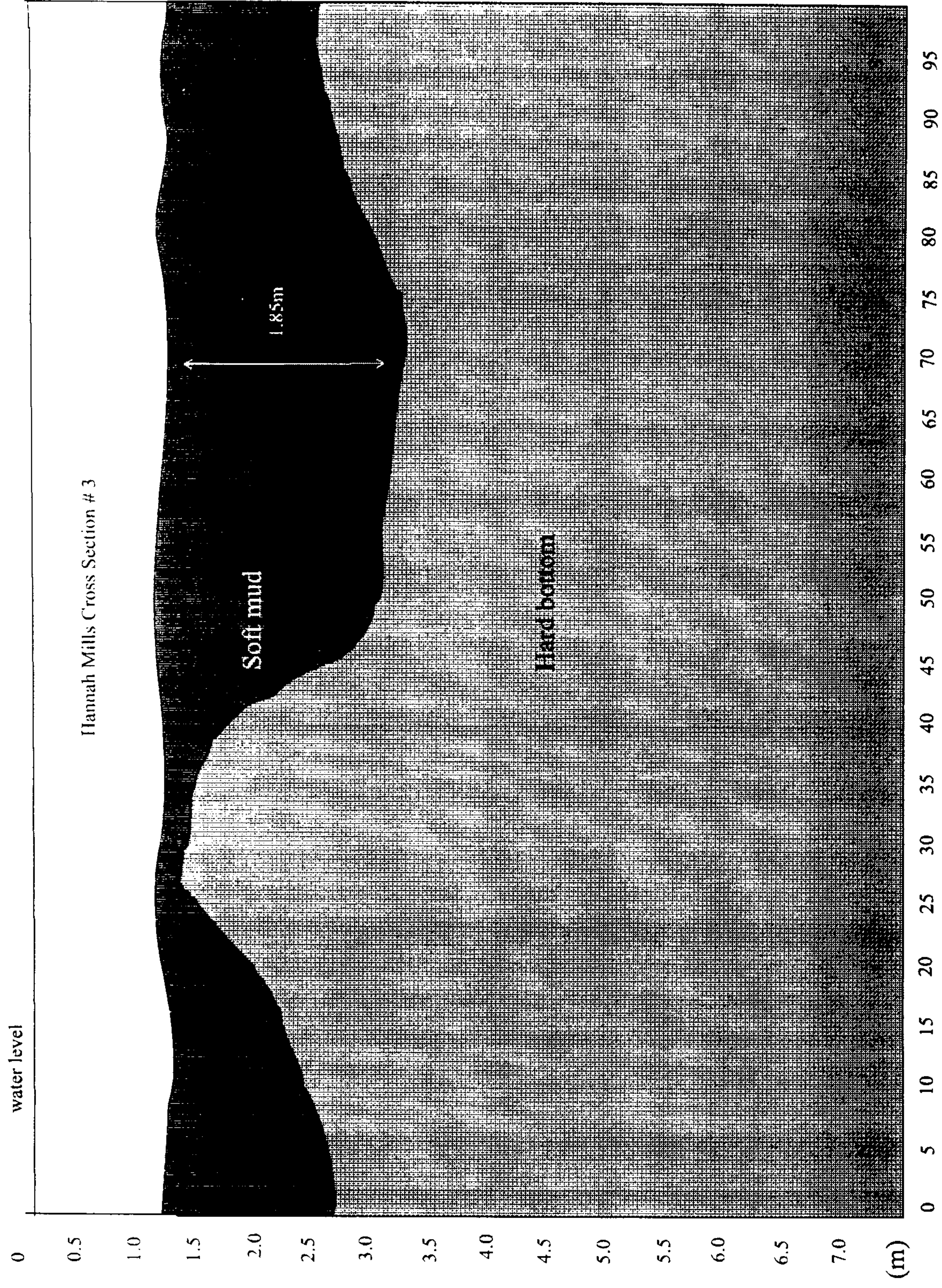


Fig. A.2 Hannah Mills Creek cross section # 3 (hard bottom refers to siliceous sand)

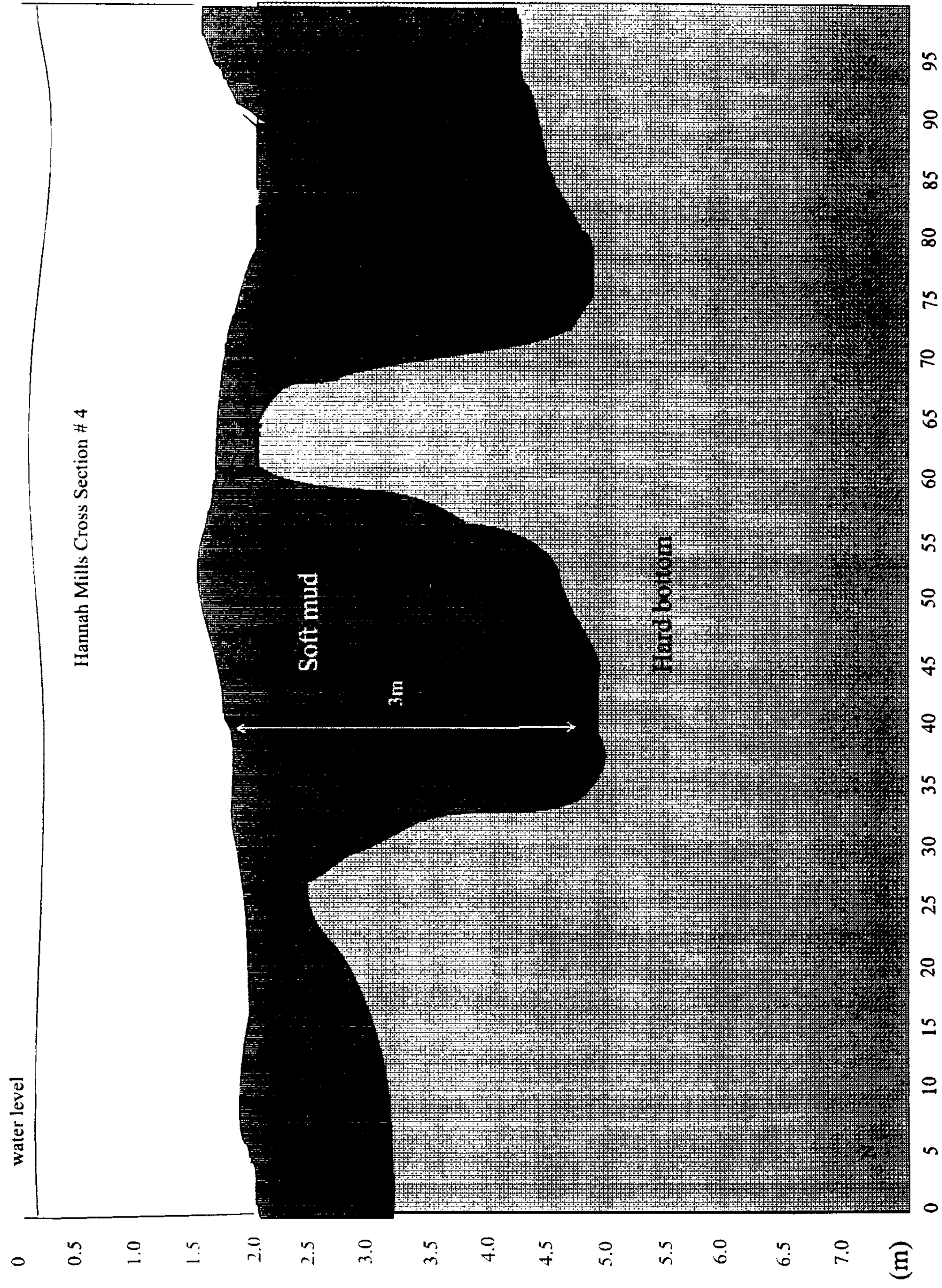


Fig. A.3 Hannah Mills Creek cross section #4 (hard bottom refers to siliceous sand)

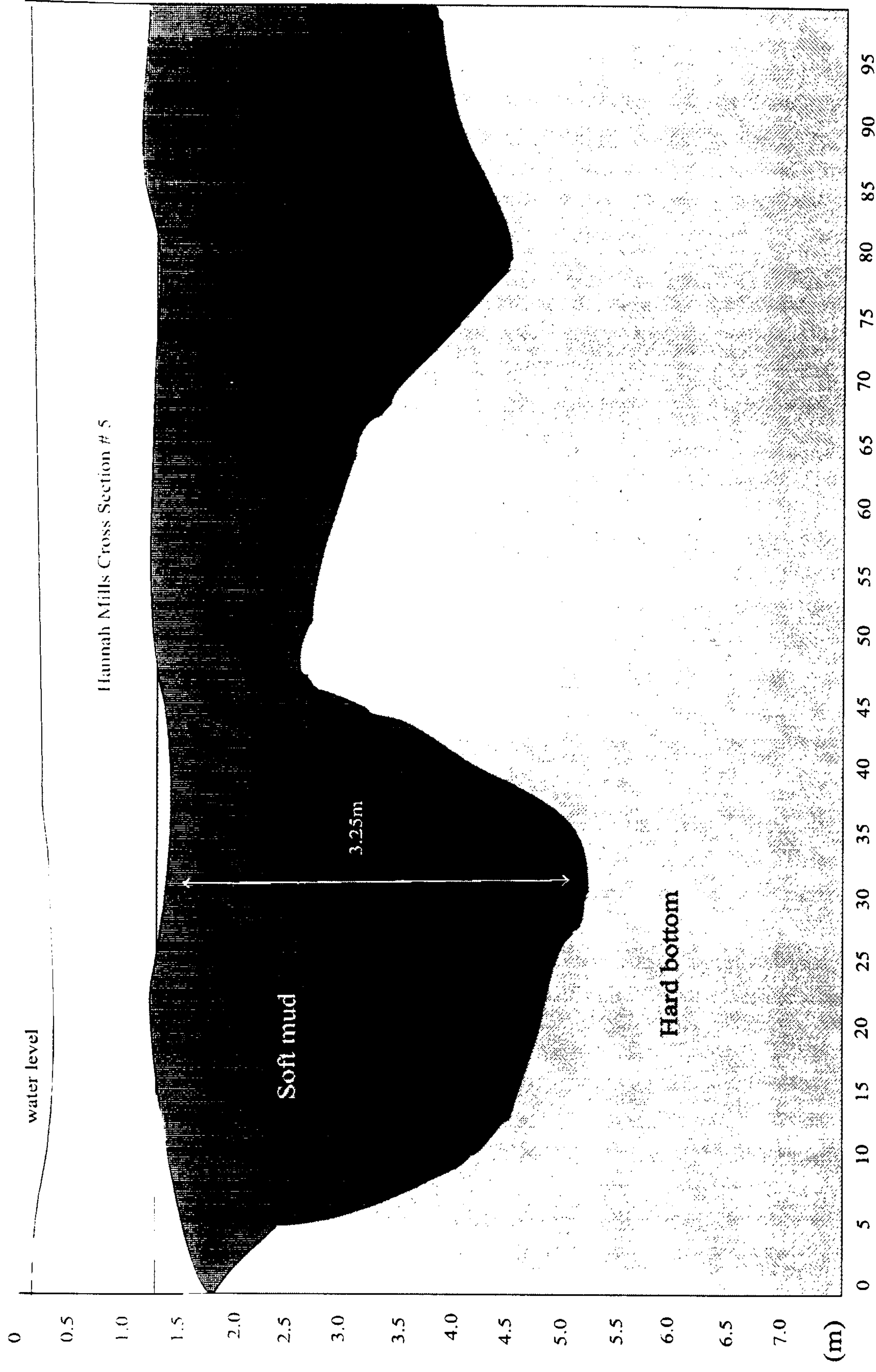


Fig. A.4 Hannah Mills Creek cross section # 5 (hard bottom refers to siliceous sand)

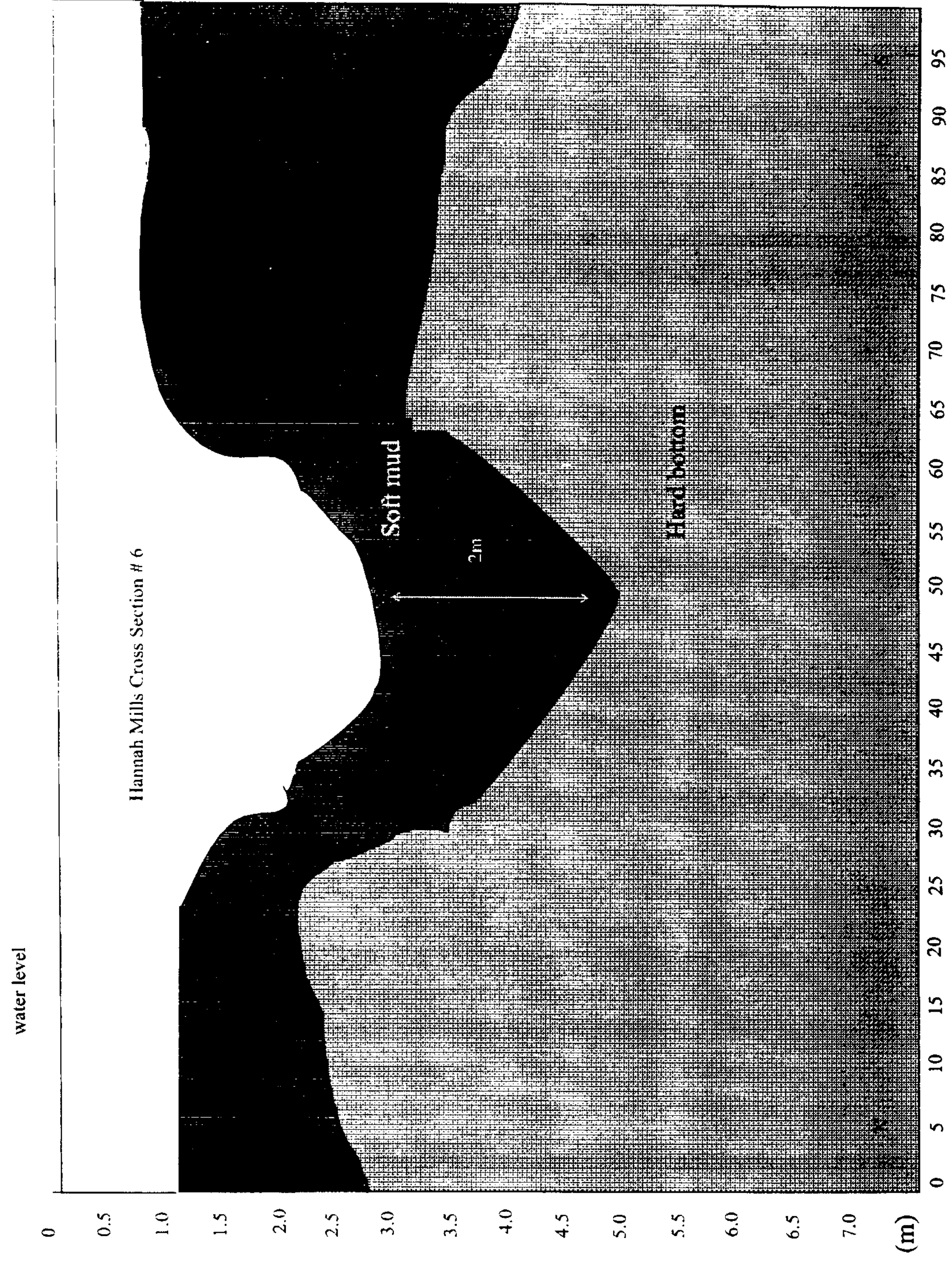


Fig. A.5 Hannah Mills Creek cross section # 6 (hard bottom refers to siliceous sand)

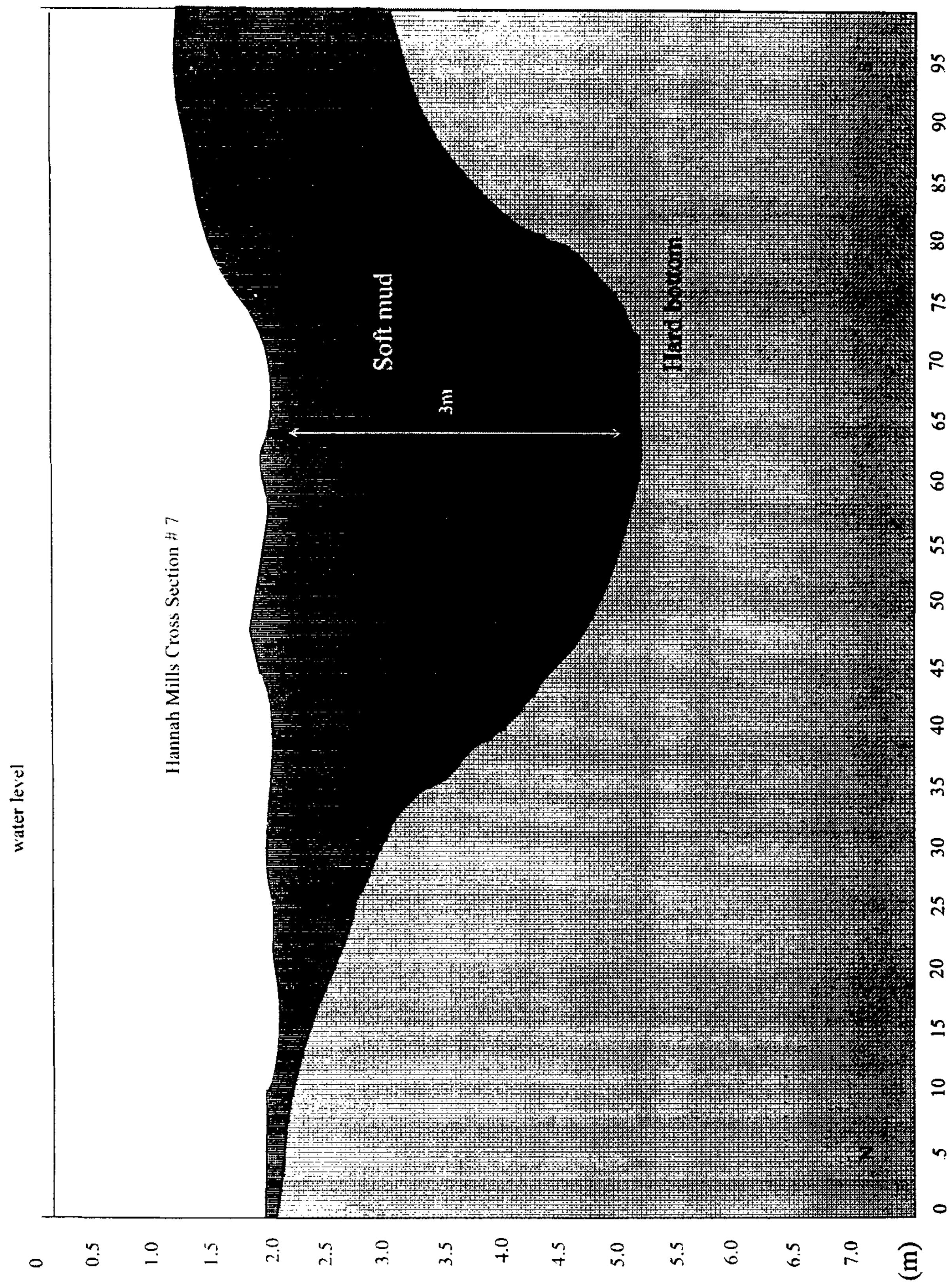


Fig. A.6 Hannah Mills Creek cross section # 7 (hard bottom refers to siliceous sand)

