

AN IN-SITU CAPPING DESIGN FOR THE REMEDIATION OF PETROLEUM
CONTAMINATED SEDIMENTS

A Thesis

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Abstract

Historical disposal practices used by oil companies have caused the accumulation of contaminated sediments in their nearby lakes and ponds. These companies are now faced with the challenge of remediating the bodies of water that contain these contaminated sediments. The contaminants that remain in the sediment continue to pose a threat to human health and the environment. For example, high concentrations of polycyclic aromatic hydrocarbons (PAHs), which are still present in the bottom sediments can have toxic effects on aquatic life. One form of remediation for this problem is In-Situ Capping (ISC), which is defined as a method whereby material is used as a covering or cap for placement over contaminated sediment located under a body of water.

This work focuses on evaluating ISC as a remediation method for oil contaminated sediments. Bench-scale laboratory experiments were conducted on oil contaminated sediment samples to observe the effect of consolidation, contaminant migration, gas generation, and ground water migration on the caps ability to contain the contaminants. It was found that, overall, ISC could be used as an effective remediation method for the oil contaminated sediments tested. However, there was some migration of PAHs into the first few centimeters of the cap in all columns tested due to a combination of intermixing during cap placement, non-aqueous phase liquid migration, and retarded transport of certain PAHs. It was also observed that contaminant migration increased when gas bubbles, which simulated gas generated by the contaminated sediment, were injected into the column experiments over an approximately one month period. These

results demonstrate that site-specific adjustments to ISC designs are necessary for the cap to most effectively contain contaminant migration in the field.

Chapter 1. Introduction

In the past, when environmental regulations were more lax, industrial effluents resulted in the accumulation of oils and other contaminants in the sediments of lakes and rivers. However, the implementation of strict environmental regulations that prohibit such disposal practices has ended this type of disposal method. Although these dumping practices have ended, persistent contaminants that remain in the sediment continue to pose a threat to human health and the environment. High concentrations of polycyclic aromatic hydrocarbons (PAHs), which are still present in the bottom sediments can have toxic effects on aquatic life. These toxic effects can move up the food chain, thus posing a risk to humans and wildlife in the community. This is why it is important to remediate, or clean up, the contaminants accumulating in the sediments of contaminated bodies of water.

Four basic options for remediation of contaminated sediments exist: 1) Containment in-place, 2) Treatment in-place, 3) Removal and containment, and 4) removal and treatment [Palermo 1998]. In-Situ Capping (ISC), a form of containment in-place, is the remediation method evaluated in this study. In-situ capping is the method by which material is used as a covering or cap for placement over contaminated sediment to contain contaminants and sediment and physically isolate the contaminants from organisms in the water and surficial sediments. The cap may be constructed of clean sediments such as sand or gravel of multiple layers. Laboratory research is needed to figure out how to best cap contaminated bodies of water in order to contain the contamination present in the sediment.

This research was conducted to evaluate ISC's effectiveness as a remediation method for two specific bodies of water. The sites chosen for this study were a refinery effluent surge pond and an adjacent lagoon located in Lake Charles, Louisiana. These areas were contaminated due to the accumulation of refinery wastewater solids deposited in the surge pond and in the adjacent lagoon over many years. The general characteristics of the lagoon and surge pond were similar, but the surge pond tended to be the more extreme case due to higher levels of the contaminants present and softer bottoms sediment. Contaminated sludge is present throughout the approximately 570,000 square foot lagoon and the slightly smaller surge pond. The sediments contained nonaqueous phase liquid (NAPL), metals and various PAH's. The average thickness of the contaminated sludge is about 8 feet, with the water depth varying from a few inches to greater than 18 feet in both bodies of water. The surge pond has a hydraulic connection to the lagoon and the lagoon has a hydraulic connection to the Calcasieu River. The tidal fluctuation of the lagoon with the Calcasieu River is between one and three feet. The estimated volume of sludge present in the lagoon is approximately 176,000 cubic yards.

This study evaluated the ability of ISC to provide physical isolation of the body of water from the contaminants under it, stabilize the contaminated sediment under the body of water, and reduce the amount of dissolved contaminants in the body of water. Further, this study looked at the adjustments necessary to scale the laboratory findings in order to make them applicable not only in the lab, but in the field sites as well. Finally, the larger environmental question this work addressed was if the ISC design would effectively protect the environment from the PAHs that can be toxic to the aquatic life, wildlife and humans in the area.