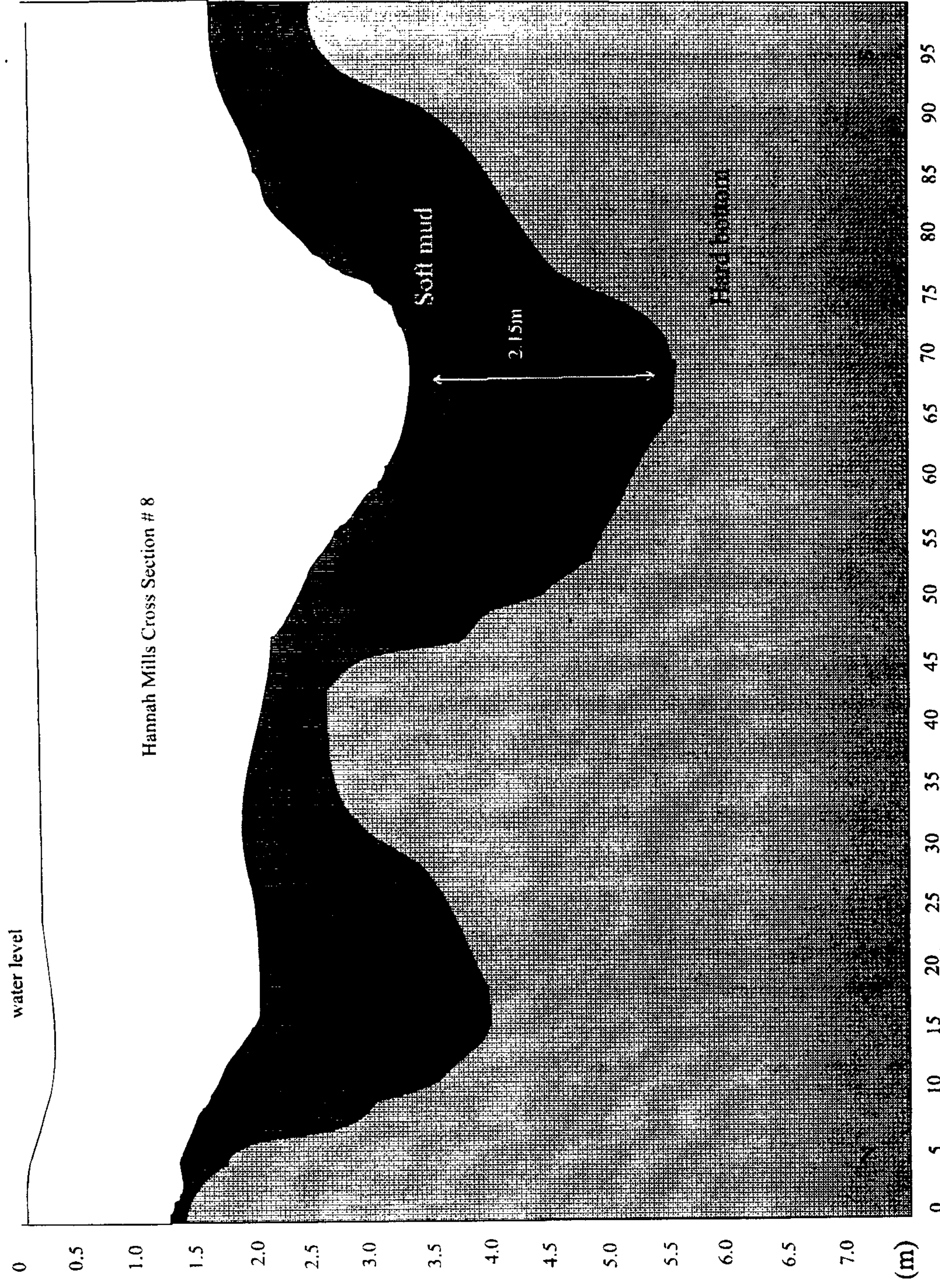


Fig. A.7 Hannah Mills Creek cross section # 8 (hard bottom refers to siliceous sand)

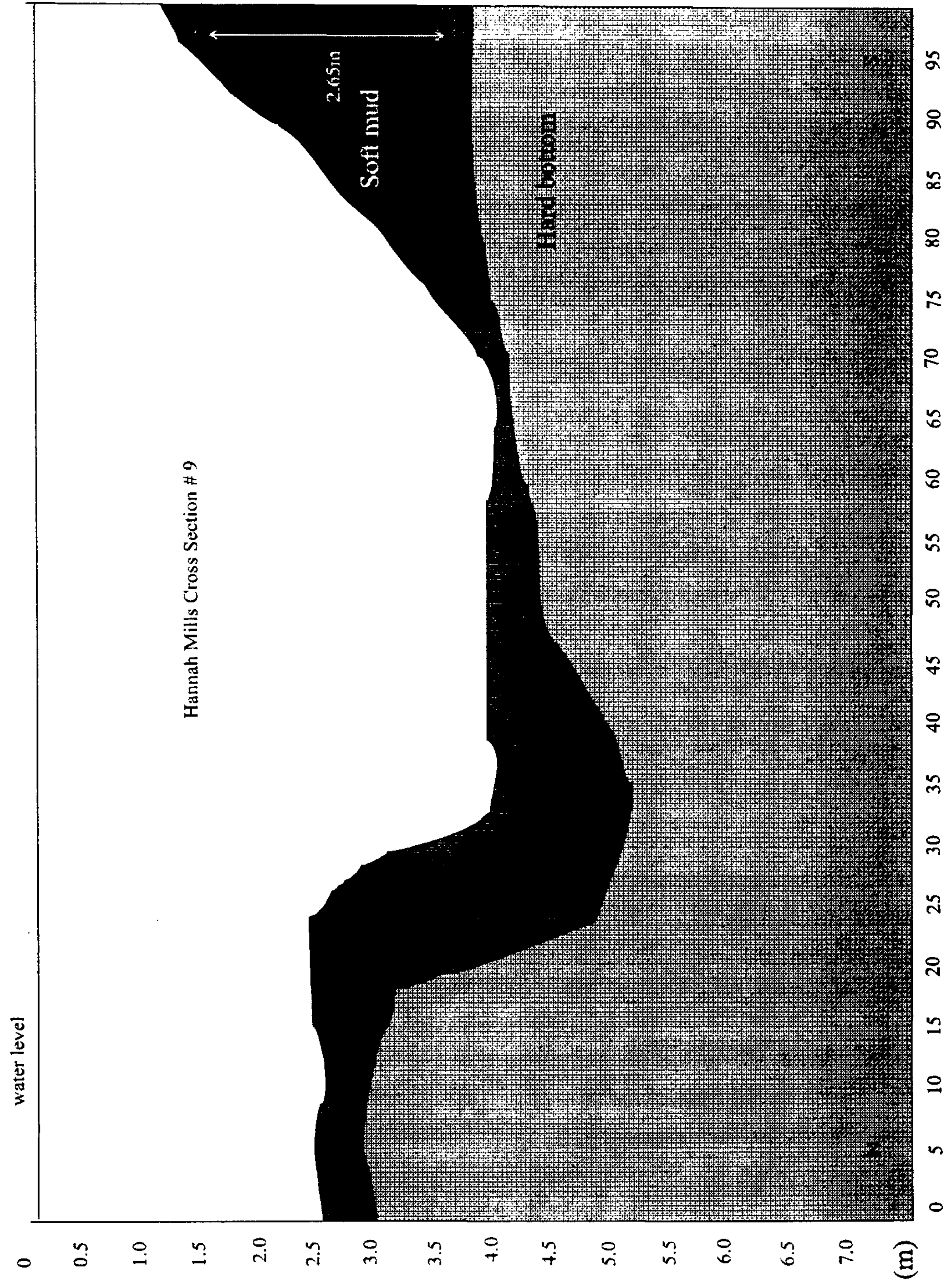


Fig. A.8 Hannah Mills Creek cross section # 9 (hard bottom refers to siliceous sand)

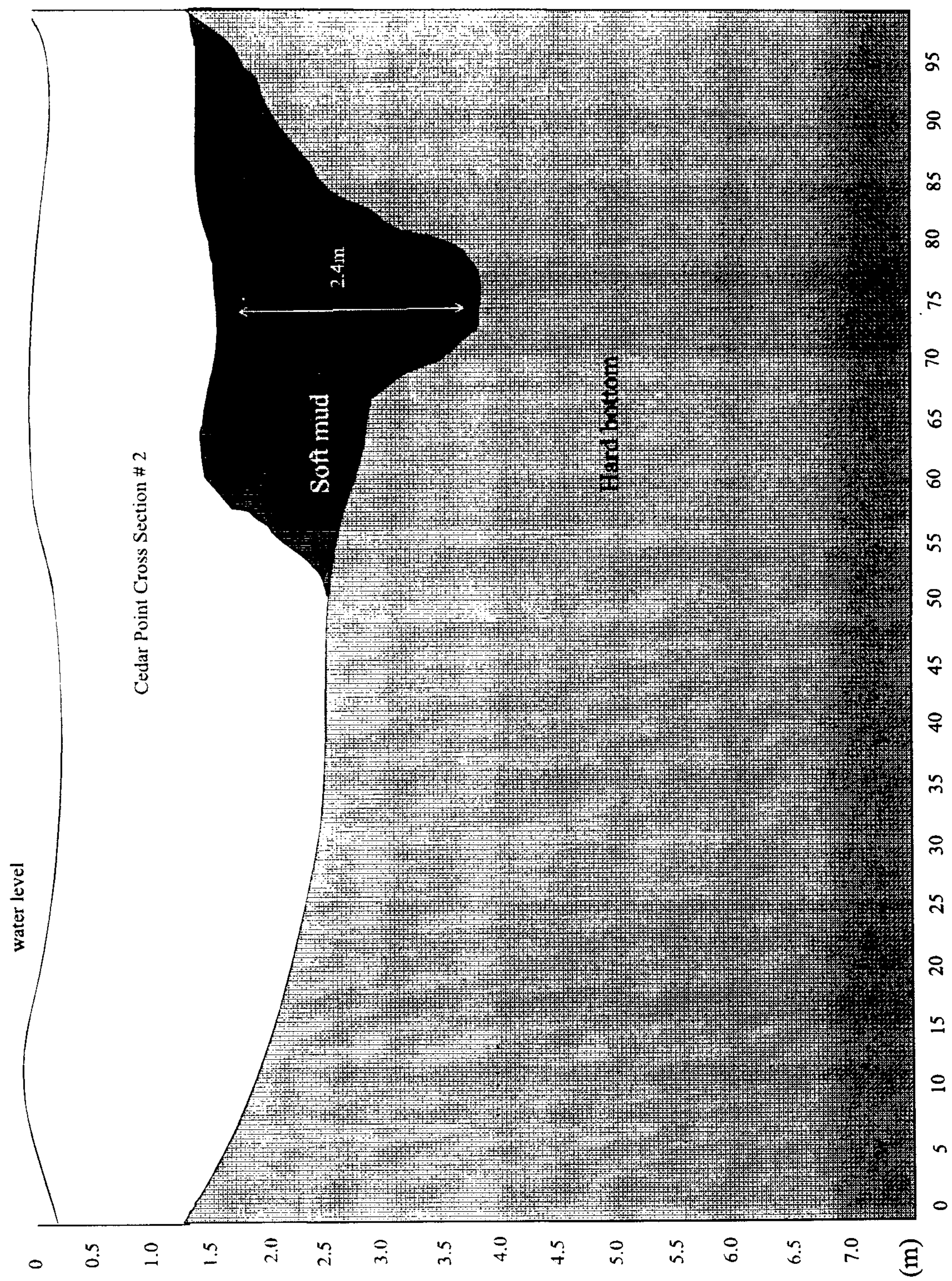


Fig. A.9 Cedar Point Creek cross section #2 (hard bottom refers to siliceous sand)

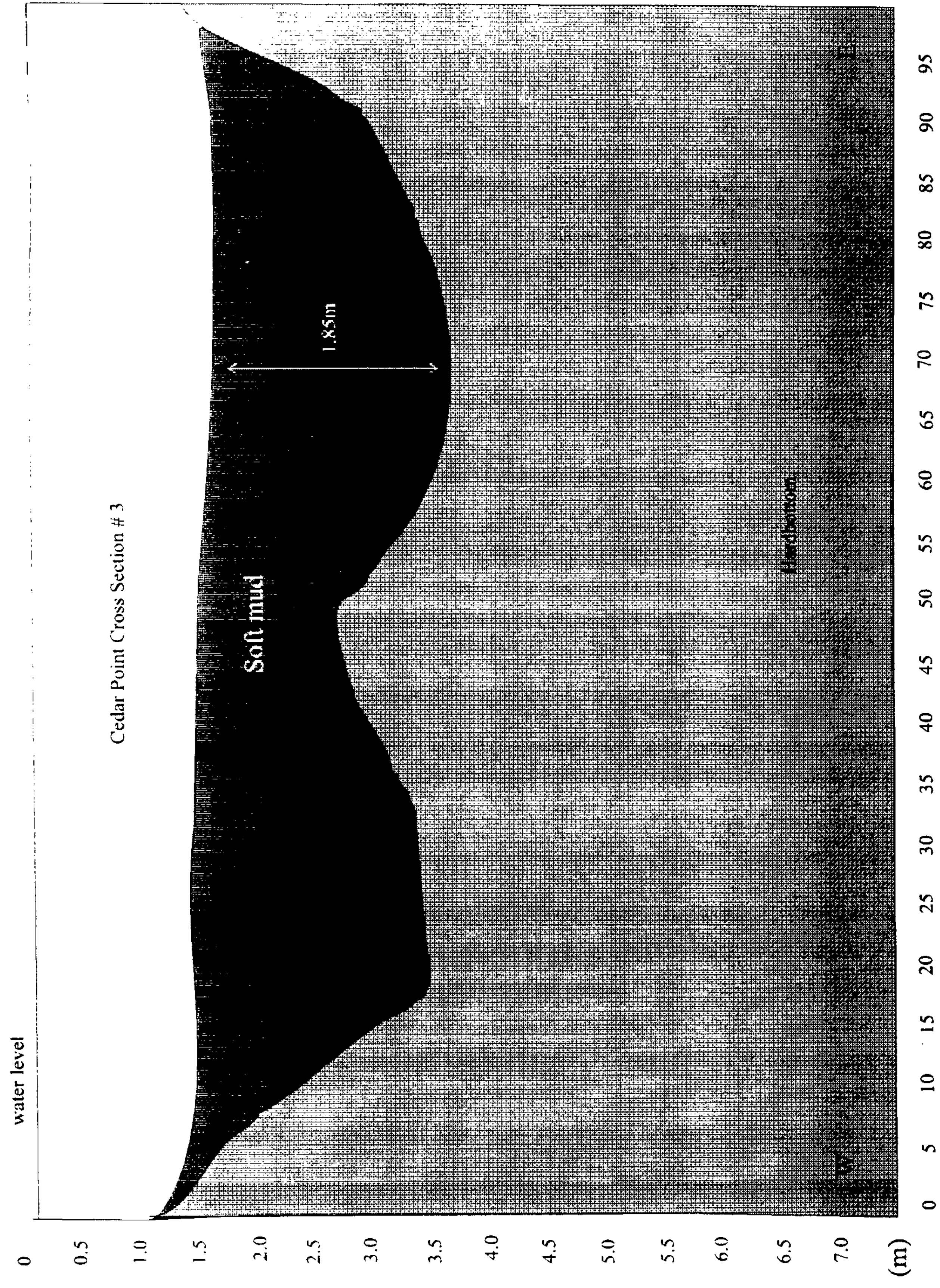


Fig. A.10 Cedar Point Creek cross section # 3 (hard bottom refers to siliceous sand)

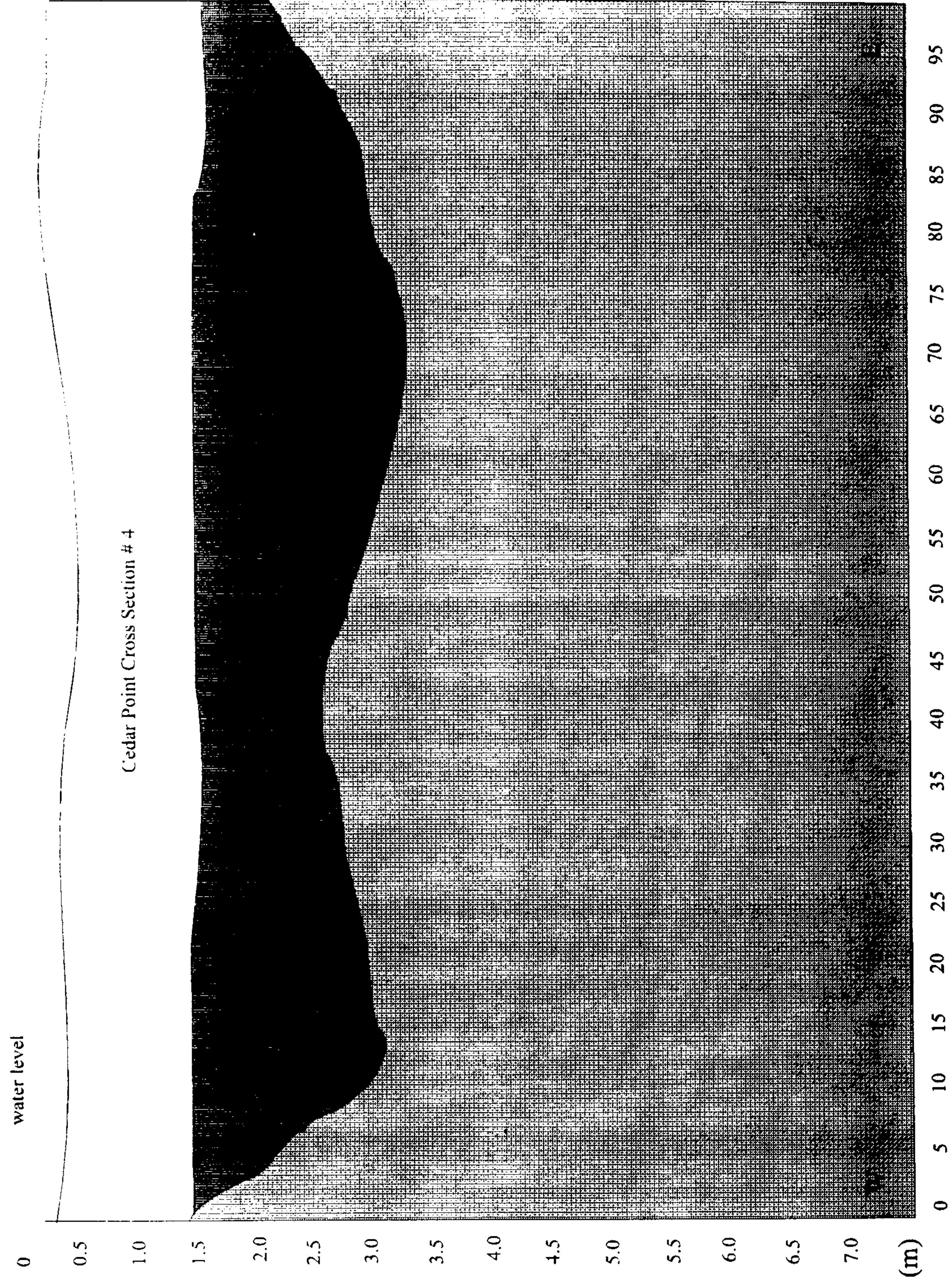


Fig. A.11 Cedar Point Creek cross section # 4 (hard bottom refers to siliceous sand)

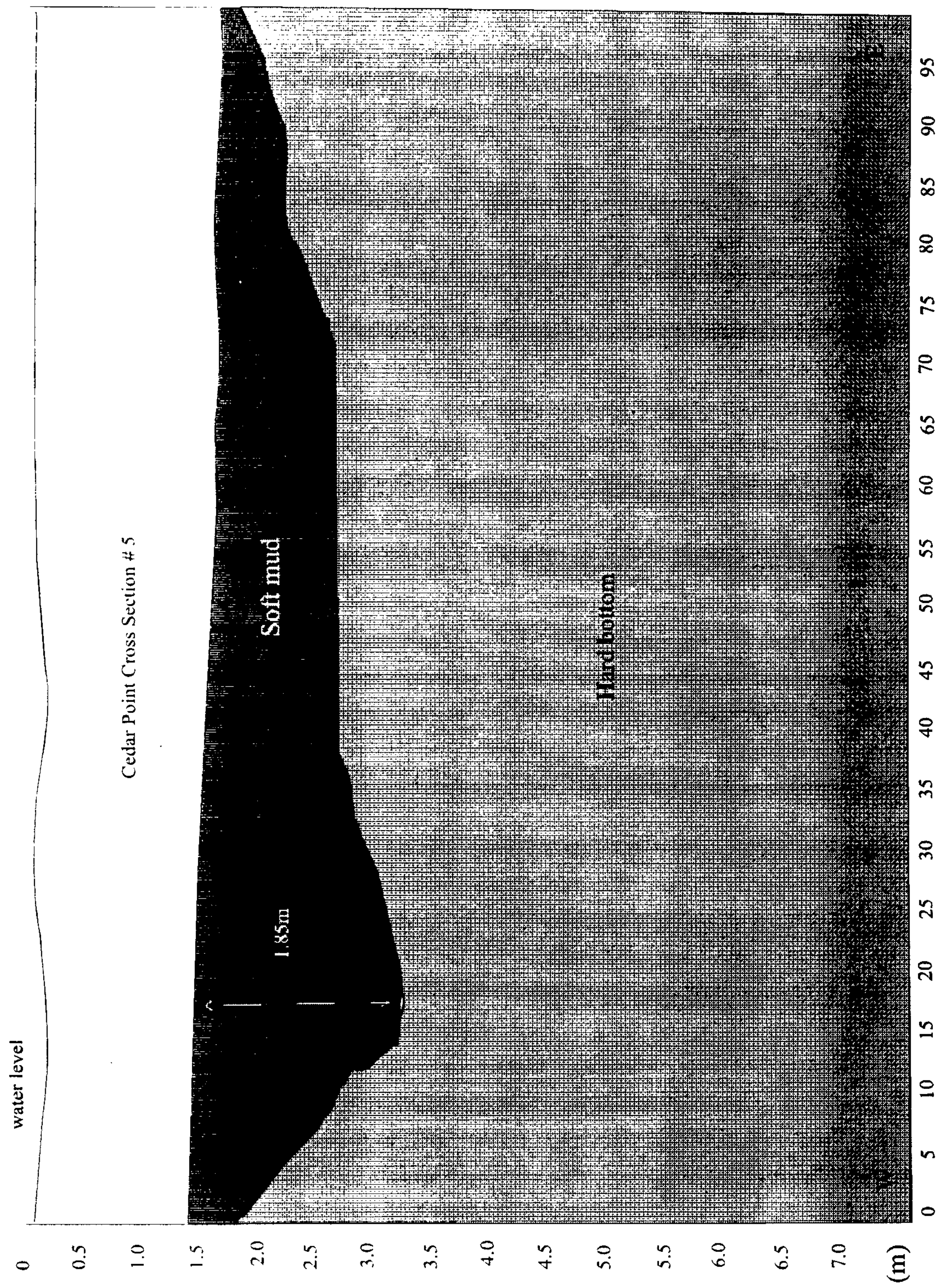


Fig. A.12 Cedar Point Creek cross section # 5 (hard bottom refers to siliceous sand)

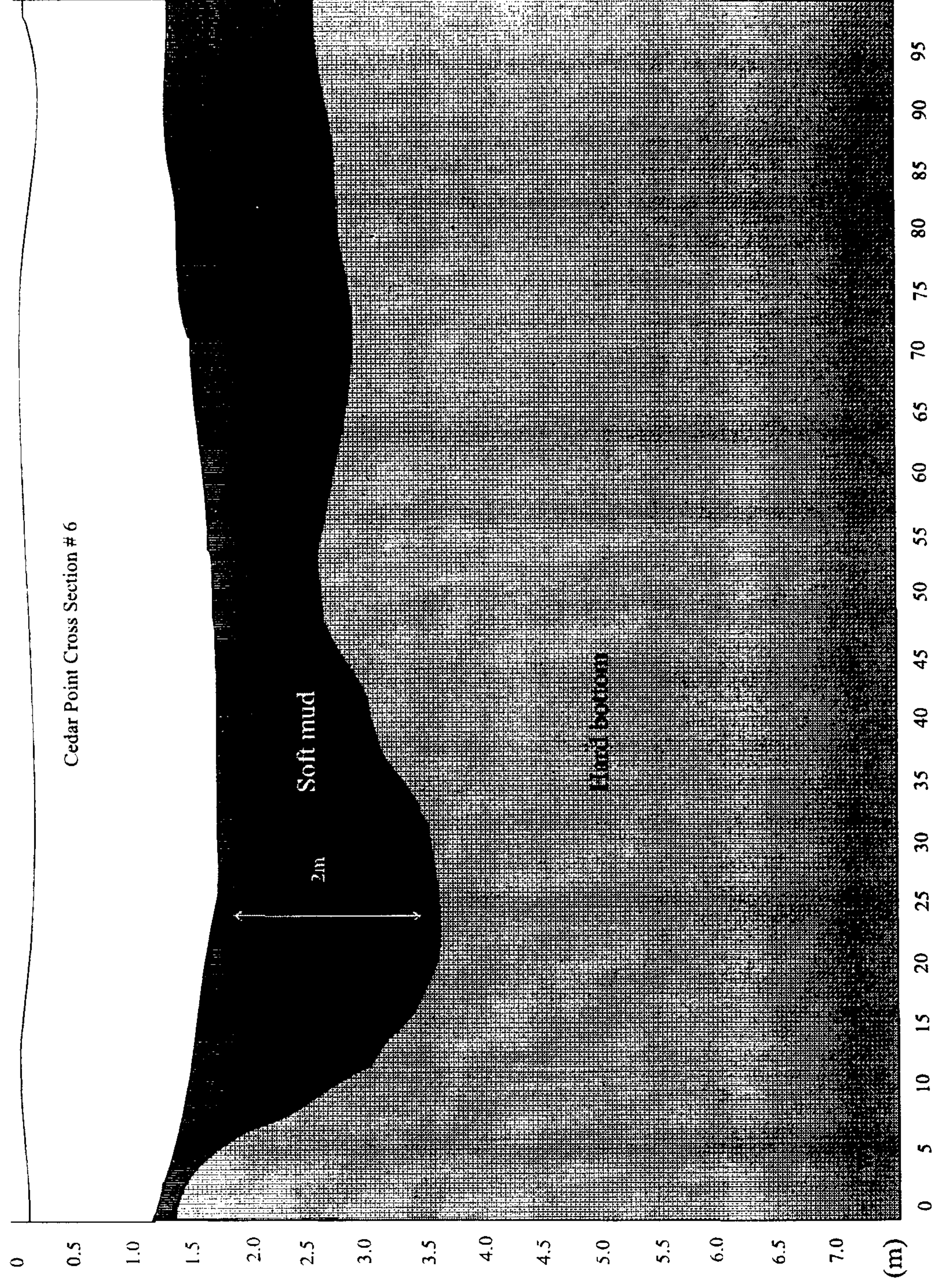


Fig. A.13 Cedar Point Creek cross section #6 (hard bottom refers to siliceous sand)

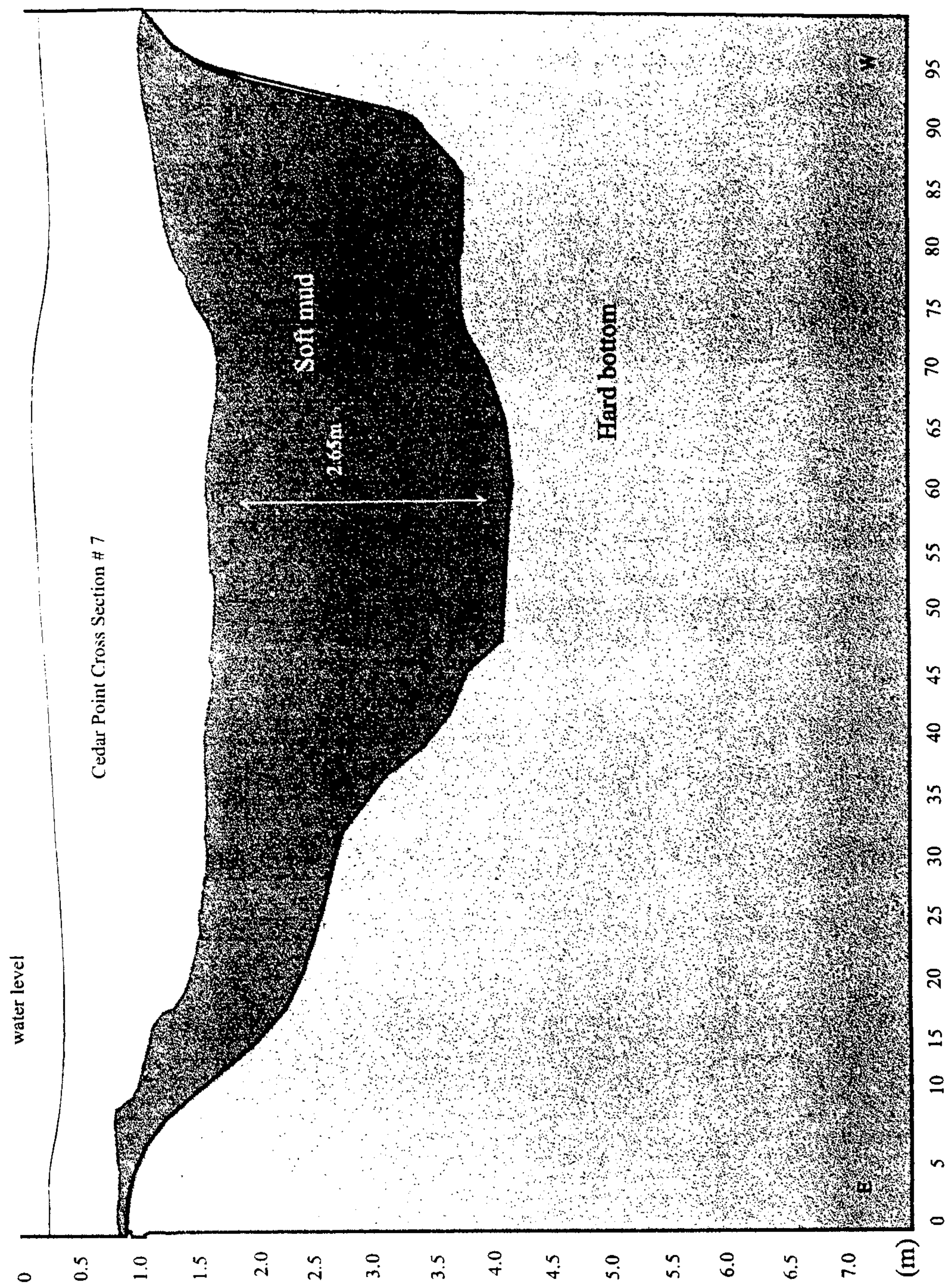


Fig. A.14 Cedar Point Creek cross section # 7 (hard bottom refers to siliceous sand)

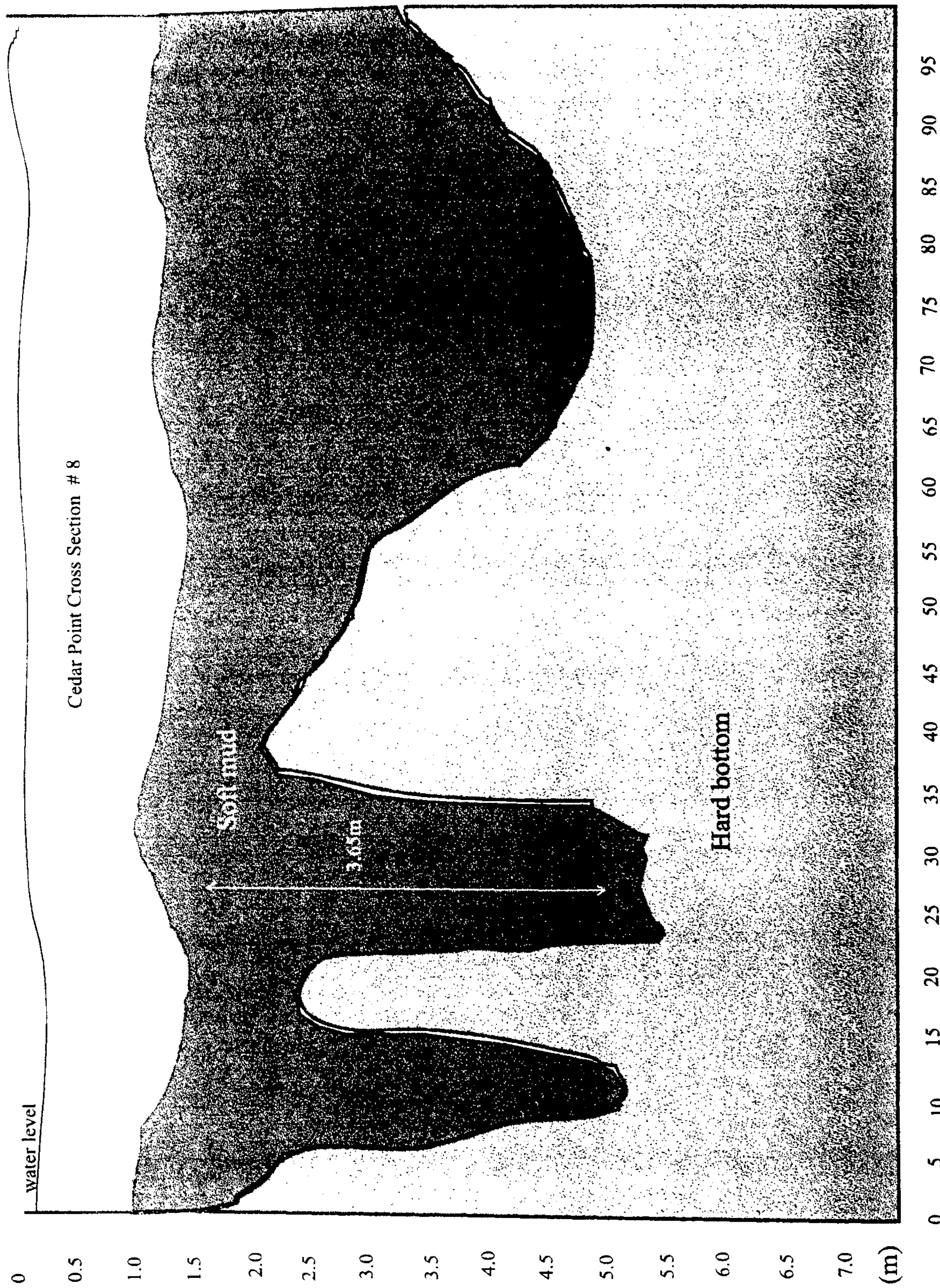


Fig. A.15 Cedar Point Creek cross section # 8 (hard bottom refers to siliceous sand)

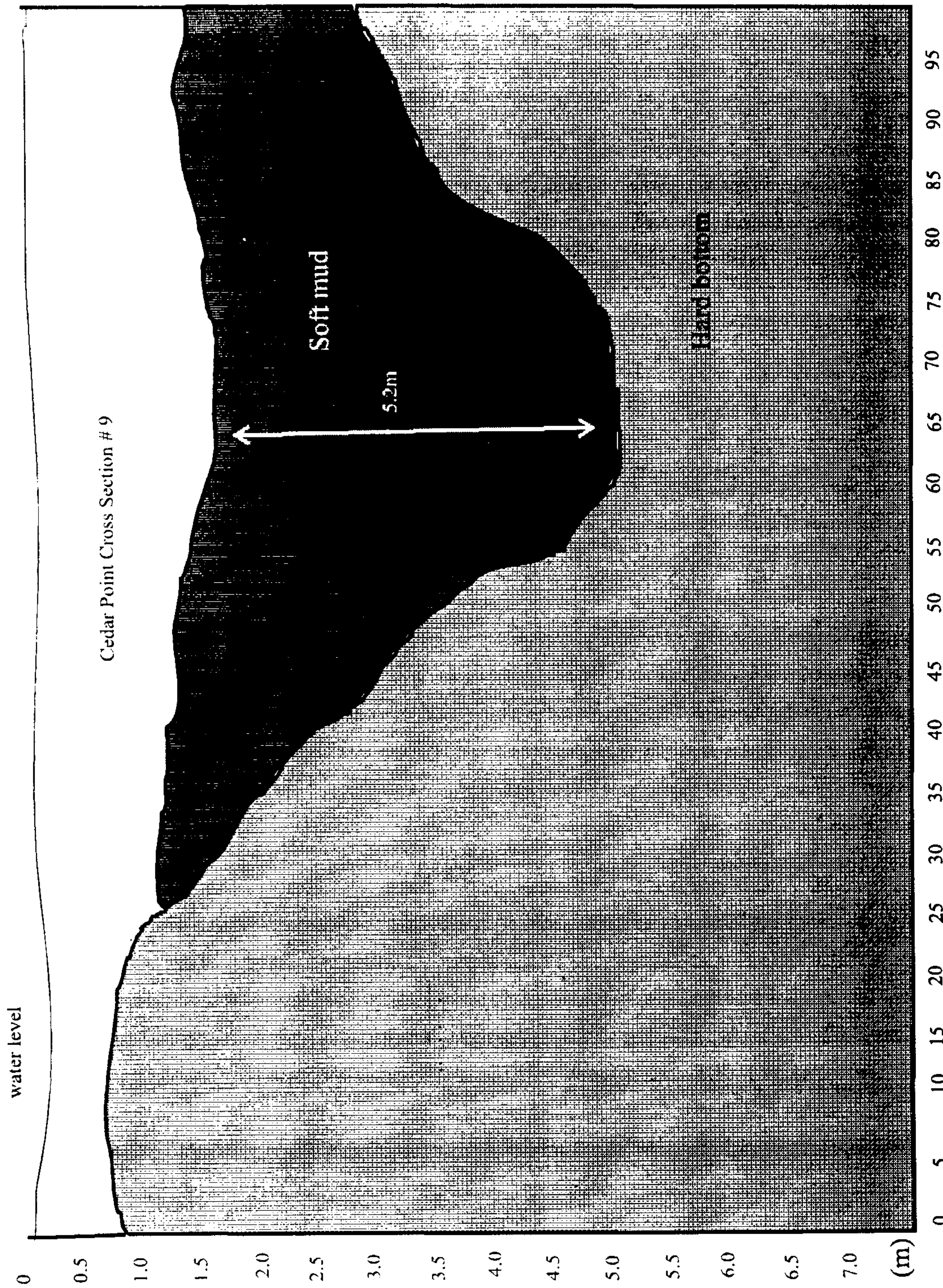


Fig. A.16 Cedar Point Creek cross section # 9 (hard bottom refers to siliceous sand)

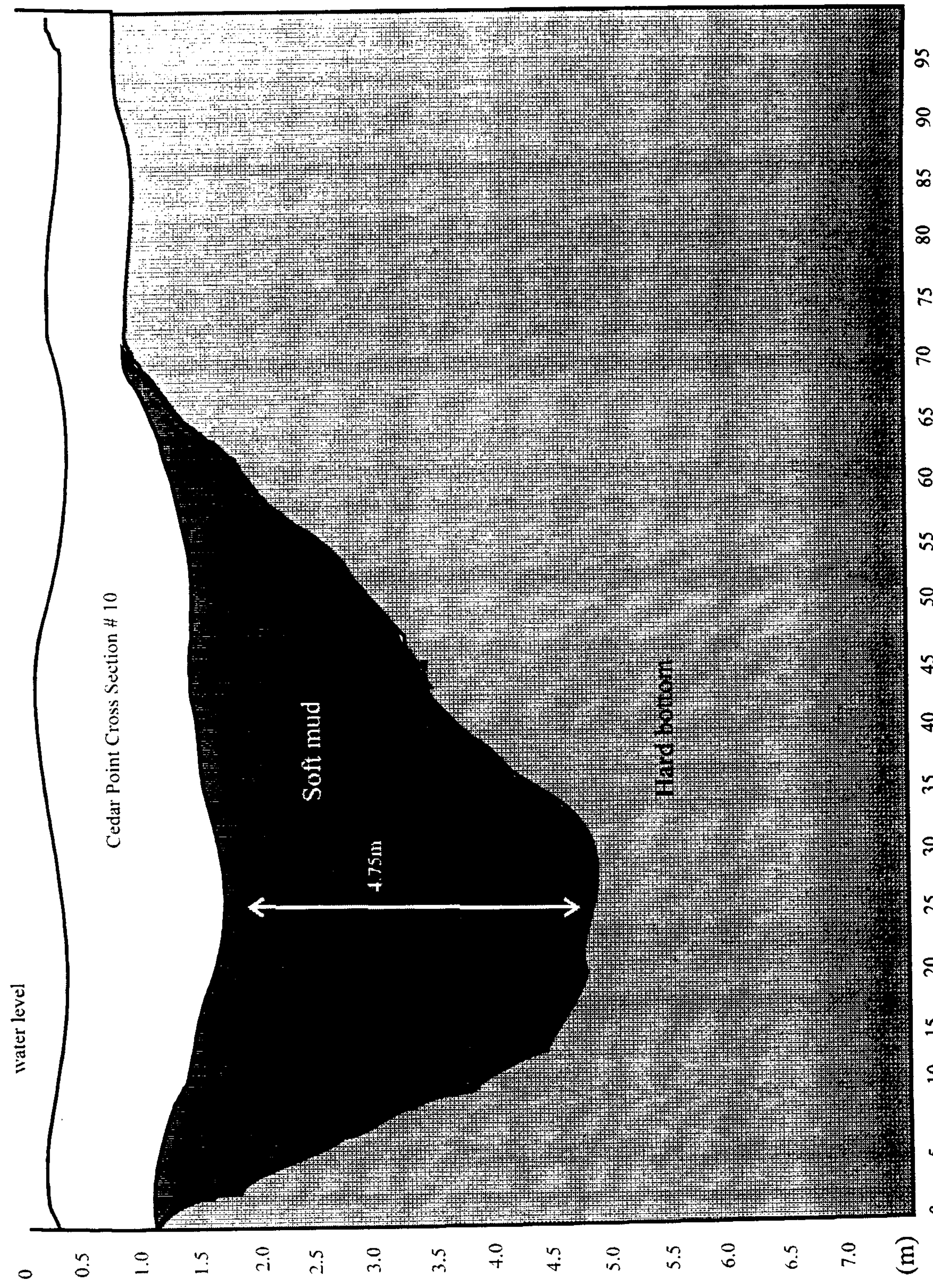


Fig. A.17 Cedar Point Creek cross section # 10 (hard bottom refers to siliceous sand)