A limited number of ISC operations have been performed under varying site conditions [Palermo 1998]. Some of these field operations include a Superfund site in Sheboygan [Elder 1992], Hamilton Harbor, in Burlington, Ontario [Zeman and Patterson 1996a and 1996b], and the General Motors Superfund site in Massena, New York [Kenna, pers com, 1995]. In many cases, the placement and effectiveness of ISC can often be site specific due to the variations associated with different types of sediment and locations. This study's objective was to explore and identify the various problematic issues that would arise during ISC for the specific sites chosen.

Objectives

The purpose of this report was to evaluate the effectiveness of ISC as a remediation method for oil contaminated wastewater sediments. A series of bench scale laboratory experiments were conducted in simulator columns. The goals of the experiments were to study the following problematic conditions.

1. Consolidation of the underlying contaminated sediment. This occurrence could become problematic if the underlying sediment is not able to support a cap. Also, consolidation could potentially cause the expression of contaminated pore fluids into the capping layer.
2. The migration of a nonaqueous phase liquid (NAPL), enriched in the contaminants, into the capping layer.
3. Significant gas generation and migration, which could increase the amount of NAPL and other contaminants that migrate into the capping layer.
4. Ground water migration via active seeps that could increase the amount of contaminant migration into the capping layer.

These issues were studied in order to modify conventional cap designs to fit the needs of the oil contaminated wastewater sediment studied in the lagoon and surge pond. The laboratory experiments conducted focused on studying the facilitated transport processes that occur in the capping layer. The results were used to understand the problems that would arise with the specific sediment studied; furthermore they were to be used when designing a cap that manages these problems.

Scope

When planning to remediate a contaminated body of water, it is necessary to define specific remediation objectives, and then evaluate various remediation methods to determine which method best fits the needs of the project. This work is a detailed evaluation of ISC as a remediation method. It focuses on the problems that occur when dealing with, specifically, oil contaminated sediments. This work was one part of a large scale remediation project for an oil company. The laboratory studies took place at the Hazardous Substance Research Center/South and Southwest located at Louisiana State University. The sediment samples studied were taken from a lagoon and surge pond, located in Lake Charles, Louisiana. The conclusions found from the laboratory evaluation were to be considered for use in the field operation. Thus, recommendations were made regarding the feasibility of the use of laboratory results at the field site.

Chapter 2. Review of Literature

The primary concern of this work is to evaluate the effectiveness of In-Situ Capping (ISC) as a remediation method for oil contaminated sediments. In order to more fully understand ISC and the facilitated transport processes that occur during ISC, a review is presented. This chapter reviews general remediation techniques, in order to help one to understand how ISC fits in the overall scheme of remediation. The design of ISC is discussed in detail. Then chemical migration is looked at in regard to migration of the contaminants into the capping layer. A discussion of the sediment contaminants present in this work is reviewed. Finally, the last section is devoted to computer modeling approaches available for ISC.

Remediation Techniques

Contaminated sediments can be disposed of on land or in the aquatic environment. In the aquatic environment, capping can be an effective means of isolating the contaminants from the water column and organisms. An example of both dredged material capping and an *in-situ* cap are shown in Figure 2.1. In Figure 2.1, the dredged material is depicted in a contained aquatic disposal (CAD) facility, which is a designed structure for disposal of dredged sediment. The ISC picture shows that the contaminated sediment is located on the floor of a body of water with a cap covering the contaminated sediment. Technologies for the treatment of contaminated sediments *in-situ* are less developed than the technologies that can be applied to dredged material [EPA 1994a] because there is less ability to control conditions of containment. Site-specific testing and analyses can help evaluate the implementation and subsequent effectiveness of ISC, so this is why studies on ISC are an important research area.

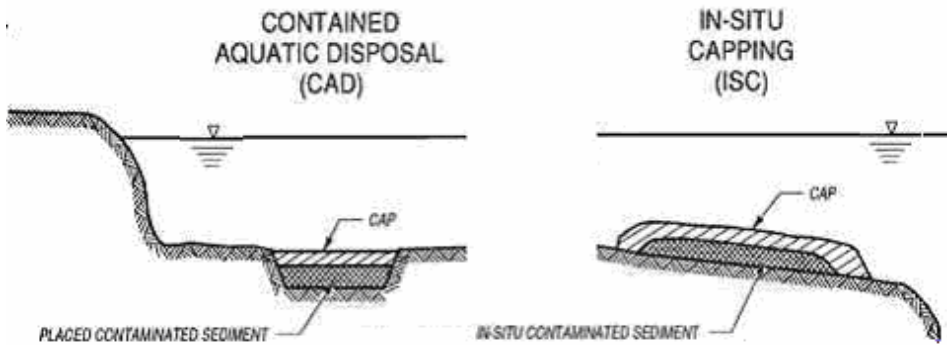


Figure 2.1
Illustration of dredged material capping and ISC [Palermo et al 1998]

Much of the work in the area of subaqueous capping is associated with the handling of contaminated dredged material removed from navigation channels performed by or in cooperation with the U.S. Army Corps of Engineers (USACE) [Palermo et al 1998]. The primary concern of this work is to discuss In-Situ Capping (ISC), but since cap designs for ISC and dredged material capping are similar, the discussion of dredged material capping will serve as important background information for ISC.

Containment in-place and treatment in-place are the two types of *in-situ* remediation procedures. Containment in-place is an *in-situ* remediation method where the contaminants are stabilized with the use of, for example, a surface barrier or capping layer. ISC is a form of containment in place [Palermo et al 1998]. Treatment in-place is another in-situ method whereby the contaminated sediment deposits are treated in place at the bottom of a river or harbor. Examples of treatment methods used for treatment in-place include: bioremediation where microorganisms are used to break down or destroy organic contaminants in the sediment, and solidification (also known as stabilization) where fly ash or other binding agents are used to reduce the amount of contaminants that

can leach from the sediments [EPA 1994a]. In general, in-situ treatment methods have not been demonstrated in the field and this thesis will focus on containment via ISC.

A study by Reible et al (2003) of the potential risks of environmental dredging vs. *in-situ* remediation of contaminated sediment concluded that, for the specific site studied, the ISC alternative remained lower in risk than any proposed dredging scenario studied for that site. Thus, the same conclusion found in the Reible et al (2003) study, that in-situ remediation methods can potentially be equally or more effective remediation methods than dredged remediation methods, could possibly apply for other specific locations. Unfortunately, the use of in-situ methods has been less than that of dredged methods possibly due to the lack of research on *in-situ* methods. So, this research is intended to help increase the literature on *in-situ* methods and demonstrate the effectiveness of ISC.

In-Situ Capping

Although there are many gaps in the literature regarding ISC, it has been determined through the monitoring of capped disposal sites that capping is technically feasible and stable under normal tidal and wave conditions [Wang et al 1991]. The feasibility of capping was determined through experiments on capping contaminated sediments with clean sediments performed by the New England Division, New York District and U.S. Army Corps of Engineers [Wang et al 1991].

ISC is the method by which material is used as a covering or cap for placement over contaminated sediment, which is located under a body of water. The cap may be constructed of clean sediments such as sand, gravel, or may involve a more complex design with geotextiles (materials such as gravel and cobble), liners and multiple liners [Palermo et al 1998]. For ISC the site of remediation is in the body of water where the

contaminants lie. Due to such variation of location and sediment involved, often ISC remediation is site-specific. Currently, the design of ISC is based on laboratory testing and modeling; two methods this study uses to determine the effectiveness ISC for the oil contaminated sediment studied.

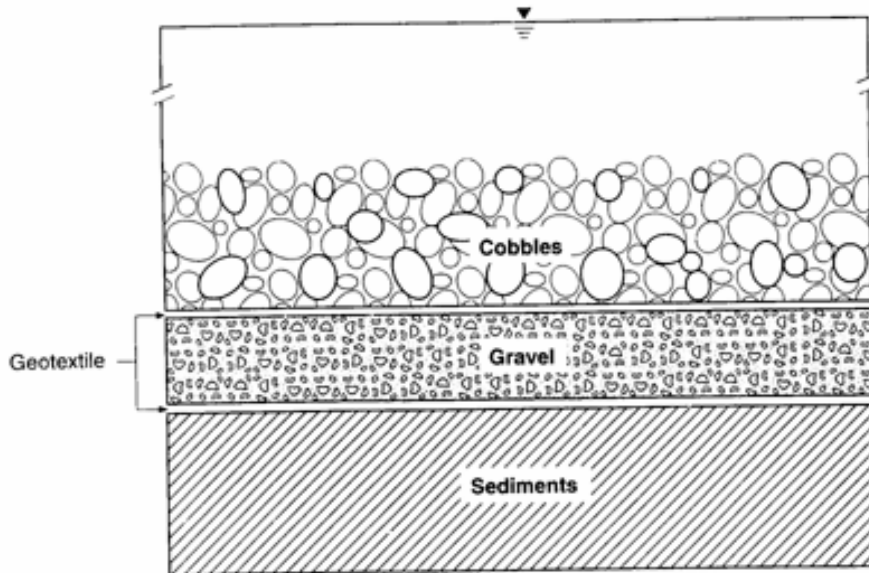
ISC designs: 1) provide physical isolation of a body of water from the contaminants under it, 2) stabilize the contaminated sediment under a body of water, and/or 3) reduce the flux of dissolved contaminants in a body of water [Palermo 1998] depending on the needs of the particular site. The steps used for creating an ISC design for this study included:

- 1) Identifying capping materials,
- 2) Designing a cap that would reduce the flux of dissolved contaminants in the water column,
- 3) Evaluating consolidation of compressible cap materials, and
- 4) Determining the “scale up” process for field implementation.