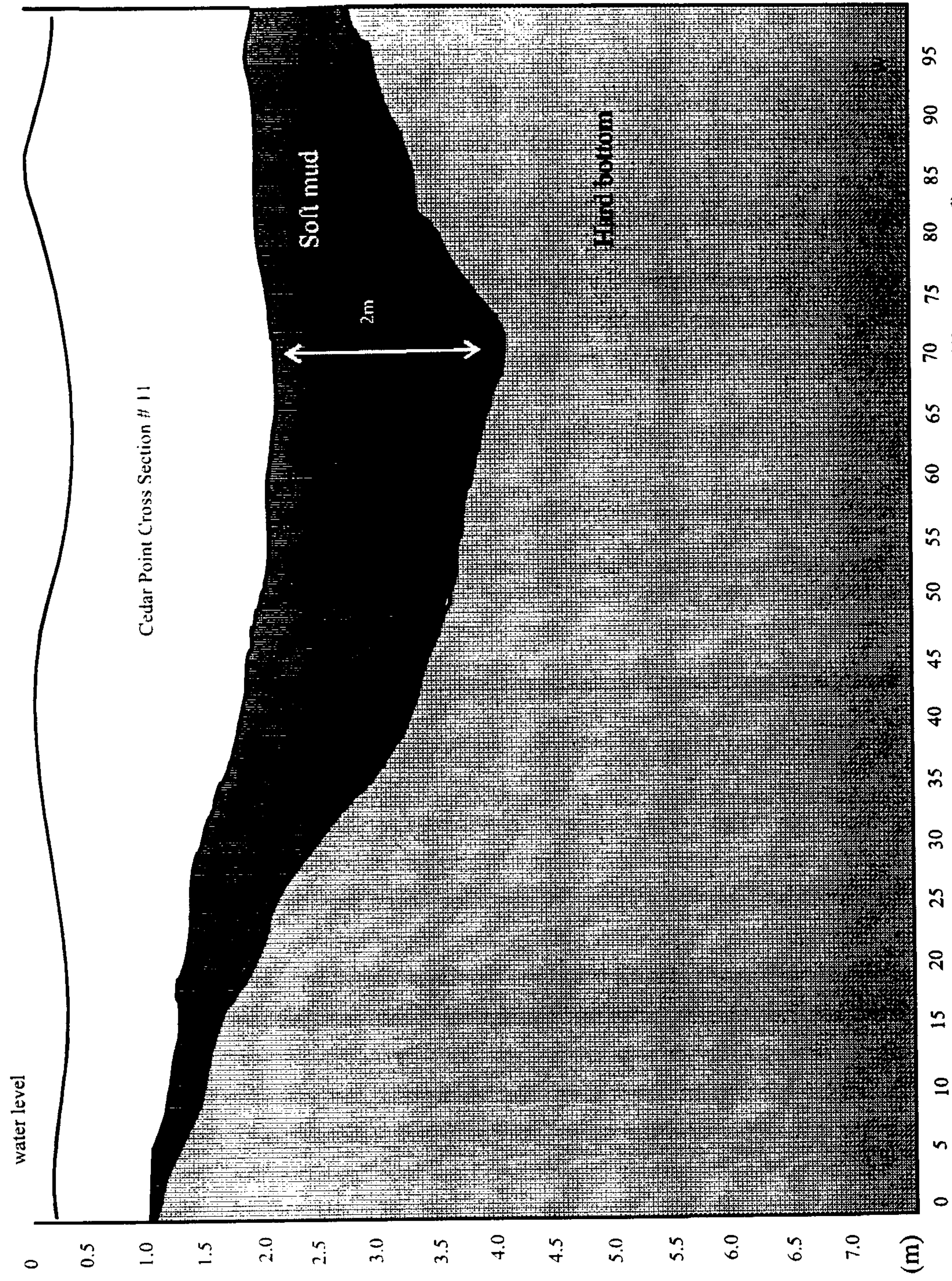


Fig. A.18 Cedar Point Creek cross section # 11 (hard bottom refers to siliceous sand)

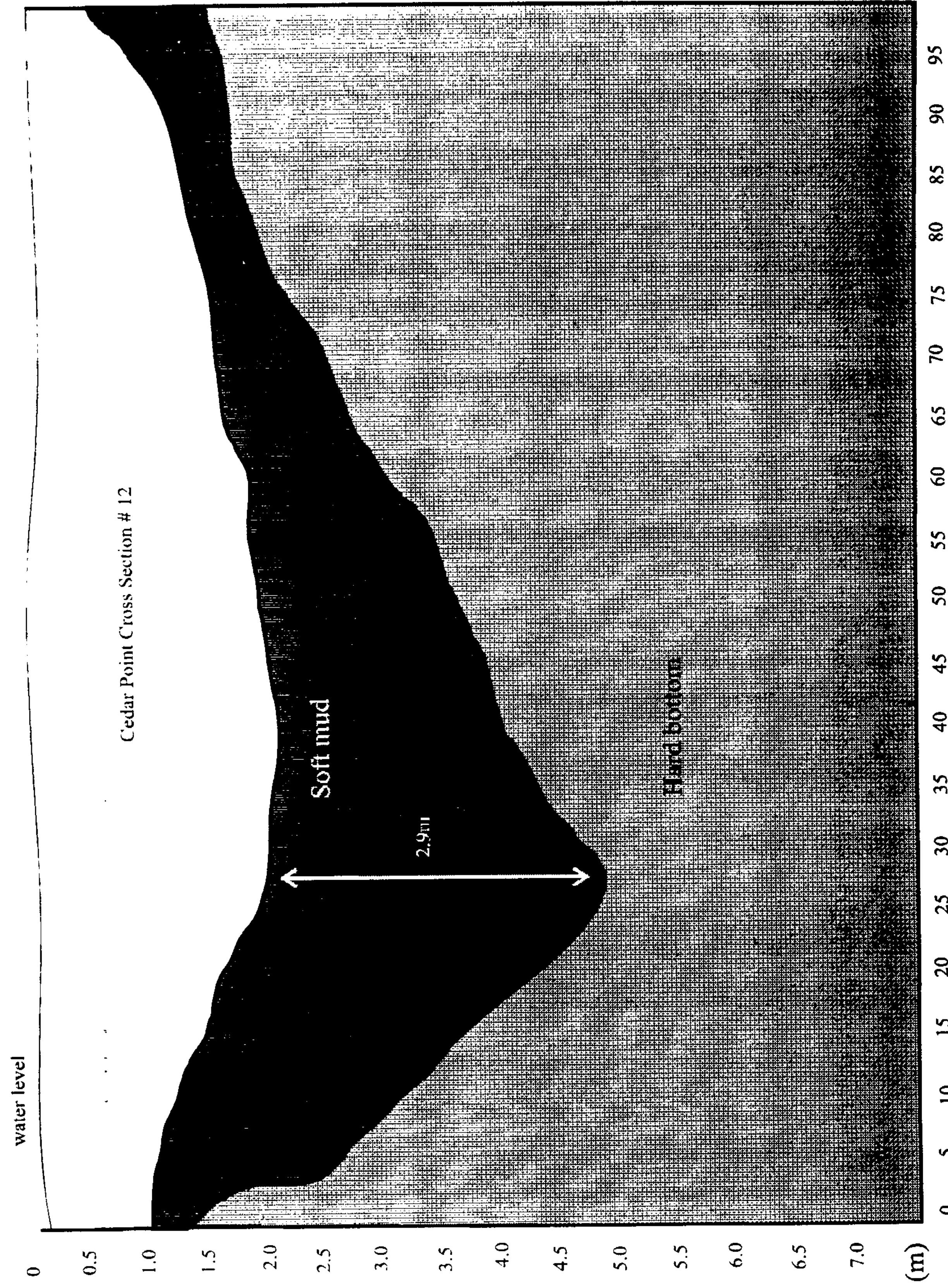


Fig. A.19 Cedar Point Creek cross section # 12 (hard bottom refers to siliceous sand)

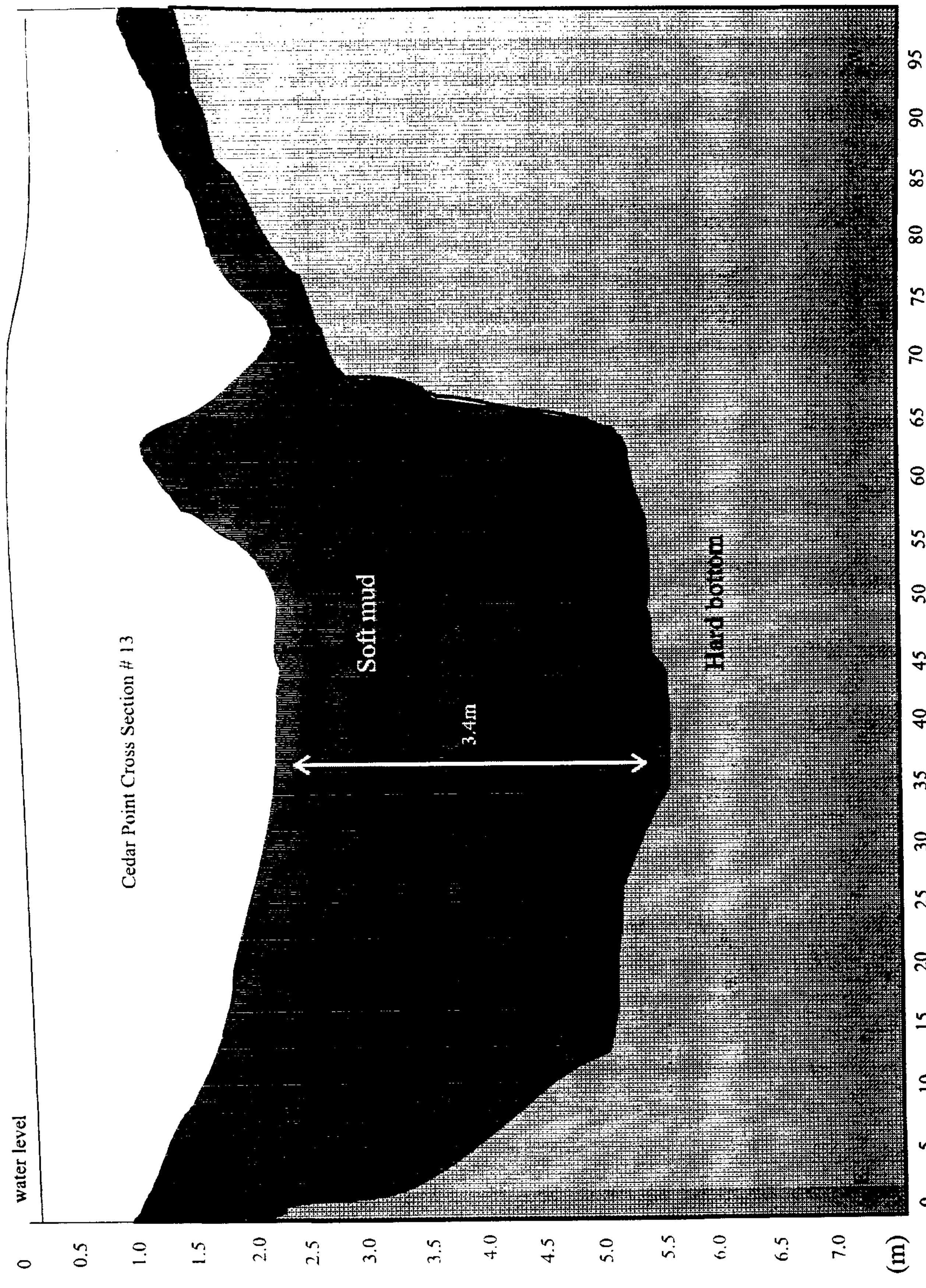


Fig. A.20 Cedar Point Creek cross section # 13 (hard bottom refers to siliceous sand)

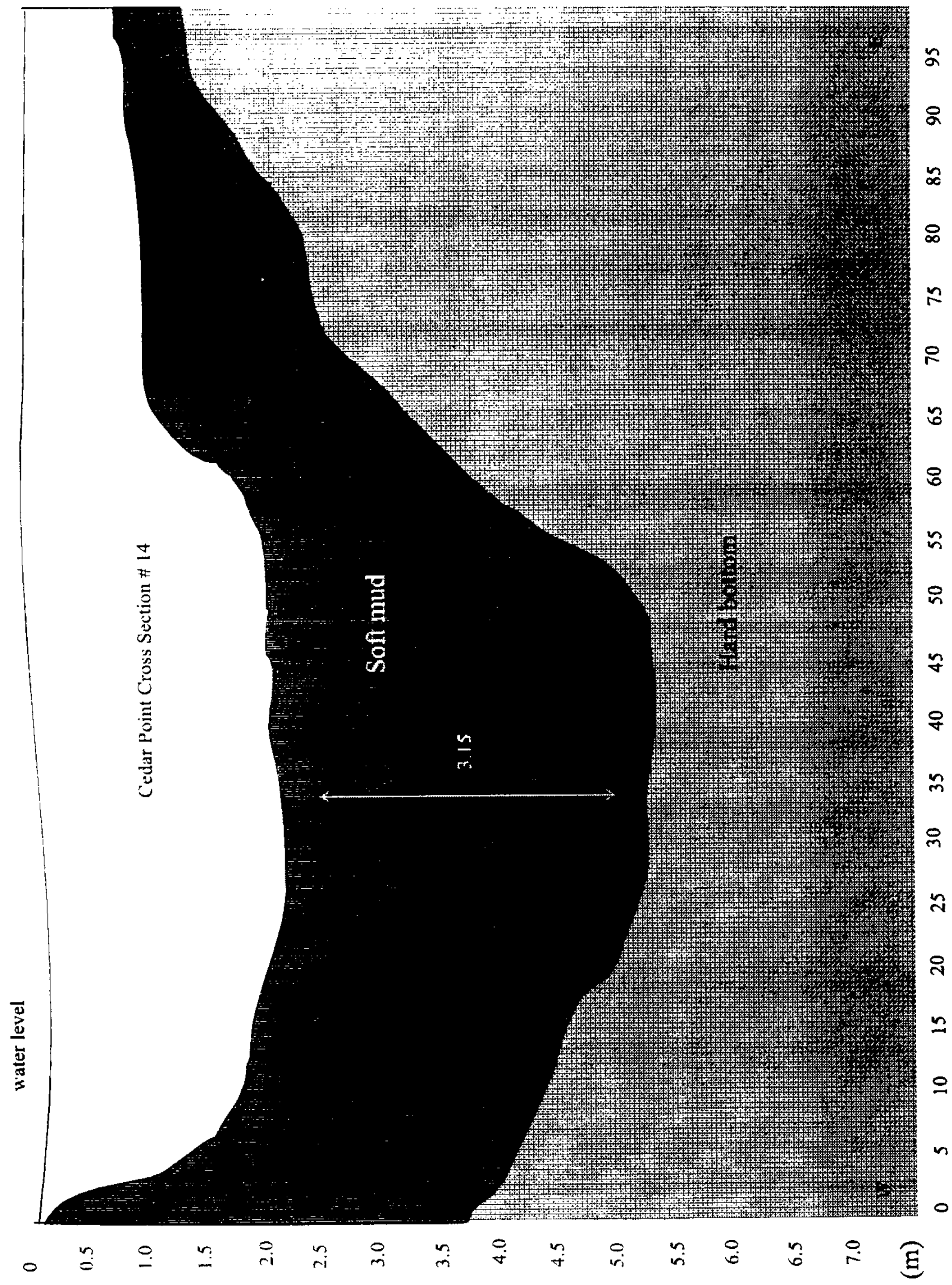


Fig. A.21 Cedar Point Creek cross section # 14 (hard bottom refers to siliceous sand)

APPENDIX B
Pb-210 RADIATION DETECTION CALCULATIONS
AND DETECTOR COMPARISON

Background Calculation

Background radiation from the surrounding environment must be subtracted from the radiation of the sample to obtain the activity due to the sample itself. Even though the detectors are located in a low radiation environment, the background noise can still be 78% as great or greater than the sample activity. Sugar was used as a background, instead of leaving the detector empty, to simulate the blocking of radiation caused by the petri dish and sediment mass. The calculation following is done for each frequency of radiation of interest:

$$\text{background counts} = \frac{\text{peak counts}}{t} \quad (1)$$

where a count is a detected disintegration of an atom.

Calibration

A substance of known activity must be measured to determine the efficiency of the detector in detecting a gamma frequency of interest. The efficiency of a detector is defined as the fraction of sample radiation detected. To determine the efficiency, a standard has to be made. Ur-238 ore, 1.07% Ur-238, with a known activity of 3.3333×10^{-7} Ci/g, was used for the calibration. Two tenths of a gram of the ore contains 0.00214 g U-238. Multiplying as follows:

$$SA = \frac{3.3333 E - 7 Ci}{g U - 238} \times 0.00214 g = 713 pCi \quad (2) \text{ SA gives the activity of the}$$

standard. After allowing equilibration of the Ur-238 decay series, the sample is then detected. The following equation gives the efficiency for the frequency of interest:

$$\frac{\text{Counts} - \text{background counts}}{\text{standard activity} \times \text{count time} \times \text{intensity factor}} \quad (3)$$

where the intensity factor is the percentage of disintegrations of an isotope of interest that produces a gamma wave at that frequency.

Concentration of sample

The concentration of each gamma frequency of interest was determined with the following:

$$Conc.(pCi / g) = \frac{\text{peak counts} - \text{background counts}}{\text{Eff.} \times \text{Int.} \times \text{count time} \times g \times 0.037 \text{dps} / pCi} \quad (4)$$

Total Pb-210 concentration was then calculated using equation 4 applied to 46.52keV.

The supported Pb-210 concentration was determined by averaging 295.2, 351.9, and 609.3 keV gamma peaks, radiation from the daughter isotopes of Radon-222 (Nagy 1988). The unsupported was calculated by the following:

$$\text{Unsupported Pb-210} = \text{Total Pb-210} - \text{Supported Pb-210}$$

Microsoft Excel spreadsheet software was used for the calculations.

Uncertainty

The Poisson distribution describes the probability of gamma disintegrations. The standard deviation of this distribution is given by the square root of the mean. Assume a

sample 1018 counts in a large number of 5 minutes. The standard deviation would then be

$$\sqrt{1018 \text{ counts}} = 3.39 \text{ counts}$$

The relative error is $3.39/1018 = 3.13\%$ (Turner 1986). Knowing this part of the uncertainty in the detection of radiation will allow one to determine the count time necessary for a desired level of accuracy.

Comparison of standard and well-type detectors

The well type detector's efficiency is much higher and the background much lower than of the planchette detector. The lower background of the well detector is due to superior shielding of the detector from extraneous photons in the environment. The greater efficiency of the well detector decreases the time required to detect a certain number of disintegrations with small relative error. The following table compares the average background and efficiency of a well detector in the University of Florida's Department of Environmental Engineering Sciences Low Background Counting Room used by S. Fox in 1996 to the planchette detector housed in the same room. This comparison applies only to these two detectors and is not necessarily valid for all detectors (source of well detector data Fox and Montague 1996).

Table B.1 Comparison of University of Florida's Department of Environmental Engineering Science's planchette and well detector background and efficiency

Radioisotope	keV	Average efficiency (well)	Average efficiency (planchette)	Average background (well)	Average background (planchette)
Pb-210	46.52	0.518	0.0175	0.000354	0.0149
Pb-214	295	0.228	0.00890	0.000616	0.00338
Pb-214	352	0.178	0.00708	0.000719	0.00392
Bi-214	609	0.057	0.00350	0.000502	0.00411

Tables B.2-B.14 report the counts (detected disintegrations) used in the date calculations for Hannah Mills Creek, Cedar Point Creek, and the "backdoor" creek. Concentrations, dates, and sedimentation rates are displayed also. Table B.15 lists the background counts used in the date calculations for the three creeks. Table B.16 lists the counts for each standard and the efficiency calculated for each standard run.