These steps were taken to design a capping layer that was then studied to determine the site specific problems that would occur for the lagoon and surge pond. The above design criteria are discussed in the next four paragraphs respectively.

Cap materials are determined as part of the cap design process because these materials will generally represent the largest single item in the overall project cost, and the utilization of locally available sediments, soils or other granular capping materials can have a significant impact of ISC feasibility and implementation. Most ISC projects conducted to date have used sediment or soil materials, either dredged from nearby waterways or obtained from upland sources, including commercial quarries [Palermo et al

1998]. In general, sandy sediments are suitable for use as a cap at sites with relatively low erosive energy, while armoring materials may be required at sites with high erosive energy [USEPA 1994b]. Geotextiles may be incorporated into *in-situ* caps for a number of purposes, including stabilizing the cap, promoting uniform consolidation, and reducing erosion of the granular capping materials [USEPA 1994b]. Also, commercial sorbents may be incorporated into *in-situ* caps to help control contaminant migration into the capping layer. An example of cap configurations is shown in Figure 2.2.



Source: Blasland and Bouck Engineers (1990)

Figure 2.2
Illustration of combinations of cap components

When designing a cap to isolate contaminants from the aquatic environment for any new site, an involved analysis that includes laboratory tests and modeling are required because of differences in sediment quality, contaminants, currents, sediment mechanical strength, and cap material [Herrenkohl et al 2001]. Laboratory tests were first developed to evaluate cap thicknesses required for physical isolation of dredged

material [Palermo et al 1998]. Since then, laboratory tests have been developed to determine the thickness of capping sediment required to chemically isolate contaminated sediment from the overlying water column [Sturgis and Gunnison 1988]. Conventional equipment and placement accuracies will dictate typical cap thickness for chemical isolation is on the order of 50-60 centimeters [USEPA 1994b]. Currently, there are still no laboratory test or procedure that has been developed to fully account for both advective and diffusive processes and their interactions during ISC [Palermo et al 1998].

One source of advection when capping is due to the expression of porewater during consolidation. Consolidation occurs because all soils subjected to stress undergo strain within the soil skeleton. This strain is caused by rolling, slipping, sliding and to some extent by crushing at the particle contact points, and elastic distortions [Bowles 1984]. The increase in vertical pressure due to the weight of the structure constructed on top of saturated soft clays and organic soil will initially be carried by the pore water in the soil. The excess pore water pressure (u_e) will decrease with time as water slowly flows out of the cohesive soil [Day 2000]. This time-dependent flow of water from the soil (which has low permeability) as the excess pore water pressures slowly dissipate is known as primary consolidation or consolidation [Day 2000]. Consolidation causes the structure to settle as the load is transferred to the soil particle skeleton, thus increasing the effective stress of the soil. The general theory including the concept of pore water pressure and effective stress was one of the developments of Terzaghi [1943] which occurred during 1920-1924. The cap design should always consider consolidation when the cap material's thickness is determined also. If the selected material for the cap is fine-grained granular material, (defined as material with greater than 50% by weight

passing a #200 sieve) the change in thickness of the capping material due to its own self weight or due to the water column pressure should be considered in the overall design. An evaluation of the consolidation of the compressible cap materials should be made in this case, and an additional cap thickness component should be added to the pre determined cap thickness, so that the appropriate cap thickness is maintained despite consolidation. Such consolidation occurs over a period of time following cap placement, but does not occur more than once. If the cap material is not a fine grained granular material, then it may be assumed that there is no consolidation of the cap material [Palermo et al 1998]. The underlying sediment may still be subject to significant consolidation, however.

In this study, the ISC designs were tested in the laboratory on a few kilograms of sediment collected from the sample field site. Then, the results of the bench-scale testing provided preliminary feasibility and design data for “scaling up” the process in the field.

Chemical Migration

The contaminant migration should be controlled with a cap that has a well designed physical isolation component. The two types of chemical migration that occur *in-situ* are advection and diffusion. Advection is defined as the process by which moving ground water carries with it dissolved solutes [Fetter 1988]. Diffusion is defined as the process whereby ionic and molecular species in water are transported by random molecular motion from an area associated with high concentrations to an adjacent area associated with a low concentration [Fetter 1994]. In this work, these two forms of chemical migration are investigated through laboratory tests and modeling.