Table B.2 Hannah Mills Creek Pb-210 core data

Depth in Core (cm)	dry density (dry g/cm ³ wet volume)	unsupported Pb-210 (pCi/cm ³)	Cumm. Resid. Unsup. Pb-210 (pCi/cm ²)	supported Pb-210 (pCi/cm ³)	Year Deposited	Sed. Rate (g/cm ² /yr)
0-2	0.2739197	13.227256	21399.368	2.79489132	1998	13.774477
2-4.0	0.2999042	12.429839	19879.033	2.97365534	1995.6291	14.908464
4-6.0	0.3107311	10.672209	18465.831	2.76972496	1993.2566	16.711669
6.0-8.0	0.366309	11.866167	17218.353	4.39064707	1991.0063	16.521494
8.0-10.0	0.3735269	10.26828	15937.15	4.12986458	1988.5186	18.020027
10.0-12.0	0.3251669	11.265687	14802.481	3.5990547	1986.1424	13.280173
12.0-14.0	0.2457699	6.7012216	13649.04	2.92308236	1983.5325	15.559562
14.0-16.0	0.4	8.5435541	12805.401	4.76544423	1981.4798	18.635249
16.0-18.0	0.2977388	8.1808337	11885.397	3.04799338	1979.0812	13.445353
18.0-20.0	0.2872729	6.108957	11019.153	2.96885834	1976.6465	16.106321
20.0-22.0	0.3038741	7.6660001	10293.371	2.86352129	1974.4545	12.682446
22.0-24.0	0.2789723	7.7239944	9514.1717	2.60020955	1971.922	10.680969
24.0-26.0	0.2786114	6.4530042	8762.8531	2.72193313	1969.2755	11.759884
26.0-28.0	0.3630609	10.799686	8100.896	2.67431906	1966.7485	8.4649045
28.0-30.0	0.2843857	8.4087976	7273.497	2.80517834	1963.2823	7.6460603
30.0-32.0	0.307483	8.7322747	6589.714	2.84848971	1960.106	7.2124183
32.0-34.0	0.3020696	6.3273975	5926.6271	4.10711275	1956.694	8.7944783
34.0-36.0	0.2775287	7.2875849	5389.8546	1.72056535	1953.6397	6.380018
36.0-38.0	0.3460988	7.3578355	4843.825	3.24835209	1950.2033	7.0820521
38.0-40	0.3276932	5.100143	4324.5572	3.77662579	1946.5552	8.636689
40-42.0	0.4240523	6.3953734	3906.9669	5.17490915	1943.2881	8.0521866
42.0-44	0.407812	7.795631	3470.9203	5.5666583	1939.4808	5.6438303
44-46.0	0.3334675	6.1699378	3021.2479	5.58018274	1935.017	5.07551
46.0-48.0	0.3417681	7.5470362	2645.0261	3.91840614	1930.7384	3.7231081
48.0-50.	0.3262496	5.161097	2260.4337	3.82222718	1925.6834	4.4414044
50-52.0	0.3428508	5.0788936	1958.5201	3.94760835	1921.071	4.1094591
52-54	0.2731979	8.0035592	1678.8949	2.6659514	1916.1147	1.7813054
54-56	0.3100093	6.4326104	1366.9414	2.36362938	1909.5014	2.0476605
56-58	0.3096484	9.0098133	1112.1372	2.49260878	1902.8646	1.1880426
58-60	0.3107311	8.3649613	846.9827	4.06054379	1894.1023	0.9779483
60-62	0.4063684	9.6726335	625.60563	4.52319559	1884.3554	0.8169518
62-64	0.304235	9.3039738	424.61169	3.38386036	1871.8873	0.4315719
64-66	0.3121747	5.8115149	265.25756	3.26401829	1856.7511	0.4428908
66-68	0.2829421	5.9443473	164.07408	2.08427924	1841.2962	0.2427471
68-70	0.3013478	6.6197213	85.605333	1.95530722	1820.366	0.1211294
70-72	0.3154227	9.371379	29.563224	1.57332677	1786.1601	0.0309287

Table B.2 continued

Depth in Core	Total Lead 210 (pCi/g dry sediment at 46.5)	same as previous but at C295	C352	C609	supported C	unsupported C	cesium concentration (pCi/g)
0-2	58.49212461	6.843083631	14.58521527	9.181668133	10.20332234	48.28880226	10.64412115
2-4.0	51.36138151	10.07414483	11.99823045	7.673675807	9.915350361	41.44603115	2.540660513
4-6.0	43.25906005	7.227753857	9.849062554	9.6639103	8.91357557	34.34548448	5.194255877
6.0-8.0	44.38005821	12.29475281	11.08866295	12.57513658	11.98618411	32.3938741	5.294824763
8.0-10.0	38.54647317	12.01096215	9.956201545	11.20204982	11.05640451	27.49006866	6.217533724
10.0-12.0	45.7141909	9.853664829	14.4916668	8.859659521	11.06833038	34.64586052	8.681572663
12.0-14.0	39.15981919	9.136645353	13.65635632	12.88772192	11.89357453	27.26624466	12.61374241
14.0-16.0	33.27249578	9.613366552	14.38610995	11.74135519	11.91361057	21.35888521	7.651773424
16.0-18.0	37.71367934	9.951353672	11.68688619	9.073172109	10.23713732	27.47654201	8.333428001
18.0-20.0	31.59997449	10.43815008	11.99233651	8.573398679	10.33462842	21.26534607	11.4276926
20.0-22.0	34.65093803	8.6004064	11.12716375	8.542574907	9.423381687	25.22755634	11.64348274
22.0-24.0	37.00799359	7.456452811	13.18808145	7.317487357	9.320673872	27.68731972	13.52956291
24.0-26.0	32.93095022	8.79496486	11.04260152	9.471356918	9.769641098	23.16130912	20.661194
26.0-28.0	37.11224031	3.361747864	11.4472026	7.28915041	7.366033626	29.74620668	7.628623301
28.0-30.0	39.43227738	5.88099261	12.8989033	10.81208047	9.863992125	29.56828526	7.040952849
30.0-32.0	37.66310239	8.90490192	8.307919011	10.57885727	9.263892735	28.39920966	3.71901492
32.0-34.0	34.54339894	13.2470572	12.92880453	14.61387295	13.59657823	20.94682072	0.860318901
34.0-36.0	32.45844728	2.069490502	6.876359012	9.652934257	6.19959459	26.25885269	7.420667884
36.0-38.0	30.64496685	9.530928612	8.564299761	10.06163034	9.385619569	21.25934728	4.714468235
38.0-40	27.0886597	9.402351936	11.93765747	13.23464268	11.52488403	15.56377567	0.268898268
40-42.0	27.28503759	10.46500113	12.46174053	13.6836669	12.20346952	15.08156807	0.471785645
42.0-44	32.76580816	14.49463714	13.93491339	12.52063113	13.65006055	19.1157476	-1.1896667
44-46.0	35.23617909	16.9260671	16.48776088	16.78761066	16.73381288	18.50236621	0.602638435
46.0-48.0	33.54743306	12.52658244	10.35809379	11.51063008	11.46510211	22.08233095	2.120244871
48.0-50.	27.53512803	12.74495018	11.35532159	11.04668913	11.71565363	15.8194744	6.049364913
50-52.0	26.32778567	10.9824009	13.70428799	9.855524752	11.51407121	14.81371446	0.547188426
52-54	39.05413981	12.39324257	7.879537636	9.002162984	9.758314396	29.29582541	5.136737369
54-56	28.37411693	7.130334532	9.397861072	6.344951736	7.624382447	20.74973449	-1.448529362
56-58	37.14671977	7.506898586	10.3122143	6.330298268	8.049803717	29.09691605	6.423040128
58-60	39.98797005	13.18816204	15.06207152	10.95289798	13.06771052	26.92025953	3.226422709
60-62	34.93339774	9.268492544	9.477798253	14.64603662	11.13077581	23.80262194	-1.128587389
62-64	41.70406384	9.743786363	10.12719263	13.49659028	11.12252309	30.58154075	-1.272433636
64-66	29.07197239	10.58369361	12.10892659	8.674611256	10.45574382	18.61622857	-2.670962884
66-68	28.37550848	4.157131482	10.05173532	7.890485869	7.366450891	21.00905759	-0.884598084
68-70	28.45558754	2.836376167	9.281701436	7.347542363	6.488539989	21.96704755	0.432396825
70-72	34.69853322	2.383728306	5.121678876	7.458576035	4.987994406	29.71053882	1.836023439
72-74	27.48124835	8.94716688	15.02458978	9.534669745	11.1688088	16.31243955	-2.589266067

Table B.2 continued

E stands for efficiency, BKG stands for background							
E46.52 (using average)	E295 (using average)	E352 (using average)	E609	BKG cps 46.5	BKG cps 295	BKG cps 352	BKG cps 609
0.0174581	0.009550067	0.007674256	0.00375849	0.0142	0.0025	0.00362	0.0041312
Depth in Core (cm)	Peak Pb-210 cps (counts/sec)	Peak 295 keV cps	Peak 352 keV cps	Peak 609 keV cps	Peak 662 keV cps		
0-2	0.025844907	0.006041667	0.01534722	0.0090741	2.6967593		
2-4.0	0.025231481	0.008125	0.01402778	0.008588	0.6944444		
4-6.0	0.023819444	0.006678241	0.01246528	0.0099421	1.4699074		
6.0-8.0	0.025787037	0.010844907	0.0153125	0.0130093	1.7592593		
8.0-10.0	0.0246875	0.01099537	0.01456019	0.0123727	2.1527778		
10.0-12.0	0.025023148	0.008564815	0.01747685	0.0098032	2.6157407		
12.0-14.0	0.021145833	0.006712963	0.01340278	0.0103125	2.8472222		
14.0-16.0	0.021041667	0.007638889	0.01556713	0.0106597	2.0023148		
16.0-18.0	0.022349537	0.008090278	0.01381944	0.0094329	2.2916667		
18.0-20.0	0.020763889	0.008136574	0.01368056	0.0089468	3.0208333		
20.0-22.0	0.021805556	0.007407407	0.0134838	0.0092014	3.2523148		
22.0-24.0	0.021712963	0.006435185	0.01443287	0.0081481	3.4953704		
24.0-26.0	0.020868056	0.00712963	0.01265046	0.0093171	5.3240741		
26.0-28.0	0.022122483	0.004365634	0.01348932	0.0083389	2.0724499		
28.0-30.0	0.022349537	0.005659722	0.01438657	0.0101736	1.8518519		
30.0-32.0	0.022673611	0.007708333	0.01116898	0.0105671	1.0648148		
32.0-34.0	0.022233796	0.010509259	0.01576389	0.0133218	0.2546296		
34.0-36.0	0.020763889	0.003587963	0.00923611	0.0094097	1.9097222		
36.0-38.0	0.021944444	0.008761574	0.01236111	0.0110069	1.5162037		
38.0-40	0.020613426	0.008287037	0.01503472	0.0126042	0.0810185		
40-42.0	0.022615741	0.010891204	0.01914352	0.015544	0.1851852		
42.0-44	0.023217593	0.01287037	0.0191088	0.0134491	-0.416667		
44-46.0	0.022708333	0.013125	0.01969907	0.0150926	0.1851852		
46.0-48.0	0.022546296	0.010601852	0.01402778	0.011875	0.6712963		
48.0-50.	0.020740741	0.01037037	0.01451389	0.0112269	1.8287037		
50-52.0	0.020763889	0.009618056	0.01741898	0.0107755	0.1736111		
52-54	0.021944444	0.008888889	0.00993056	0.0089583	1.2962963		
54-56	0.020613426	0.006689815	0.01219907	0.0080093	-0.416667		
56-58	0.022615741	0.006921296	0.01305556	0.0080093	1.8518519		
58-60	0.023217593	0.010231481	0.01733796	0.0108102	0.9259259		
60-62	0.022708333	0.008368539	0.01294298	0.0137771	-0.34981		
62-64	0.022546296	0.007569444	0.01180556	0.0114352	-0.324074		
64-66	0.020740741	0.008690231	0.01462276	0.0094086	-0.76474		
66-68	0.020034722	0.004722222	0.01196759	0.0085185	-0.231481		
68-70	0.020185185	0.004050926	0.01150463	0.0083102	0.1157407		
70-72	0.022106481	0.003912037	0.00833333	0.0087269	0.5324074		
72-74	0.020763889	0.008055556	0.01811343	0.0102894	-0.787037		

Table B.2 continued

Depth in Core (cm)	Live time (s)	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV
0-2	86400	4130	2233	2435	522	3119
2-4.0	86400	4070	2180	2533	702	2917
4-6.0	86400	4197	2058	2354	577	2985
6.0-8.0	86400	4339	2228	2639	937	3346
8.0-10.0	86400	4314	2133	2788	950	3413
10.0-12.0	86400	4056	2162	2503	740	3277
12.0-14.0	86400	3864	1827	2548	580	3031
14.0-16.0	86400	3834	1818	2594	660	3209
16.0-18.0	86400	3951	1931	2428	699	3182
18.0-20.0	86400	3873	1794	2439	703	3072
20.0-22.0	86400	3858	1884	2478	640	3038
22.0-24.0	86400	3805	1876	2408	556	2881
24.0-26.0	86400	3784	1803	2400	616	2930
26.0-28.0	81546	3659	1804	2331	356	2832
28.0-30.0	86400	3730	1931	2525	489	3178
30.0-32.0	86400	3811	1959	2368	666	2961
32.0-34.0	86400	3832	1921	2671	908	3305
34.0-36.0	86400	3681	1794	2374	310	2909
36.0-38.0	86400	3940	1896	2609	757	3259
38.0-40	86400	3902	1781	2650	716	3340
40-42.0	86400	4075	1954	2868	941	3721
42.0-44	86400	3924	2006	2766	1112	3550
44-46.0	43200	1933	981	1455	567	1920
46.0-48.0	43200	1951	974	1374	458	1666
48.0-50.	43200	1876	896	1261	448	1590
50-52.0	86400	3821	1731	2587	831	3272
52-54	43200	1870	872	1279	384	1542
54-56	43200	1967	955	1218	289	1605
56-58	43200	1823	829	1215	299	1509
58-60	43200	1882	929	1221	442	1562
60-62	37163	1653	750	1070	311	1470
62-64	43200	1838	595	1263	327	1544
64-66	43151.9	1898	585	1154	375	1479
66-68	43200	1818	530	1133	204	1418
68-70	43200	1865	678	1132	175	1451
70-72	43200	1854	608	1180	169	1394
72-74	86400	3925	2122	2562	696	3226

Table B.2 continued

Depth in Core (cm)	Live time (s)	Peak Area 351.9 keV	Total Area 609.3 keV	Peak Area 609.3 keV	Total Area 661.2 keV (Cs-137)	Peak Area 661.3 keV (Cs-137)
0-2	86400	1326	1953	784	745	233
2-4.0	86400	1212	1873	742	643	60
4-6.0	86400	1077	1999	859	743	127
6.0-8.0	86400	1323	2074	1124	746	152
8.0-10.0	86400	1258	2152	1069	753	186
10.0-12.0	86400	1510	2054	847	908	226
12.0-14.0	86400	1158	1946	891	796	246
14.0-16.0	86400	1345	2042	921	833	173
16.0-18.0	86400	1194	1889	815	803	198
18.0-20.0	86400	1182	1904	773	778	261
20.0-22.0	86400	1165	1916	795	826	281
22.0-24.0	86400	1247	1863	704	902	302
24.0-26.0	86400	1093	1926	805	884	460
26.0-28.0	81546	1100	1811	680	785	169
28.0-30.0	86400	1243	2000	879	727	160
30.0-32.0	86400	965	1968	913	714	92
32.0-34.0	86400	1362	2206	1151	704	22
34.0-36.0	86400	798	1982	813	721	165
36.0-38.0	86400	1068	2110	951	692	131
38.0-40	86400	1299	2201	1089	629	7
40-42.0	86400	1654	2369	1343	610	16
42.0-44	86400	1651	2217	1162	630	-36
44-46.0	43200	851	1213	652	322	8
46.0-48.0	43200	606	1083	513	304	29
48.0-50.	43200	627	1027	485	321	79
50-52.0	86400	1505	2052	931	598	15
52-54	43200	429	995	387	298	56
54-56	43200	527	1002	346	329	-18
56-58	43200	564	1002	346	300	80
58-60	43200	749	1009	467	310	40
60-62	37163	481	930	512	284	-13
62-64	43200	510	960	494	305	-14
64-66	43151.9	631	910	406	303	-33
66-68	43200	517	919	368	298	-10
68-70	43200	497	863	359	280	5
70-72	43200	360	938	377	326	23
72-74	86400	1565	2001	889	587	-68

Table B.2 continued

Depth in Core(cm)	Crucible wt (g)	Crucible + wet wt (g)	wet wt	Crucible + dry wt (g)	Dry Wt	Sample dry wt + vial (g)	Vial weight	Sample dry wt (g)
0-2	27.69	30.55	2.86	28.42	0.73	13.87	6.26	7.61
2-4.0	28.72	31.82	3.1	29.69	0.97	14.42	6.21	8.21
4-6.0	16.51	19.47	2.96	17.42	0.91	14.7	6.2	8.5
6.0-8.0	27.87	30.66	2.79	28.81	0.94	16.16	6.18	9.98
8.0-10.0	26.05	29.04	2.99	27.08	1.03	16.59	6.19	10.4
10.0-12.0	27.56	30.29	2.73	28.31	0.75	15.32	6.27	9.05
12.0-14.0	15.72	18.09	2.37	16.39	0.67	13	6.22	6.78
14.0-16.0	16.32	19.19	2.87	17.12	0.8	14.06	6.2	7.86
16.0-18.0	26.57	29.47	2.9	27.33	0.76	14.47	6.21	8.26
18.0-20.0	27.39	30.29	2.9	28.19	0.8	14.13	6.19	7.94
20.0-22.0	27.04	29.97	2.93	27.85	0.81	14.54	6.15	8.39
22.0-24.0	27.55	29.81	2.26	28.12	0.57	13.93	6.17	7.76
24.0-26.0	16.51	19.34	2.83	17.2	0.69	13.94	6.2	7.74
26.0-28.0	27.43	30.25	2.82	28.14	0.71	14.39	6.23	8.16
28.0-30.0	15.73	18.67	2.94	16.5	0.77	14.1	6.2	7.9
30.0-32.0	26.58	29.56	2.98	27.39	0.81	14.74	6.14	8.6
32.0-34.0	27.04	30.01	2.97	27.87	0.83	15.11	6.22	8.89
34.0-36.0	27.81	30.77	2.96	28.66	0.85	13.91	6.18	7.73
36.0-38.0	16.32	19.26	2.94	17.17	0.85	15.84	6.18	9.66
38.0-40	27.68	30.65	2.97	28.61	0.93	15.23	6.18	9.05
40-42.0	28.73	31.78	3.05	29.82	1.09	18.02	6.23	11.79
42.0-44	26.06	28.9	2.84	27	0.94	16.66	6.14	10.52
44-46.0	16.31	19.24	2.93	17.19	0.88	15.39	6.16	9.23
46.0-48.0	27.42	30.18	2.76	28.24	0.82	15.69	6.18	9.51
48.0-50.	28.73	31.59	2.86	29.53	0.8	15.25	6.17	9.08
50-52.0	27.55	30.5	2.95	28.43	0.88	15.71	6.18	9.53
52-54	15.72	18.55	2.83	16.49	0.77	13.81	6.23	7.58
54-56	16.5	19.43	2.93	17.32	0.82	14.81	6.17	8.64
56-58	26.57	29.3	2.73	27.32	0.75	14.86	6.2	8.66
58-60	27.69	30.57	2.88	28.49	0.8	14.77	6.15	8.62
60-62	27.33	30.26	2.93	28.13	0.8	15.54	6.23	9.31
62-64	27.82	30.7	2.88	28.59	0.77	13.84	6.19	7.65
64-66	27.03	29.94	2.91	27.83	0.8	14.81	6.21	8.6
66-68	26.06	28.84	2.78	26.76	0.7	14.06	6.2	7.86
68-70	27.27	30.09	2.82	28.05	0.78	14.24	6.2	8.04
70-72	18.34	21.1	2.76	19.1	0.76	14.9	6.19	8.71
72-74	26.04	28.8	2.76	26.79	0.75	15.3	6.17	9.13