Advection can occur as a result of compression or consolidation of the contaminated sediment layer or other layers of underlying sediment [Palermo et al 1998]. The weight of the cap would “squeeze” the contaminated sediment layer and displace pore water into the capping layer. In this case, movement of the pore water due to consolidation would be finite and movement would slow down considerably as consolidation slows. This displacement could ultimately cause contaminants to move part or all the way through the cap layer in a short period of time [Palermo et al 1998]. During laboratory experiments, pore water displacement must be monitored along with the cap consolidation in order to develop a cap layer thickness that is able to contain the entire volume of pore water that is “squeezed” upward into the capping layer.

Advection can also occur as an essentially continuous process if there is an upward hydraulic gradient due to groundwater flow [Palermo et al 1998]. Contaminants that are advecting tend to travel at the same rate as the average linear velocity of the ground water as described by Darcy’s law (in one dimension). In Darcy’s equation,

$$v_x = \frac{K}{n_e} \cdot \frac{dh}{dl} \quad (2.1)$$

v_x is the average linear velocity,

K is the hydraulic conductivity,

n_e is the effective porosity and

dh/dl is the hydraulic gradient [Freeze 1988].

Diffusion can take place, in porous media, only through pore openings because mineral grains block many of the possible pathways [Fetter 1988]. Diffusional mass transport assumes that the rate of transport is directly proportional to the concentration gradient. In an isotropic medium diffusion occurs in a direction perpendicular to the plane

of constant concentration at all points in the medium [Palermo et al 1998]. The diffusion of a solute through water is described by Fick's first law.

$$F = -D \frac{dC}{dx} \quad (2.2)$$

In this equation F is the mass flux of solute per unit area per unit time, D is the diffusion coefficient, C is the solute concentration, and dC/dx is the concentration gradient [Fetter 1994]. For systems where the concentration may be changing with time, Fick's second law may be applied [Fetter 1988].

$$\frac{dC}{dt} = D \frac{d^2C}{dx^2} \quad (2.3)$$

In Fick's second law D is the diffusion coefficient, dC/dt is the solute concentration per time, and dC/dx is the concentration gradient [Fetter 1994]. Diffusion is a very slow process, so its effects during ISC in this study will most likely be minimal.

Sediment Contaminants

Industrial, agricultural, and municipal discharges of pollutants into bodies of water over many years have contaminated the bottom sediments in bodies of water. This study focuses on oily contaminants due to historical effluents from petroleum refining and processing. The implementation of strict environmental regulations that prohibit such disposal practices has reduced the continuing load of contaminants. However, the past accumulation of contaminants, particularly toxic substances, in bottom sediments is an important factor in continued impairment of water quality and may contribute to toxic effects in aquatic biota and, potentially, in human receptors [Averett 1990]. Specific concerns associated with oil contamination include polycyclic aromatic hydrocarbons (PAHs).

High concentrations of polycyclic aromatic hydrocarbons (PAHs) present in the bottom sediments of contaminated bodies of water can have toxic effects on aquatic life. From analysis of petroleum-contaminated soils, soil surface-bound PAHs can be qualitatively determined to consist, primarily, of two- and three-ringed un-substituted and alkyl-substituted PAHs [Rodgers et al 2000] for example Naphthalene, Acenaphthene and Phenanthrene. The two- and three- ringed PAHs are less sorbing and less hydrophobic compounds, when compared to the four- and five- ringed PAHs. Consequently, two- and three- ringed PAHs are able to migrate through a capping layer at a fast velocity. PAHs are considered an environmental health hazard due to the carcinogenic nature of several of its members [Herbes and Schwall, 1978]. These toxic effects can move up the food chain, thus posing a risk to humans and wildlife in communities surrounding contaminated bodies of water. The environmental sources of PAHs include both anthropogenic processes and natural processes. Anthropogenic sources of PAHs include fuel refining, coke production, and other high-temperature industrial processes [Means et al 1980].

In order to fully understand the mobility and behavior of PAH's contained in sediments, the concentration of these compounds in sediment pore waters must be determined. Equilibrium relationships are needed to relate chemical concentrations in the adjoining liquids within soil pore spaces [Thibodeaux 1996]. As described by Thibodeaux [1996], equation 2.4

$$K_{d32} \equiv \frac{x_3}{x_2} = \frac{\gamma_2 f_2^0}{\gamma_3 f_3^0} \quad (2.4)$$

shows the first step in obtaining the sediment water partitioned coefficient derived from the ratio of concentrations of the water phase (2) and the sediment phase (3). Where the

products of $\gamma_2 f_2^\circ$ and $\gamma_3 f_3^\circ$ is dependent on the material assumed to comprise the sand cap. In the absence of a NAPL phase, the partitioning between water and solid is normally written as