Table B.3 Cedar Point Creek age and sedimentation rate data

Depth in Core (cm)	dry density (dry g/wet volume)	unsupported Pb-210 (pCi/cm3).	Cumm. Resid. Unsup. Pb-210 (pCi/cm2)	Age Depos. (yr)	Sed. Rate g/cm2/yr
0-2	0.0775925	2.22424337	3703.4727	1998	4.0157572
2.0-4	0.162403	5.90815472	3449.8361	1995.7176	2.9475505
4.0-6	0.1541024	0.12457397	2984.0618	1991.0513	114.73886
6.0-8	0.1826132	-2.80452742	2877.3677	1989.8799	-5.823557
8.0-10	0.1977708	0.32267579	2935.2017	1990.5202	55.91834
10.0-12	0.2291687	4.35279029	2812.9486	1989.1515	4.6033067
12.0-14	0.2468526	1.53228714	2482.4202	1985.13	12.430637
14-16	0.272837	1.18870268	2310.3281	1982.8186	16.482548
16-18	0.2057105	-2.22614748	2160.8573	1980.6668	-6.206534
18-20	0.2699499	-2.26467231	2173.2244	1980.8504	-8.051985
20-22	0.2847466	2.9368249	2178.3819	1980.9266	6.5650058
22-24	0.2634538	1.89996421	1956.0179	1977.4626	8.4304821
24-26	0.2446872	3.7606343	1786.8756	1974.5529	3.6138079
26-28	0.2648973	-0.67783957	1554.6278	1970.0735	-18.88416
28-30	0.2122066	2.48257444	1497.2075	1968.8627	3.9779486
30-32	0.2511833	2.21198865	1329.6217	1965.0437	4.6930653
32-34	0.2461308	1.79161121	1180.6251	1961.22	5.0414416
34-36	0.2804159	4.69825718	1053.0877	1957.5422	1.9536686
36-38	0.2540705	2.78847336	851.33061	1950.6998	2.4110518
38-40	0.2944908	3.23969813	718.02098	1945.2208	2.028733
40-42	0.2879947	1.453581	585.03584	1938.6311	3.6028673
42-44	0.2403564	4.03569923	504.30407	1933.8538	0.9335768
44-46	0.2652582	0.49334153	377.74426	1924.5572	6.3130565
46-48	0.2612884	2.69392085	331.08969	1920.3161	0.9981631
48-50	0.2948517	3.54280764	251.19921	1911.432	0.6498227
50-52	0.2605666	0.46049717	170.2	1898.9083	2.9934495
52-54	0.2768069	4.46923193	140.35975	1892.7066	0.2702136
54-56	0.3201144	1.23726275	72.274139	1871.3526	0.5812283
56-58	0.2890773	3.92632502	47.921209	1858.1328	0.1096671
58-60	0.3359938	4.20791969	12.382957	1814.5963	0.0307333
60-62	0.3298585	-6.64832941	-8.576374	#NUM!	0.0132263
62-64	0.3323848	1.53651948	9.0084717	1804.3606	0.0605724
64-66	0.3201144	2.9677164	2.9677164	1768.6376	0.0099501

Table B.4 Cedar Point Creek unsupported and supported Pb-210 data

Depth in Core (cm)	Total Lead 210 (pCi/g dry sediment at 46.5)	same as previous but at C295	C352	C609	supported Pb-210 C	unsupported Pb-210 C	cesium concentration (pCi/g).
0-2	31.723882	6.058038	2.0597243	1.056834	3.0581988	28.66568361	-3.535393697
2.0-4	48.472668	10.994457	8.2975801	16.987196	12.093078	36.37959029	11.69078565
4.0-6	5.5735134	3.4320012	7.1761329	3.6872533	4.7651291	0.808384302	1.144517027
6.0-8	-5.40444	-0.241532	14.444523	15.656944	9.9533115	-15.3577513	7.162887645
8.0-10	11.095331	11.157625	3.8944328	13.339243	9.4637667	1.631564609	15.52785041
10.0-12	31.850201	6.600291	13.418691	18.550141	12.856374	18.99382692	7.911198824
12.0-14	16.388239	11.727471	8.6451949	10.17016	10.180942	6.207296817	7.20560501
14-16	16.502631	9.6076087	14.091064	12.738751	12.145808	4.356822888	5.954871009
16-18	4.3064031	12.283708	13.729998	19.370757	15.128154	-10.8217509	9.616945336
18-20	-0.151911	9.7309383	5.4280463	9.5529791	8.2373212	-8.38923248	16.7799936
20-22	22.532824	11.623505	11.94784	13.085669	12.219005	10.31381907	9.04957519
22-24	16.106986	2.0405586	8.9302897	15.714841	8.8952298	7.211755901	10.41993874
24-26	25.882113	12.281457	10.460313	8.7971165	10.512962	15.36915061	6.348782595
26-28	7.789055	10.294645	9.3481687	11.40098	10.347931	-2.55887645	11.17775246
28-30	21.315674	7.0720517	12.922758	8.8556428	9.6168174	11.69885642	4.93282972
30-32	20.877442	12.840367	9.8126237	13.560519	12.07117	8.806272344	13.11482872
32-34	13.742632	2.2026029	9.4783657	7.7096184	6.463529	7.279102809	8.282179647
34-36	25.086986	5.3688566	8.7292792	10.899005	8.3323801	16.75460623	8.386537008
36-38	16.977497	5.3064838	6.990729	5.7096896	6.0023008	10.97519635	9.277098162
38-40	17.569214	1.6111498	8.7259561	9.3674843	6.5681968	11.00101722	7.594231607
40-42	13.535504	12.40177	4.9197116	8.1432806	8.488254	5.047249858	8.979059996
42-44	24.520881	6.4355054	3.0156865	13.740021	7.7304042	16.79047647	13.65939653
44-46	13.025932	6.4257214	10.015924	17.05659	11.166079	1.85985376	12.74547313
46-48	17.262488	5.6341745	10.105837	5.1170215	6.9523445	10.31014382	13.88685878
48-50	18.903691	11.552738	5.5488222	3.5628371	6.8881325	12.01555884	14.37956155
50-52	10.767713	8.1773149	8.585959	10.237991	9.0004217	1.767291639	11.76802416
52-54	21.565043	3.1501187	6.3695247	6.7384839	5.4193758	16.14566685	14.29910733
54-56	11.392144	4.655136	5.3380284	12.588075	7.5270797	3.865064778	6.193962442
56-58	17.698109	-1.568104	7.2352845	6.6803538	4.1158447	13.58226467	13.24782022
58-60	21.177682	5.7266095	4.8191805	15.415849	8.6538797	12.52380276	4.240489742
60-62	-8.28559	7.9926003	11.063418	16.55249	11.869503	-20.1550923	16.13908018
62-64	11.248955	8.0988955	5.0295655	6.7502662	6.6262424	4.622712638	19.30130443
64-66	16.221588	5.06537	9.4646808	6.3223126	6.9507878	9.270800467	17.95065924

Table B.5 Cedar Point Creek counts per second for 46.5, 295, 352, 609, and 662 keV

E46.52	E295 (using average)	E352(using average)	E609	BKG cps 46.5	BKG cps 295	BKG cps 352	BKG cps 609
0.0174581	0.0095501	0.00767426	0.0037585	0.010796	0.001736	0.002704	0.00333
Depth in Core (cm)	Peak Pb-210 cps (counts/sec)	cps 295 keV	cps 352 keV	cps 609 keV	cps 662 keV		
0-2	0.0127546	0.00270833	0.0032176	0.003472	-0.277778		
2.0-4	0.0165278	0.00511574	0.0066667	0.007708	1.7592593		
4.0-6	0.0115046	0.00287037	0.0063889	0.004352	0.1851852		
6.0-8	0.01	0.00164352	0.0112963	0.008356	1.3425926		
8.0-10	0.0125463	0.00631173	0.0051852	0.007917	3.117284		
10.0-12	0.0159954	0.00453704	0.0115509	0.009931	1.6435185		
12.0-14	0.0139815	0.00766204	0.0094907	0.007639	1.7824074		
14-16	0.014375	0.00715278	0.0150463	0.009352	1.6435185		
16-18	0.0115046	0.00699074	0.0118287	0.010278	2.0138889		
18-20	0.0107639	0.00708333	0.007338	0.007731	4.5138889		
20-22	0.0153704	0.00787037	0.0125	0.00912	2.337963		
22-24	0.0138889	0.00275463	0.0096296	0.009907	2.5462963		
24-26	0.0153935	0.00740741	0.0102083	0.006736	1.4351852		
26-28	0.0122917	0.006875	0.0099537	0.008102	2.7314815		
28-30	0.0140972	0.00458333	0.010787	0.006319	0.9722222		
30-32	0.0144444	0.00756944	0.0096296	0.008495	2.9166667		
32-34	0.0132407	0.00275463	0.0095139	0.006319	1.875		
34-36	0.0158889	0.00456944	0.0098611	0.008153	2.1666667		
36-38	0.0139583	0.00430556	0.007963	0.005648	2.1990741		
38-40	0.0145833	0.00263889	0.0103009	0.007731	2.0833333		
40-42	0.0136111	0.00844136	0.0068364	0.007022	2.3765432		
42-44	0.0151389	0.00469907	0.0048611	0.008634	3.0787037		
44-46	0.013287	0.00493056	0.0104398	0.01044	3.1018519		
46-48	0.0140972	0.00453704	0.0105093	0.005463	3.3796296		
48-50	0.0148611	0.00819444	0.0075231	0.005	3.9351852		
50-52	0.0127932	0.00567901	0.0091358	0.007469	2.7777778		
52-54	0.0151852	0.00340278	0.0079398	0.006319	3.7037037		
54-56	0.0131713	0.00425926	0.0071991	0.009051	1.6435185		
56-58	0.0145139	0.00087963	0.0088426	0.006389	3.5416667		

Table B.5 Cedar Point Creek counts per second for 46.5, 295, 352, 609, and 662 keV

Depth in Core (cm)	Peak Pb-210 cps (counts/sec)	cps 295 keV	cps 352 keV	cps 609 keV	cps 662 keV		
58-60	0.0160648	0.00543981	0.0075463	0.01169	1.3425926		
60-62	0.0091898	0.00576389	0.0113657	0.010324	3.9814815		
62-64	0.0135417	0.006875	0.007662	0.006921	5.9953704		
64-66	0.0145602	0.00479167	0.0115741	0.006528	5.3009259		

Table B.6 Cedar Point Creek counts for 46.5, 295, and 352 keV

Depth in Core(cm)	Live time (s)	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV
0-2	43200	1678	551	1012	117	1155
2.0-4	43200	1810	714	1062	221	1251
4.0-6	43200	1313	497	1026	124	1133
6.0-8	43200	1283	432	1069	71	1195
8.0-10	64800	2028	813	1666	409	2014
10.0-12	43200	1923	691	1187	196	1382
12.0-14	43200	1318	604	1158	331	1408
14-16	43200	1370	621	1273	309	1551
16-18	43200	1365	497	1245	302	1527
18-20	43200	1302	465	1078	306	1289
20-22	43200	1882	664	1201	340	1415
22-24	43200	1934	600	1117	119	1344
24-26	43200	1887	665	1147	320	1316
26-28	43200	1861	531	1103	297	1340
28-30	43200	1897	609	1162	198	1376
30-32	43200	1804	624	1079	327	1220
32-34	43200	1843	572	1124	119	1303
34-36	72000	3216	1144	1798	329	2238
36-38	43200	1930	603	986	186	1298
38-40	43200	1964	630	1071	114	1399
40-42	64800	2090	882	1647	547	2042
42-44	43200	1902	654	1105	203	1297
44-46	43200	1896	574	1142	213	1308
46-48	43200	1901	609	1125	196	1329

Table B.6 Cedar Point Creek counts for 46.5, 295, and 352 keV

Depth in Core(cm)	Live time (s)	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV
48-50	43200	1955	642	1147	354	1367
50-52	64800	2009	829	1748	368	2050
52-54	43200	1843	656	1158	147	1368
54-56	43200	1892	569	1113	184	1274
56-58	43200	1852	627	1063	38	1283
58-60	43200	1972	694	1151	235	1404
60-62	43200	1321	397	1233	249	1507
62-64	43200	1852	585	1254	297	1409
64-66	43200	1434	629	1116	207	1339

Table B.7 Cedar Point Creek counts for 352, 609, and 661 keV

Depth in Core(cm)	Live time (s)	Peak Area 351.9 keV	Total Area 609.3 keV	Peak Area 609.3 keV	Total Area 661.3 keV (Cs-137)	Peak Area 661.3 keV (Cs-137)
0-2	43200	139	777	150	296	-12
2.0-4	43200	288	780	333	346	76
4.0-6	43200	276	749	188	355	8
6.0-8	43200	488	779	361	350	58
8.0-10	64800	336	1254	513	554	202
10.0-12	43200	499	885	429	385	71
12.0-14	43200	410	919	330	407	77
14-16	43200	650	1012	404	407	71
16-18	43200	511	995	444	362	87
18-20	43200	317	819	334	437	195
20-22	43200	540	926	394	354	101
22-24	43200	416	837	428	347	110
24-26	43200	441	890	291	365	62
26-28	43200	430	854	350	388	118
28-30	43200	466	891	273	400	42
30-32	43200	416	899	367	379	126
32-34	43200	411	796	273	301	81
34-36	72000	710	1509	587	629	156
36-38	43200	344	833	244	370	95

Table B.7 continued

Depth in Core(cm)	Live time (s)	Peak Area 351.9 keV	Total Area 609.3 keV	Peak Area 609.3 keV	Total Area 661.3 keV (Cs-137)	Peak Area 661.3 keV (Cs-137)
38-40	43200	445	961	334	387	90
40-42	64800	443	1310	455	567	154
42-44	43200	210	867	373	403	133
44-46	43200	451	882	451	404	134
46-48	43200	454	797	236	421	146
48-50	43200	325	843	216	434	170
50-52	64800	592	1292	484	659	180
52-54	43200	343	834	273	364	160
54-56	43200	311	866	391	385	71
56-58	43200	382	808	276	417	153
58-60	43200	326	952	505	416	58
60-62	43200	491	940	446	447	172
62-64	43200	331	945	299	490	259
64-66	43200	500	947	282	493	229

Table B.8 Cedar Point Creek sample weight data

Depth in Core(cm)	Crucible wt (g)	Crucible + dry wt (g)	Dry Wt used in dry density calculation	Sample dry wt + vial (g)	Vial weight	Sample dry wt (g)
0-2	27.42	27.54	0.12	8.57	6.21	2.36
2.0-4	19.28	19.74	0.46	10.7	6.18	4.52
4.0-6	17.58	18.01	0.43	11.06	6.2	4.86
6.0-8	18.45	18.96	0.51	11.81	6.18	5.63
8.0-10	15.82	16.37	0.55	12.24	6.21	6.03
10.0-12	16.32	16.85	0.53	12.44	6.2	6.24
12.0-14	19.41	19.99	0.58	13.62	6.19	7.43
14-16	27.59	28.21	0.62	14.45	6.16	8.29
16-18	27.44	27.9	0.46	12.48	6.19	6.29
18-20	17.28	17.85	0.57	14.3	6.22	8.08
20-22	17.17	17.9	0.73	13.96	6.2	7.76
22-24	17.17	17.87	0.7	13.57	6.23	7.34
24-26	15.72	16.42	0.7	12.98	6.19	6.79

Table B.8 Cedar Point Creek sample weight data

Depth in Core (cm)	Crucible wt (g)	Crucible + dry wt (g)	Dry Wt used in dry density calculation	Sample dry wt + vial (g)	Vial weight	Sample dry wt (g)
26-28	27.26	27.95	0.69	13.57	6.23	7.34
28-30	19.28	19.92	0.64	12.11	6.19	5.92
30-32	17.47	18.15	0.68	12.86	6.18	6.68
32-34	18.35	19.1	0.75	13.01	6.21	6.8
34-36	27.41	28.17	0.76	13.96	6.2	7.76
36-38	17.47	18.12	0.65	13.31	6.19	7.12
38-40	17.17	17.87	0.7	14.45	6.21	8.24
40-42	18.42	19.22	0.8	14.16	6.21	7.95
42-44	19.29	19.98	0.69	12.95	6.18	6.77
44-46	27.27	27.95	0.68	13.56	6.25	7.31
46-48	15.72	16.32	0.6	13.5	6.19	7.31
48-50	18.36	19.07	0.71	14.4	6.18	8.22
50-52	27.53	28.33	0.8	13.24	6.15	7.09
52-54	27.43	28.1	0.67	13.97	6.19	7.78
54-56	18.62	19.38	0.76	14.23	6.26	7.97
56-58	27.33	28.06	0.73	14.22	6.19	8.03
58-60	28.73	29.53	0.8	15.68	6.17	9.51
60-62	15.72	16.53	0.81	13.56	6.15	7.41
62-64	26.57	27.32	0.75	15.51	6.18	9.33
64-66	16.5	17.35	0.85	15.03	6.16	8.87

Table B.9 "Backdoor creek" sedimentation rate and sediment age data

Depth in Core (cm)	bulk density (dry g/cm ³ wet volume)	unsupporte d PB-210 (pCi/cm ³)	Cumm. Resid. Unsup. Pb-210 (pCi/cm ²)	Age Depos. (yr)	Sed. Rate g/cm ² /yr
0-2	0.1230769	3.6683928	3523.856	1997	3.67484935
2-4.0	0.4	7.3697585	3206.8189	1993.9669	5.41005607
4.0-6	0.4115385	6.5670905	2734.1925	1988.8373	5.32582776
6.0-8	0.3923077	4.5765879	2326.3626	1983.6405	6.19844888
8-10.0	0.4076923	4.2432692	2028.4022	1979.2311	6.05768375
10.0-12	0.2846154	3.6575337	1762.0808	1974.7028	4.26202956
12.0-14	0.3884615	11.108249	1534.9905	1970.264	1.66850957

Table B.9 continued

Depth in Core (cm)	bulk density (dry g/cm ³ wet volume)	unsupported PB-210 (pCi/cm ³)	Cumm. Resid. Unsup. Pb-210 (pCi/cm ²)	Age Depos. (yr)	Sed. Rate g
14-16	0.3692308	3.7985745	1054.3046	1958.1787	3.1853996
16-18	0.3461538	2.1865121	866.58055	1951.8704	4.26429077
18-20	0.3269231	3.0428594	745.63683	1947.0344	2.4900705
20-22	0.1884615	2.9552081	607.74875	1940.4559	1.20470118
22-24	0.3538462	1.2406508	484.48634	1933.1634	4.29503853
24-26	0.4307692	-0.533771	417.62325	1928.3856	-10.475978
26-28	0.3576923	3.785626	398.3089	1926.8621	1.1698024
28-30	0.4115385	-0.084526	281.83272	1915.7334	-42.651353
30-32	0.2538462	2.2678337	257.90208	1912.8786	0.89729412
32-34	0.2923077	-0.955699	191.29087	1903.2661	-1.818586
34-36	0.3346154	-1.634011	185.32751	1902.2472	-1.1796451
36-38	0.15	0.7726594	185.03773	1902.1968	1.11656507
38-40	0.3423077	3.2231086	149.33186	1895.2995	0.49296352
40-42	0.2807692	1.7562528	92.212128	1879.79	0.45821693
42-44	0.3423077	1.3003099	59.71968	1865.8135	0.48866121
44-46	0.3	3.0189889	36.987901	1850.4007	0.11424574
46-48	0.2692308	1.549367	12.582645	1815.7105	0.0679615

Table B.10 "Backdoor creek" Cs-137, unsupported and supported Pb-210 concentrations

Depth in Core	Total Pb-210 (pCi/g dry sediment at 46.5)	same as previous but at C295	C352	C609	supported Pb-210 C	unsupported Pb-210 C	cesium conc.
0-2	42.842533	7.2886826	16.944407	14.877435	13.036842	29.805692	12.20859
2-4.0	26.585025	10.333352	6.345704	7.8028296	8.1606287	18.424396	6.9605067
4.0-6	23.558858	9.3627386	6.7266936	6.7148926	7.6014416	15.957416	11.599743
6.0-8	19.827234	9.0411192	6.8506263	8.5925197	8.1614217	11.665812	6.2286763
8-10.0	16.30224	2.6983226	6.914222	8.0701189	5.8942212	10.408019	5.8563169
10.0-12	18.642649	5.9673843	6.2052933	5.2028873	5.7918549	12.850794	10.691594
12.0-14	45.213597	16.782988	18.492171	14.579153	16.618104	28.595493	11.473727
14-16	17.52118	6.606672	7.987661	7.1057896	7.2333742	10.287806	9.8571665
16-18	13.384657	7.9033611	6.4194644	6.8813737	7.0680664	6.3165905	6.5842244
18-20	16.03472	8.8724516	6.2967156	5.0122821	6.7271498	9.3075699	8.2601259