$$K_{d32} = \frac{\omega_{A3}}{\rho_{A2}} \quad (2.5)$$

where ω_{A3} is the solid phase concentration and ρ_{A2} is the porewater phase concentration. This partition coefficient can be written as a sum of the partitioning to the organic and inorganic phases in the cap material as

$$K_{d32} = K_{c2}\omega_c + K_{I2}\omega_I \quad (2.6)$$

where ω_c and ω_I are the weight fractions of natural organic matter and inorganic matter in sediment. The organic matter one-phase form of this equation is used in this research since organic matter is the primary sorption site for hydrophobic organic contaminants. It is reduced to give the sediment water partition coefficient [Palermo et al 1998] as

$$K_d = K_{oc}f_{oc} \quad (2.7)$$

where, K_{oc} is the organic carbon-water coefficient for the chemical and f_{oc} is the sediment fraction of organic carbon. The K_{oc} can be determined from literature values and the f_{oc} can be determined experimentally, thus the K_d can be calculated.

The sediment water partition coefficient (K_d) can also be estimated from experimental contaminant profile data by relating it to the retardation factor (R_f). Retardation occurs as chemicals sorb onto grains of aquifers, thus the transport of chemicals which sorb into the sediment layer is slowed or retarded. Palermo et al [1998] describe the equation for R_f as

$$R_f = \varepsilon + \rho_B \cdot K_d \quad (2.8)$$

where ε is the sediment porosity (void volume/ total volume), and ρ_B is the sediment bulk density. K_d determined from the contaminant profile data can be related to the K_d determined from the actual data found from equation 2.7.

Computer Modeling

Transport modeling of capped contaminated sediment can quantify the effectiveness of a cap as a chemical barrier [Thoma et al 1993]. Thoma et al (1993) developed a model of diffusion through a cap that explicitly accounts for depletion in the underlying sediment. Another example of a numerical model that simulates the behavior of the chemical flux is by Dueri et al (2003). A simpler model of diffusion through the cap, however, assumes that the contaminant concentration in the underlying sediment is essentially constant. Though in reality, migration of contaminants into the cap reduce the sediment concentration and the long-term flux to the overlying water over time [Palermo et al 1998].

The complete model of chemical movement must be composed of two components: 1) an advective component considering the short term consolidation of the contaminated sediment underlying the cap, and 2) a diffusive or advective-dispersive component considering contaminant movement as a result of porewater movement after the cap has been stabilized [Palermo et al 1998].

The following equation, used in the model by Thoma et al (1993), is a differential mass balance for the diffusive transport for a nonreactive sorbing species in a porous medium.

$$\frac{\partial \rho_A}{\partial t} = \left(\frac{D_e}{R_f} \right) \frac{\partial^2 \rho_A}{\partial z^2} \quad (2.9)$$

In this equation ρ_A is the pore-water concentration in the contaminated sediment, t is the time, D_e is an effective diffusivity, R_f is a retardation factor associated with accumulation on the immobile sediment phase, and z is a distance. The following Figure 2.4 depicts a mathematical capped system.

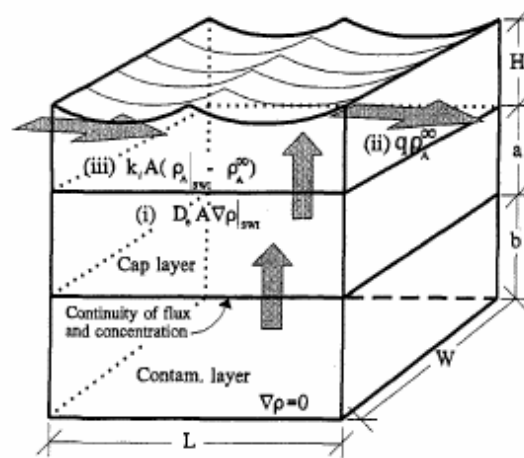


Figure 2.4
Conceptual diagram of a capped contaminated sediment. The rate of diffusive transport from the sediment (i) is equal to the rate of flushing of the overlying water (ii) and the rate of transport through the benthic boundary layer (iii) [Thoma et al 1993].

When developing a model, it is necessary to measure or estimate certain parameters that describe the capping site and material. These parameters are the porosity and bulk density of the sediments, the partition coefficient for the chemicals between the pore water and the sediment, and the molecular diffusivity chemicals in the water. Once the model has been developed, these parameters can be altered to represent different systems.

Conclusion

Feasible technologies for the remediation of contaminated sediments are available. It is important to understand the relationship between ISC and other

remediation techniques to help advance research for ISC. There is no panacea for sediment remediation. No single technology can work in all applications or remediate all possible contaminants [EPA 1994b]. Therefore, ISC is an important technique that must be continually researched in order to expand the number remediation options available that can sufficiently meet the remediation objectives for each particular project site. It is through laboratory experimentation and modeling simulations that advancements in ISC can occur.