Table B.10 continued

Depth in Core	Total Pb-210 (pCi/g dry sediment at 46.5)	same as previous but at C295	C352	C609	supported Pb-210 C	unsupported Pb-210 C	cesium conc.
20-22	21.102587	6.9690621	6.873443	2.4231681	5.4218911	15.680696	8.5966134
22-24	12.52143	7.1143568	8.2423062	11.689066	9.0152429	3.506187	7.3376323
24-26	5.415336	5.8462083	6.6609411	7.4561957	6.6544484	-1.2391124	8.4399861
26-28	16.411763	4.449811	5.6039676	7.4310995	5.8282927	10.58347	7.1225249
28-30	19.943594	15.835282	19.624474	24.987195	20.148984	-0.20539	5.5729239
30-32	17.94615	9.4564463	10.115339	7.4649945	9.0122598	8.9338905	8.4945432
32-34	13.092831	14.671843	16.225598	18.189545	16.362329	-3.2694973	14.855973
34-36	10.33232	12.524744	16.569391	16.55258	15.215572	-4.8832518	10.175036
36-38	19.111188	10.758417	16.387705	14.734251	13.960125	5.1510629	11.869007
38-40	19.425441	12.872494	10.585698	6.570661	10.009618	9.4158228	8.6541924
40-42	11.775486	2.3611031	6.6405397	7.5593741	5.520339	6.2551468	7.3950354
42-44	14.860707	12.892636	9.3107946	10.982715	11.062048	3.7986581	7.1549634
44-46	20.064237	10.753939	8.7787775	10.470106	10.000941	10.063296	10.587812
46-48	11.960038	6.3688686	5.0448597	7.2020109	6.2052464	5.7547917	16.7849
50-52	9.7528052	1.051011	6.1221364	5.4838083	4.2189852	5.5338199	14.839163

Table B.11 "Backdoor creek" counts per second for 45.2, 295, 352, and 609 keV

E46.52	E295 (using average)	E352 (using average)	E609	BKG cps 46.5	BKG cps 295	BKG cps 352	BKG cps 609
0.0174581	0.0095501	0.0076743	0.0037585	0.008539	0.001736	0.003306	0.0036365
Depth in Core	Peak Pb-210 cps (counts/sec)	cps 295	cps 352	cps 609	cps 662		
12.0-14	0.0205093	0.013287	0.0230787	0.0128241	3.8657407		
14-16	0.0133565	0.0064583	0.0121759	0.008287	3.4490741		
16-18	0.0116204	0.006466	0.0092747	0.0074074	1.9290123		
18-20	0.0121759	0.0069676	0.0090741	0.0063426	2.3842593		
20-22	0.0141204	0.0065278	0.0106481	0.005162	2.8935185		
22-24	0.0117361	0.0064583	0.0118056	0.0107407	2.3842593		
24-26	0.0102546	0.0065509	0.0118287	0.0092593	3.4027778		
26-28	0.0129398	0.004838	0.009375	0.0083796	2.4305556		
28-30	0.013219	0.0113963	0.0219049	0.0175937	1.664268		
30-32	0.0137269	0.0088426	0.0151157	0.0087731	3.125		
32-34	0.0112963	0.0097685	0.0171065	0.0127546	3.9814815		
34-36	0.011088	0.0097685	0.0198148	0.0133565	3.1944444		
36-38	0.0130787	0.0083796	0.0190278	0.0119676	3.587963		

Table B.11 continued

E46.52	E295 (using average)	E352 (using average)	E609	BKG cps 46.5	BKG cps 295	BKG cps 352	BKG cps 609
0.0174581	0.0095501	0.0076743	0.0037585	0.008539	0.001736	0.003306	0.0036365
Depth in Core	Peak Pb- 210 cps (counts/sec)	cps 295	cps 352	cps 609	cps 662		
38-40	0.013316	0.0099653	0.0138194	0.0074826	2.7083333		
40-42	0.0112037	0.003125	0.009375	0.0077083	2.1296296		
42-44	0.012209	0.0100132	0.0125926	0.0100926	2.2486772		
44-46	0.0129167	0.0078356	0.0110417	0.0090741	2.9398148		
46-48	0.0115396	0.0058899	0.0084177	0.0079374	5.3590162		
50-52	0.0104398	0.0022685	0.008125	0.0061806	3.6805556		

Table B.12 "Backdoor creek" counts per second for 45.2, 295, and 352 keV

Depth in Core (cm)	Live time (s)	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV	Peak Area 351.9 keV
0-2	43200	1344	595	1050	175	1237	504
2-4.0	43200	1405	645	1181	354	1328	409
4.0-6	43200	1467	637	1158	352	1406	452
6.0-8	43200	1400	584	1123	330	1371	443
8-10.0	43200	1450	592	1162	171	1373	525
10.0-12	43200	1473	584	1177	254	1457	432
12.0-14	43200	2273	886	1749	574	2173	997
14-16	43200	1477	577	1270	279	1524	526
16-18	64800	2066	753	1704	419	2076	601
18-20	43200	1387	526	1155	301	1381	392
20-22	43200	1489	610	1232	282	1432	460
22-24	43200	1330	507	1174	279	1482	510
24-26	43200	1374	443	1253	283	1553	511
26-28	43200	1473	559	1166	209	1421	405
28-30	63090.8	2133	834	2113	719	2848	1382
30-32	43200	1503	593	1291	382	1598	653
32-34	43200	1458	488	1290	422	1658	739
34-36	43200	1494	479	1372	422	1757	856
36-38	43200	1447	565	1332	362	1644	822
38-40	57600	1901	767	1633	574	2059	796
40-42	43200	1401	484	1167	135	1394	405

Table B.12 continued

Depth in Core (cm)	Live time (s)	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV	Peak Area 351.9 keV
42-44	75600	2558	923	2267	757	2772	952
44-46	86400	2845	1116	2385	677	2950	954
46-48	79119	2597	913	2120	466	2512	666
50-52	43200	1284	451	1130	98	1349	351

Table B.13 "Backdoor creek" counts for 609 and 661 keV

Depth in Core (cm)	Live time (s)	Total Area 609.3 keV	Peak Area 609.3 keV	Total Area 661.2 keV (Cs-137)	Peak Area 661.3 keV (Cs-137)
0-2	43200	810	344	379	82
2-4.0	43200	911	350	378	92
4.0-6	43200	966	339	388	168
6.0-8	43200	892	379	361	86
8-10.0	43200	886	420	355	102
10.0-12	43200	927	300	394	157
12.0-14	43200	1457	554	596	167
14-16	43200	909	358	391	149
16-18	64800	1383	480	587	125
18-20	43200	911	274	395	103
20-22	43200	907	223	422	125
22-24	43200	930	464	411	103
24-26	43200	951	400	494	147
26-28	43200	923	362	424	105
28-30	63090.8	1861	1110	611	105
30-32	43200	968	379	427	135
32-34	43200	1083	551	425	172
34-36	43200	1119	577	397	138
36-38	43200	1097	517	419	155
38-40	57600	1277	431	569	156
40-42	43200	922	333	422	92
42-44	75600	1875	763	814	170
44-46	86400	1848	784	914	254
46-48	79119	1683	628	886	424
50-52	43200	809	267	456	159

Table B.14 "Backdoor creek" sample weight data

Depth in Core	Crucible wt (g)	Crucible + dry wt (g)	Dry Wt (used to compute bulk density)	Sample dry wt + vial (g)	Vial weight	Sample dry wt (g)
0-2	17.28	17.6	0.32	10.89	6.22	4.67
2-4.0	27.82	28.86	1.04	15.4	6.21	9.19
4.0-6	26.06	27.13	1.07	16.32	6.25	10.07
6.0-8	28.07	29.09	1.02	15.81	6.21	9.6
8-10.0	18.41	19.47	1.06	18.26	6.15	12.11
10.0-12	28.73	29.47	0.74	16.36	6.15	10.21
12.0-14	18.21	19.22	1.01	16.31	6.19	10.12
14-16	27.81	28.77	0.96	16.68	6.17	10.51
16-18	26.05	26.95	0.9	15.01	6.21	8.8
18-20	27.4	28.25	0.85	14.85	6.18	8.67
20-22	27.06	27.55	0.49	16.29	6.18	10.11
22-24	16.51	17.43	0.92	15.96	6.2	9.76
24-26	28.72	29.84	1.12	18.31	6.2	12.11
26-28	15.73	16.66	0.93	16.47	6.22	10.25
28-30	27.27	28.34	1.07	15.16	6.19	8.97
30-32	27.18	27.84	0.66	17.24	6.19	11.05
32-34	26.05	26.81	0.76	14.26	6.21	8.05
34-36	28.74	29.61	0.87	15.58	6.15	9.43
36-38	27.72	28.11	0.39	15.28	6.2	9.08
38-40	26.6	27.49	0.89	15.61	6.21	9.4
40-42	26.63	27.36	0.73	14.87	6.22	8.65
42-44	27.82	28.71	0.89	15.64	6.2	9.44
44-46	15.74	16.52	0.78	14.51	6.17	8.34
46-48	27.42	28.12	0.7	15.85	6.26	9.59
50-52	26.41	27.16	0.75	13.64	6.19	7.45

Table B.15 Background radiation data

Sample	Live time	Total Area 46.52 keV (Pb-210)	Peak Area 46.52 keV (Pb-210)	Total Area 295.2 keV	Peak Area 295.2 keV	Total Area 351.9 keV	Peak Area 351.9 keV	Total Area 609.3 keV	Peak Area 609.3 keV	Total Area 661.2 keV (Cs-137)	Peak Area 661.3 keV (Cs-137)
1	86400	3219	1595	1863	250	2189	396	1422	329	457	28
2	86400	3192	1536	1825	164	2090	465	1333	250	495	-17
3	73268.9	3242	1377	3481	812	1477	-20	1706	257	1143	221
4	72000	2706	1309	1573	370	1717	454	1159	323	474	-43
5	72000	2667	1414	1635	200	1870	430	1283	437	440	0
6	43200	1536	566	984	75	1084	236	709	243	267	-14
8	86400	3001	950	1815	120	2085	106	1330	285	557	100
9	72000	1820	763	1515	135	1617	301	1107	242	426	13
10	43200	1187	280	916	69	1006	105	720	169	272	-36
	Live time	Total Lead 210 cps (cps 46.5)	Peak Lead 210 cps	Peak cps 295	Peak cps 352	Peak cps 609	Supported lead 210 cps	Peak cps 662			
1	86400	0.0372569	0.0184606	0.0028935	0.0045833	0.0038079	0.0037616	0.0175549			
2	86400	0.0369444	0.0177778	0.0018981	0.0053819	0.0028935	0.0033912	-0.0110677			
3	73268.9	0.044248	0.0187938	0.0110825	-0.000273	0.0035076	0.0047724	0.1604938			
4	72000	0.0375833	0.0181806	0.0051389	0.0063056	0.0044861	0.0053102	-0.0328495			
5	72000	0.0370417	0.0196389	0.0027778	0.0059722	0.0060694	0.0049398	0			
6	43200	0.0355556	0.0131019	0.0017361	0.005463	0.005625	0.0042747	-0.024735			
8	86400	0.0347338	0.0109954	0.0013889	0.0012269	0.0032986	0.0019715	0.1052632			
9	72000	0.0252778	0.0105972	0.001875	0.0041806	0.0033611	0.0031389	0.017038			
10	43200	0.0274769	0.0064815	0.0015972	0.0024306	0.003912	0.0026466	-0.1285714			
		average:	0.014892	0.0033764	0.003919	0.0041068	0.0038008	0.0114585			
		stdev	0.0047064	0.003109	0.0022908	0.0010879	0.0011197	0.0826131			

APPENDIX C
NON-EQUILIBRIUM SUSPENSION PROFILE MODELING
COASTAL COHESIVE SEDIMENT TRANSPORT OCP 6297 CLASS NOTES
BY ASHIS J. MEHTA AND YIGONG LI

5.1 Description

In this section, the time-evolution of suspended sediment concentration in the mobile suspension layer is modeled through a one-dimensional, vertical sediment transport model called VEST. The time-varying concentration profile is simulated for: 1) fluid mud subjected to wave motion or waves plus a weak current, and 2) a sediment bed subjected to a (steady, or quasi-steady, e.g., tidal) current, wave motion or waves plus a weak current. Brief descriptions of the simulation options are as follows.

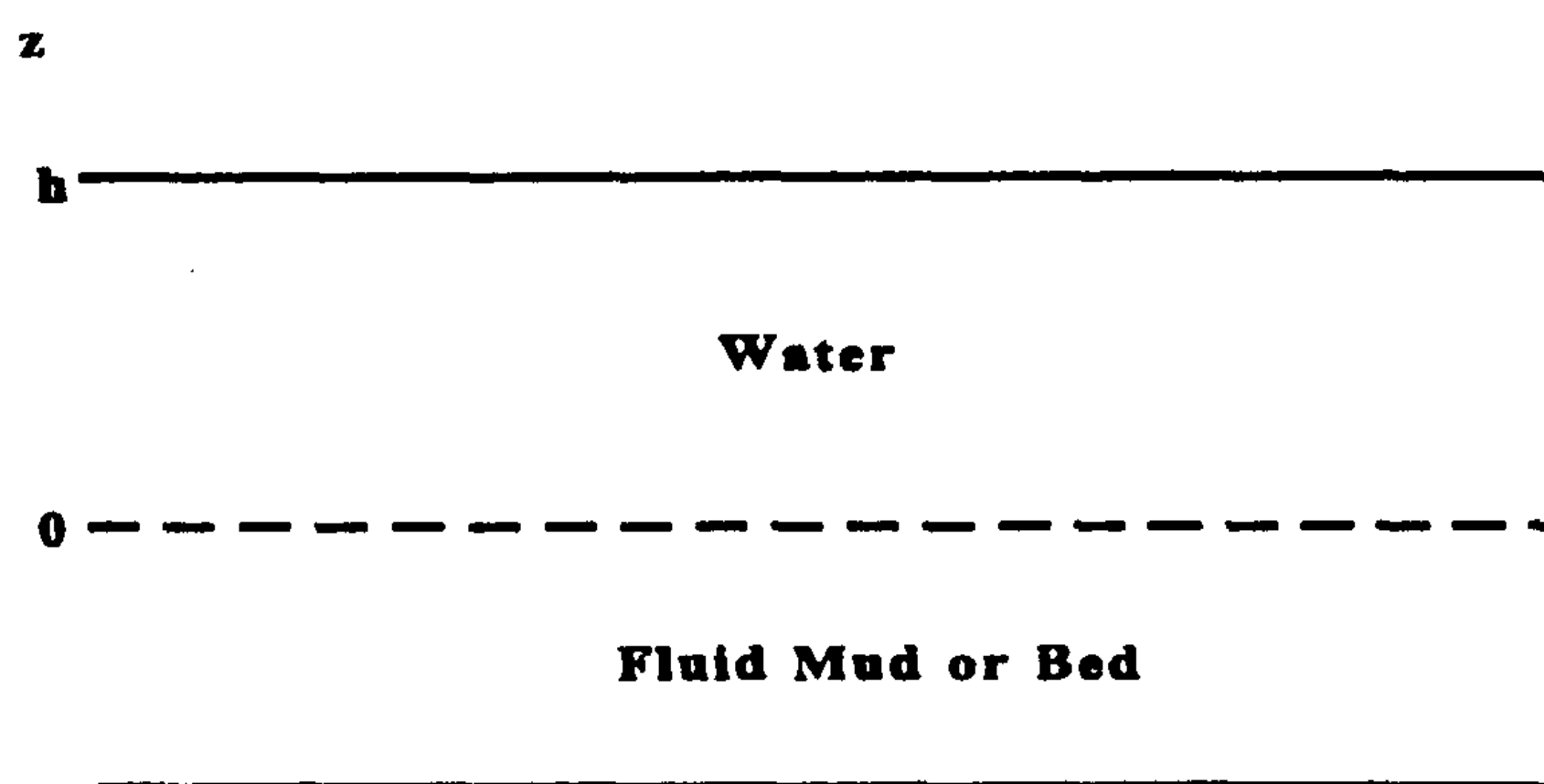


Fig. C.1 Sediment-water interface

5.1.1 Fluid Mud Resuspension

Under this option, the entrainment of fluid mud into the water column and its redeposition can be simulated either under a short period progressive wave, or under a wave and a weak current. A weak current is considered to be one that modulates the

wave-induced sediment diffusion, without however changing the wave-induced flow field.

5.1.2 Bed Resuspension

Under this option, the erosion of sediment from bed into the water column and its redeposition can be simulated under a current, under wave motion, or under a wave and a weak current.

The theoretical bases for these simulations are briefly described next.

5.2 Theory

Referring to the coordinate system defined in Fig. 5.1, vertical suspended sediment transport is described by the (wave-mean) vertical settling-diffusion equation as

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial z} \left(K \frac{\partial C}{\partial z} + W_s C \right)$$

a particular case of the general mass conservative equation:

where K is the diffusion coefficient, W_s is the settling velocity, and C is the sediment concentration in water. To solve Eq. 5.1 the usual net zero flux boundary condition at the

$$\left(K \frac{\partial C}{\partial z} + W_s C \right) \Big|_{z=h} = 0$$

water surface, $z=h$, where h is the water depth, is:

and the boundary condition at the bottom of the water layer, $z=0$, is:

$$\left(K \frac{\partial C}{\partial z} + W_s C \right) \Big|_{z=0} = -F_n$$

where F_n is the net resuspension flux.

The diffusion coefficient is modeled by the suspended sediment concentration

$$K = \frac{K_n}{(1 + \alpha_0 R_i)^{\beta_0}}$$

gradient, and is expressed as (Munk and Anderson, 1948):

where K_n is the neutral diffusion coefficient for non-stratified flows, α_0 and β_0 are non-

$$R_i = \left(\frac{g}{\rho} \right) \frac{-\partial \rho / \partial z}{(\partial u / \partial z)^2}$$

dimensional empirical coefficients and R_i is the gradient Richardson number expressed as

where u is the horizontal velocity, ρ is the fluid density and g is the gravitational acceleration. For a current, the neutral diffusivity can be expressed as (Vanoni, 1975)

$$K_n = \kappa u_* z \left(1 - \frac{z}{h} \right)$$

where u_* is the friction velocity and κ is the Karman constant. For wave motion, K_n can be expressed as (Hwang and Wang, 1982):

$$K_a = \alpha_w H^2 \sigma \frac{\sinh^2 kz}{2 \sinh^2 kh}$$

where H is the wave height, $\sigma = 2\pi/T$ is the wave frequency, T is the wave period, k is the wave number and α_w is a non-dimensional wave diffusion constant.

The bottom boundary condition is determined by the external hydrodynamics and the bottom sediment properties. For the boundary at the interface between water and fluid mud, the rate of entrainment of sediment under waves or under waves and a weak

$$F_a = \begin{cases} \rho_m u_b \beta (R_{ic}^2 R_{ig}^{-1} - R_{ig}) - W_s C|_{z=0} & (R_{ig} < R_{ic}) \\ -W_s C|_{z=0} & (R_{ig} \geq R_{ic}) \end{cases}$$

current can be expressed as (Li, 1996):

where ρ_m is the density of fluid mud, u_b is the amplitude of the horizontal velocity just outside the bottom boundary layer in water, β is a non-dimensional coefficient and R_{ic} is the critical value (for initiating entrainment) of the global Richardson number R_{ig} , defined

$$\text{as: } R_{ig} = \frac{\frac{\rho_m - \rho}{\rho} g \delta}{\Delta u_0^2}$$

where δ is the thickness of the wave boundary layer in water and Δu_0 is the difference between the near-bottom velocity in water and the near-surface velocity in fluid mud, which must be obtained from a wave-mud interaction model. For using the wave-mud interaction model of Jiang (1993), the rheological description of mud must be known, which is modeled here as a three-parameter standard solid (Eq. 4.1). If necessary, this

description can be simplified to a Voigt model (Eq. 4.2) and further as a Newtonian fluid (Eq. 4.3).

The mechanism of entrainment of fluid mud differs from the erosion of settled mud bed having a structured matrix. Fluid mud entrainment depends on the interaction between the turbulent mixing energy and the potential energy stored in mud, and on mud settling, cohesion and viscosity (Mehta and Srinivas, 1993). To calculate the entrainment rate, the critical Richardson number, R_{ic} , and the empirical coefficient, β , need to be specified. Li (1996) found R_{ic} to be 0.043 as a representative average value from his experiments.