Chapter 3. Materials and Methods

This chapter contains the experimental methods and procedures used in this In-Situ Capping (ISC) study. The experiments performed were done to determine the effect of consolidation, nonaqueous phase liquid (NAPL) and polycyclic aromatic hydrocarbons (PAHs) migration into the capping layer, along with gas migration and groundwater migration into the capping layer. Tests were performed to observe consolidation of the contaminated sediment and contaminant migration into the capping layer. High performance liquid chromatography (HPLC) analysis was used to measure the contaminant migration into the capping layer. In these experiments ISC was simulated in bench-scale column experiments. This section outlines the procedures and analytical methods used for the tests.

Column Test Materials

Column tests were the major simulation experiments performed in this study. It is important to mimic the field site conditions when doing ISC experiments in the laboratory. In order to do this, the same field site materials were used in the tests which included: sand, contaminated sediment and water. These materials were all placed inside the test columns during experimentation.

Sand

For the ISC column tests, the capping material used was sand because it is often used in ISC, it is widely available in the local area, and it is available in large quantities. The sand used in all capping experiments was pre-packaged dried and cleaned sand.

The sand was characterized in order to determine the grain size distribution as shown in Figure 3.1. The entire grain size distribution medium grade sand, was used for all experiments.

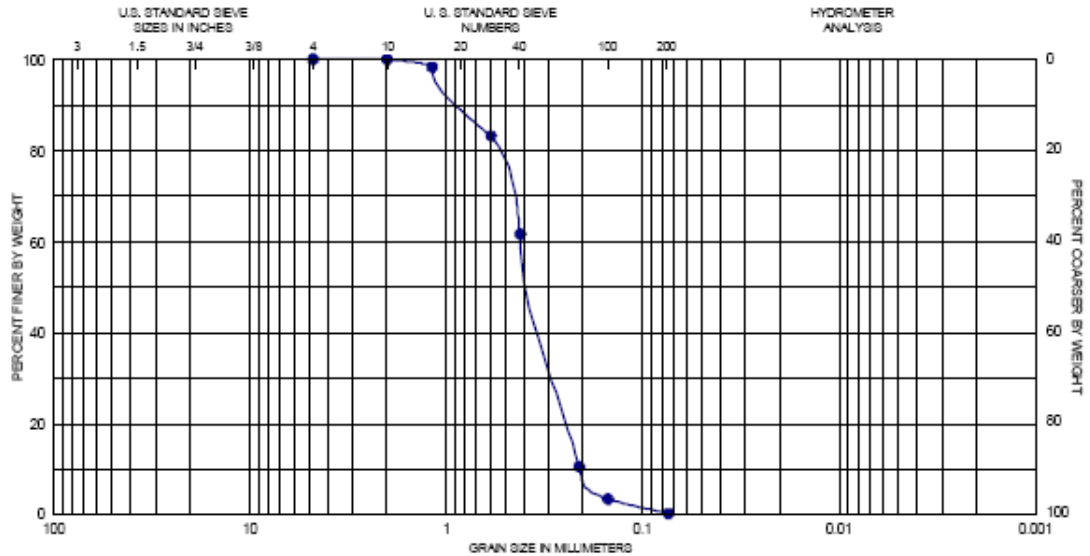


Figure 3.1
Sand Grain Size Distribution

Contaminated Sediment

The oil contaminated sediment samples used for these experiments were collected from the lagoon and surge pond located near a petroleum refinery in Lake Charles, Louisiana. A contracted company took 4-inch diameter and 6-inch diameter intact core samples from the lagoon and surge pond, as well as five buckets of reconstituted samples for each location. The contaminated sediment samples were then sent to Louisiana State University’s chemical engineering department for testing.

The concentration of PAHs contaminants, in ug/kg, initially present in the cored samples before testing are shown in Table 3.1. These samples were collected and analyzed by an outside contractor and provided to this author. All samples corresponded to locations employed in further column testing. The surge pond samples

(SP-1 and SP-2) showed considerably higher contamination levels and significant amounts of NAPL while the lagoon sediment (L-29) showed significantly lower concentrations and little or no NAPL. The results for the contaminants detected were taken from core samples depths that were between 2.0 feet and 6.3 feet for SP-1, between 2.0 feet and 7.0 feet for SP-2, and between 2.0 feet and 5.0 feet for the L-29 columns.