The settling velocity is obtained from the following equation (see Eqs. 2.1 and

$$W_s = \begin{cases} W_{sf} & (C < C_1) \\ \frac{aC^n}{(C^2 + b^2)^m} & (C > C_1) \end{cases}$$

2.4):

where W_{sf} is the free settling velocity, C_1 is the minimum concentration for flocculation settling and a , b , m and n are empirical coefficients.

For the boundary condition at the bed surface, $z=0$, the net rate of erosion is expressed as (Ross, 1988; Lee et al., 1994):

$$F_n = \begin{cases} -W_s C|_{z=0} \left(1 - \frac{\tau_b}{\tau_c}\right) & (\tau_b \leq \tau_c) \\ 0 & (\tau_c < \tau_b \leq \tau_s) \\ s(\tau_b - \tau_s) & (\tau_b > \tau_s) \end{cases}$$

where τ_b is the bed shear stress, τ_c is the characteristic deposition shear stress, τ_s is the bed shear strength for erosion and s is an empirical parameter (Mehta, 1988). The factor, $1 - (\tau_b / \tau_c)$, is called the probability of deposition (Krone, 1962).

The bed shear stress is calculated from:

$$\tau_b = \begin{cases} \frac{1}{2} f_w \rho u_b^2 & \text{(for wave motion)} \\ \frac{1}{2} f_c \rho U^2 & \text{(for current)} \end{cases}$$

where u_b is the amplitude of the bottom horizontal velocity under wave motion, f_w is the wave friction coefficient (Jonsson, 1966), U is the characteristic depth-averaged current

$$f_c = 2g \frac{n^2}{h^{1/3}}$$

velocity and f_c is the current friction coefficient, which is expressed as (Vanoni, 1975):

where n is the Manning's bed resistance coefficient.

$$\tau_s = \alpha_e (\phi - \phi_e)^{\beta_e}$$

The bed shear strength for erosion is expressed as (Mehta, 1991):

where α_e and β_e are empirical coefficients, the solids volume fraction $\phi = \rho_D / \rho_s$ and ϕ_e is the critical solids volume fraction below which mud has fluid-like consistency. Here, ρ_s is the sediment granular density and ρ_D is the bed dry density, expressed as (Mehta, et

$$\rho_D = \bar{\rho}_D \zeta \left(\frac{h_b - \Delta z}{h_b} \right)^\xi$$

al., 1982):

where h_b is the bed depth, $\bar{\rho}_D$ is the bed average dry density, Δz is the incremental depth from the bed surface and ζ, ξ are non-dimensional bed-dependent constants.

$$s = s_{\max} e^{-a_r r^{b_r}}$$

The parameter, s , for erosion in Eq. 5.11 can be expressed as (Lee et al., 1994):

where a_r , b_r and $s_{\max}$ are sediment dependent coefficients.

The initial suspended sediment profile in water, $C(z,0)$, must be specified for solving Eq. 5.1. The selected initial condition will influence the time-evolution of the concentration profile during the early period of simulation.

Current is assumed to be steady over the fluid mud or bed. For the wave field, a linear wave is considered to propagate over the fluid mud or bed. For the wave plus

ACKNOWLEDGEMENTS

I wish to thank Dr. Clay Montague, chair of my committee, whose critical reviews and comments made this manuscript clearer, more coherent and freer of errors. Reviews by Dr. Ashish J. Mehta and Dr. W. Emmett Bolch also suggested valuable improvements. I also wish to thank Dr. Mehta for allowing me the use of his particle erosion simulator and settling velocity column and Dr. Montague for supplying petri dishes and filter paper. Fellow students Sandra Fox and Phil Stevens were of tremendous help in collecting cores and measuring sediment depth. I also wish to thank Ron Wheeler and Sandra Fox for instruction in using the gamma ray spectrometer. I particularly wish to thank my beloved parents, without whose support I would not have been able to complete this manuscript.

The third and fourth code files are called VEST1.FOR and VEST2.FOR. These are for wave-fluid mud interaction modeling (described in Section 3), for supplying the velocity difference, Δu_0 , required to calculate the global Richardson number (Eq. 5.9).

A program called VESTG.M in MATLAB is used to graphically display the time-variation of the suspended sediment concentration profile obtained from the calculations. The flow chart for the program is shown in Fig. 5.3.

Note: To run VEST.FOR, it is essential to enter FORTRAN POWER STATION and close MATLAB. Once the program is run, to view the results it is necessary to enter MATLAB and run VESTG.M.

5.4 Input Parameters For Modeling

The input parameters can be divided into the following six groups:

(1) Hydrodynamic parameters:

- * Wave height, H [m] and wave period, T [s];
- * Mean current velocity, U [m/s];
- * Water depth, h [m];
- * Water density, ρ_{how} [kg/m^3].

(2) Sedimentary parameters:

- * Sediment granular density, ρ_{hos} [kg/m^3];
- * Parameters for settling velocity dependence on concentration, a , b , m and n ;
- * Maximum free settling velocity, W_{sf} [m/s];
- * Limit concentration, C_1 [kg/m^3].

(3) Diffusion related parameters:

- * Empirical parameters for stabilized diffusivity (α_0 and β_0), $ds1$ and $ds2$;
- * Empirical constant for neutral mass diffusivity under wave motion, α_{pw} .

(4) Fluid mud characteristics:

- * Mud bulk density, ρ_m [kg/m^3];
- * Fluid mud depth, h_b [m];
- * Mud rheological constants, $G1$ [Pa], $G2$ [Pa] and μ_2 [Pa.s];
- * Entrainment rate parameters, $Beta$.

(5) Bed characteristics:

- * Wave friction factor, f_w ;
- * Manning's coefficient, n ;
- * Characteristic stress for deposition, τ_{uc} [Pa];
- * Depth average dry density ($\bar{\rho}_D$), ρ_{dbar} [kg/m^3], ξ and ζ ;
- * Bed shear strength parameters, α_{be} , β_{be} and ϕ ;
- * Coefficients for erosion rate, s_{mx} , a_r and b_r .

(6) Other parameters:

- * Initial values of sediment concentration and their elevations, c_i [kg/m^3] and z_i [m];
- * Initial time, stt [min] end time, ett [min] and output time, ott [min];

* Calculation time step, dt [s] and calculation grids, n_{grids} .

The program allows two ways to read-in the input data, namely screen input or file input. Screen input is easy but time-consuming. The program will ask for the required data on the screen in sequence to guide the input of data. Input data from the screen are saved in a specific file with comments explaining the data. This file can be a typical input file for later file input. File input is faster, but needs an input file with a specified format. This formatted file is the saved file from the screen input. Both, screen input and file input must have the same order for all the input parameters.

It is suggested that you select screen input for the first time. As a result you will create a typical input file, which can be updated/revised as necessary. Note that for the input file saved from screen input for next time use, single quotes must be added to the *output file name*, *graphics file name* and *description for input data*, because the computer can only read in the characters within quotes. For example, the output file name in the input file saved from screen input is **FILEOUT.OUT**, which must be changed to **'FILEOUT.OUT'**.

The first output file is meant for reading. In this file, there are comments for making the results readable. The input data are also saved at the beginning of the output file for convenience and checking. The time-variation of suspended sediment concentration at each elevation of the grid point is listed in the file.

The second file is designed as the input file for graphics. This file has data in a special format. These data are read-in by the program VESTG.M written in MATLAB,

to display the results graphically. This program is also able to animate the time-variation of the vertical distribution of suspended sediment concentration in water.

5.5 Tutorial For Data Input

DP denotes display on the screen and \> denotes input data.

Note: To run VEST.FOR, it is essential to enter FORTRAN POWER STATION and close MATLAB. Once the program is run, to view the results it is necessary to enter MATLAB and run VESTG.M.

DP Non-Equilibrium Suspension Profile Simulation

DP Which option would you like to use for input data?

DP file input == 1; screen input ==2

\> 2

DP You are using screen input

DP Input data from the screen will be saved in an input file

DP Give file name to save your input data (Characters)

\> 'FILEIN.INP'

DP Give output file name (Characters)

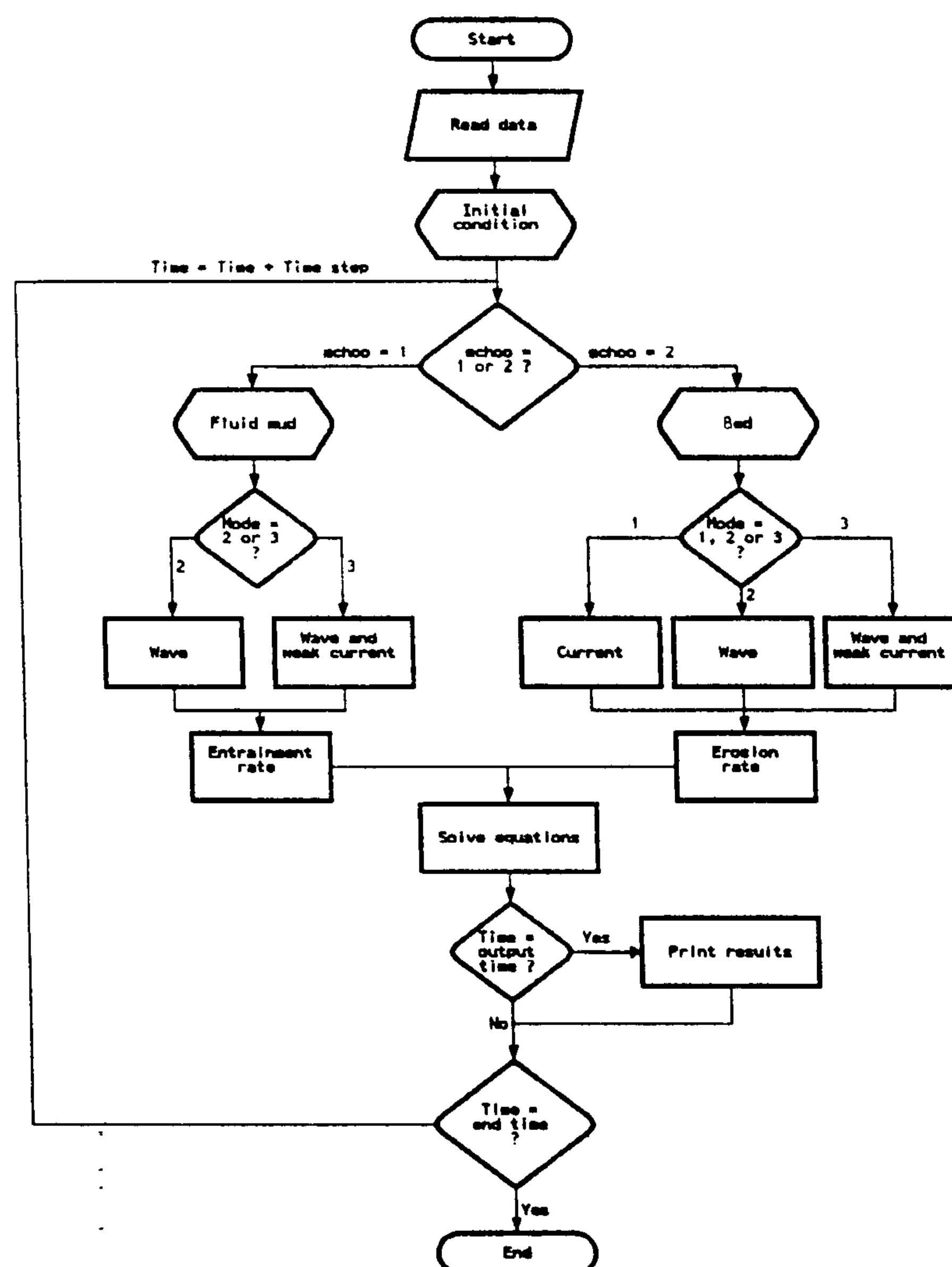
\> 'FILEOUT.OUT'

DP Give graphics file name (Characters)

➤ 'FILEGRA.GRA'

DP Give description of input data

➤ 'DATA FOR FLUID MUD UNDER WAVES AND WEAK CURRENT'



DP Water depth: $h = ?$ (m)

▷ 4.5

DP Bed (or fluid mud) depth: $h_b = ?$ (m)

▷ 1.0

DP Number of vertical grids in water: $n_{\text{grids}} = ?$ (Integer)

▷ 30

DP Starting time of simulation: $stt = ?$ (min)

▷ 0.0

DP End time of simulation, $ett = ?$ (min)

▷ 200

DP Time step for calculation: $dt = ?$ (s)

▷ 60

DP Output time step: $ott = ?$ (min)

,
:
:

▷ 10

DP Settling velocity parameters

DP C1=?, Wsf=?, a=?, b=?, m=?, n=?
\\> 0.1 2.15E-5 0.16 7.0 1.5 1.33

DP Stabilized diffusion parameters

DP $\alpha_0 = ?$, $\beta_0 = ?$

\\> 0.5 0.33

DP Selection of external hydrodynamic mode

DP mode: 1==CURRENT, 2==WAVE, 3==WAVE+WEAK CURRENT.

\\> 3

DP Mean current velocity: $U = ?(\text{m/s})$

\\> 0.1

DP Manning's coefficient, $n = ?$

\\> 0.02

DP Wave height: $H = ?(\text{m})$

\\> 0.8

DP Wave period: $T = ?(\text{s})$

\\> 8.5

DP Wave diffusion coefficient: $\alpha_{\text{haw}} = ?$

\> 0.2

DP Granular density: $\rho_{\text{os}} = ? \text{ (kg/m}^3\text{)}$

\> 2200

DP Bed bulk density: $\rho_{\text{om}} = ? \text{ (kg/m}^3\text{)}$

\> 1270

DP Water density: $\rho_{\text{ow}} = ? \text{ (kg/m}^3\text{)}$

\> 1030

DP Bed density $> 1,200 \text{ kg/m}^3$ and $< 1,300 \text{ kg/m}^3$

DP Bottom sediment may be considered as fluid mud or as bed

DP Fluid mud = 1, bed = 2.

DP Choose 1 or 2 for input: (Both "1" and "2" are tutored)

[If "1" is chosen]:

\> 1

DP Critical Richardson number for entrainment: Ric

\> 0.043

DP entrainment rate coefficient: Beta =?

\> 2.5E-5

DP Bottom sediment rheological parameters: G1, G2 and U2

DP (G1 and G2 in Pa and mu2 in Pa.s)

DP (Note: if G1 > 0: three-parameter rheological model

DP if G1 < 0: two-parameter rheological model

DP if G1 < 0 and G2 = 0: viscous model)

\> -5.0 100 5000

[If "2" is chosen]:

\> 2

DP Critical stress for deposition: taudep = ?(Pa)

\> 0.1

DP Wave bottom friction coefficient: fw = ?

\> 0.015

DP Bed density parameters: zeta=?, xi=?, rhodbar=?

\> 0.794 -0.45 350

DP Erosion critical stress parameters: phie=?, alphae=? and betae ?

\> 0.05 12.0 1.0

DP Erosion rate parameters: smax, ar & br = ?

➤ 0.2 8.0 0.5

DP Number of points for initial concentration input:

➤ 2

DP Elevation: $z_i(i)$ (m), Concentration: $c_i(i)$ (kg/m³)

DP Elevations must be in an increasing order from water bottom

DP For $i = 1$, give, $z_i = ?$, $c_i = ?$

➤ 1.0 0.0

DP For $i = 2$, give, $z_i = ?$, $c_i = ?$

➤ 3.0 0.0

[Go to MATLAB for display]

DP Suspended Sediment Concentration Profile Variation with Time

DP Input file name

\> FILEGRA.GRA

DP Minimum concentration for replotting = ?

\> 0.03

DP Maximum concentration for replotting = ?

\> 3

[Time-simulation option - Insert Yes or No. If Yes]:

DP Select minimum concentration for time-simulation plot (g/l)

\> 0.03

DP Select maximum concentration for time-simulation plot (g/l)

\> 3

DP Show time-simulation how many times?

\> 2

[State speed options - Insert high, intermediate or low]

Based on the above tutorial and selecting fluid mud as bottom sediment, the graphical output is as follows:

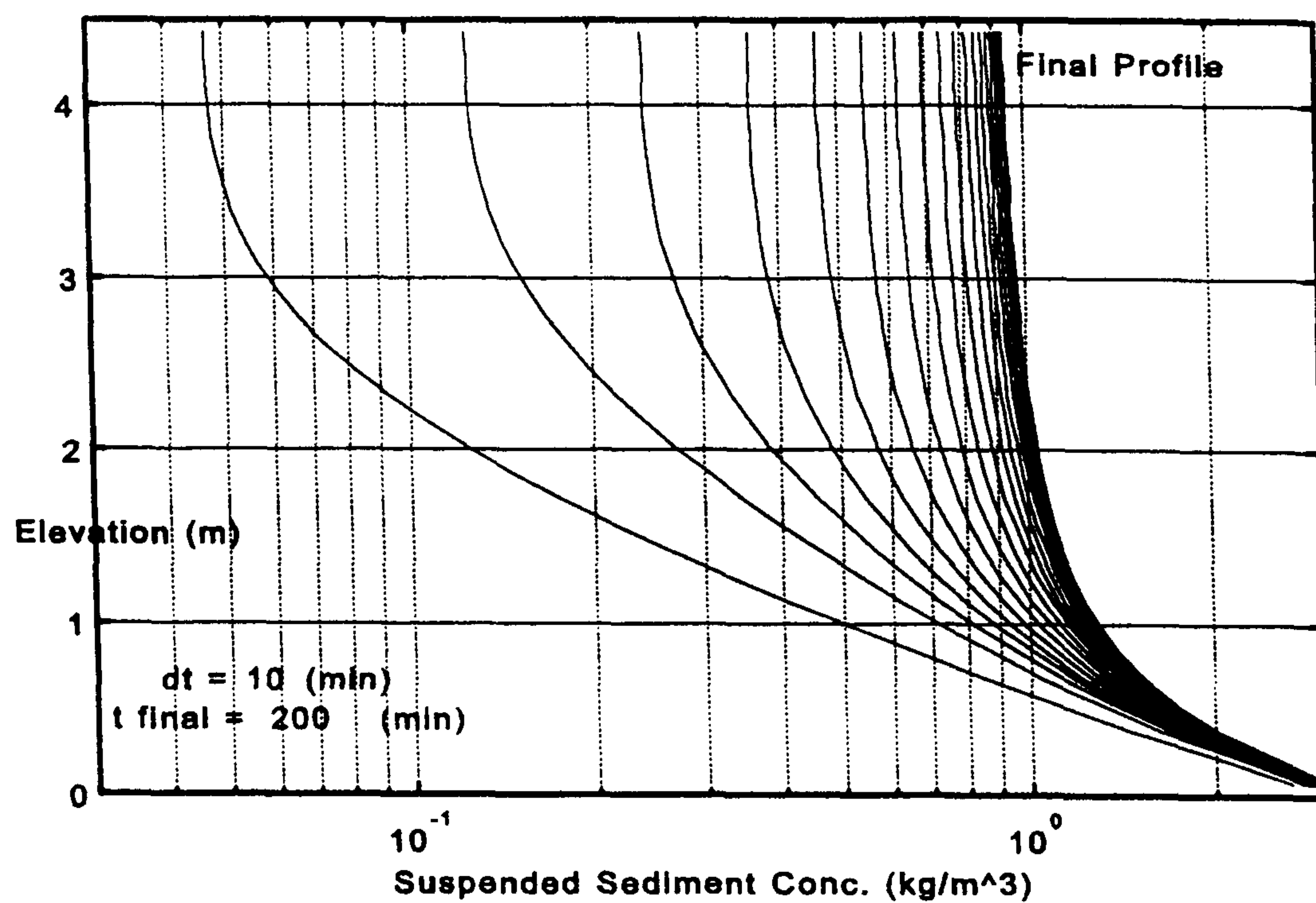


Fig. C.2 Suspended sediment concentration profile evolution. Suspended sediment concentration is zero at $t=0$. The first curve to the left is at $t=10$ min; each curve thereafter is at 10 minute increments.

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BIOGRAPHICAL SKETCH

Hugh R. Graham, Jr. was born in Portsmouth, Virginia on August 14, 1973. He received a B.S. degree in biological sciences from Clemson University in 1995. He earned a Master of Science degree from the University of Florida, Department of Environmental Engineering Sciences in 1999. He has always loved natural systems and so has decided to devote his life to their study and protection.