**Table 3.1
Initial Concentrations of Sediment Detected Contaminants**

	SP-1 2.0-6.3'	L-29 2.0'-5.0'
	Sediment	Sediment
	ug/kg	ug/kg
Poly aromatic hydrocarbons		
Naphthalene	110000	540
Acenaphthene	12000	NA
Phenanthrene	110000	43000
Anthracene	11000	6200
Fluoranthene	NA	5400
Pyrene	21000	24000
Benzo(a)anthracene	9000	2300
Chrysene	12000	4900
Benzo(b)fluoranthene	NA	640
Benzo(k)fluoranthene	NA	540
Benzo(a)pyrene	7000	1200

*NA = Data not available

Water

Baton Rouge tap water was used as the water source for all column experiments. The water contained essentially none of the contaminants being monitored and is not a significant factor in the mobility of hydrophobic organic compounds.

Column Fabrication

It was necessary to make all of the vessels used in these experiments to perform the column tests. Three different types of settling columns and a 2-D aquarium were used for the consolidation and chemical migration tests. The three types of settling columns

included: a 4-inch inside diameter column, 6-inch inside diameter columns, and an 8-inch diameter column. It was expected that larger diameter columns would reduce any experiment artifacts associated with wall effects but would be correspondingly harder to collect and ensure uniformity. By examining behavior in multiple column sizes it was hoped that the effects of column diameter could be inferred and factored out of the conclusions. The 4-inch and 6-inch columns were both constructed in the same manner. The 8-inch inside diameter columns were made following methods given by the U.S. Army Corps of Engineers (1987). The method of fabrication for these columns is described below.

Four-Inch and Six-Inch Diameter Columns

The 4-inch inside diameter and six-inch inside diameter columns were developed to allow for testing on intact core sample sediments. The contaminated sediment cores were delivered to the lab in 4-inch inside diameter and 6-inch inside diameter clear polyvinyl chloride (PVC) cylinders. The top and bottom of each cylinder was sealed with a cap to prevent leakage. The cylinder heights ranged from three feet to four feet.

In order to perform cap placement tests on these columns, an upper column addition was needed to extend the height of each intact core cylinder to approximately seven to eight feet. As seen in Figure 3.2, the columns were extended by flanging an addition length of pipe to the PVC cylinder containing the contaminated sediment core. A total of four 4-inch, and two 6-inch acrylic column additions, each 4 ft tall, were constructed. A PVC flange was affixed to the base of each acrylic column addition. Another PVC flange was affixed to the top of each contaminated sediment core. A rubber gasket was placed on top of each contaminated sediment core column's flange in order to

create a tight seal. Then the acrylic addition was placed on top of the contaminated sediment core column with the acrylic column's flange on top of the gasket. The two flanges were then sealed together tightly with PVC nuts and bolts. The bottom contaminated sediment core and upper addition were both secured to a wall.

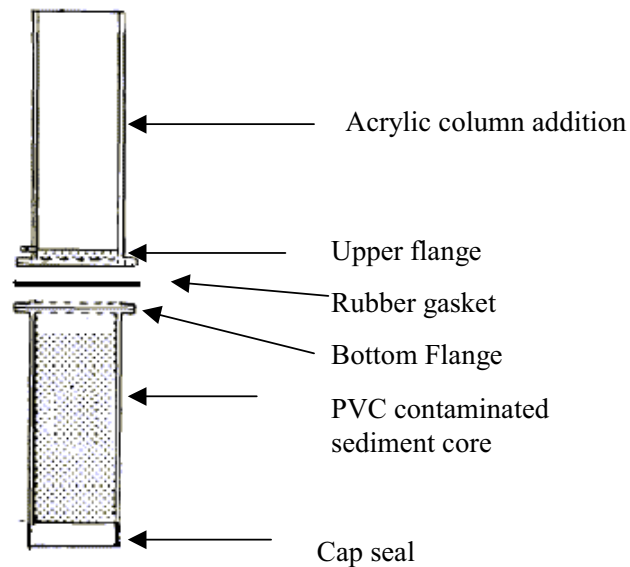


Figure 3.2
Four and 6-inch Column

Eight-Inch Diameter Columns

The 8-inch inside diameter columns used in the ISC tests were modeled after the settling column in U.S. Army Corps of Engineers (1987). The column shown in Figure 3.3 was made of 8-inch inside diameter acrylic cylinders. The column was made in two sections of 27-inches and 57-inches for easier handling and cleaning as suggested by the U.S. Army Corps of Engineers (1987). The column has seven sample extraction valves spaced 6-inches apart for extracting water samples. The column also was made with a porous plate at the base to allow for evenly distributed air and water injections into the

column through a 1/4 inch opening. More detailed fabrication diagrams of this column are located in Appendix A [USACE 1987].

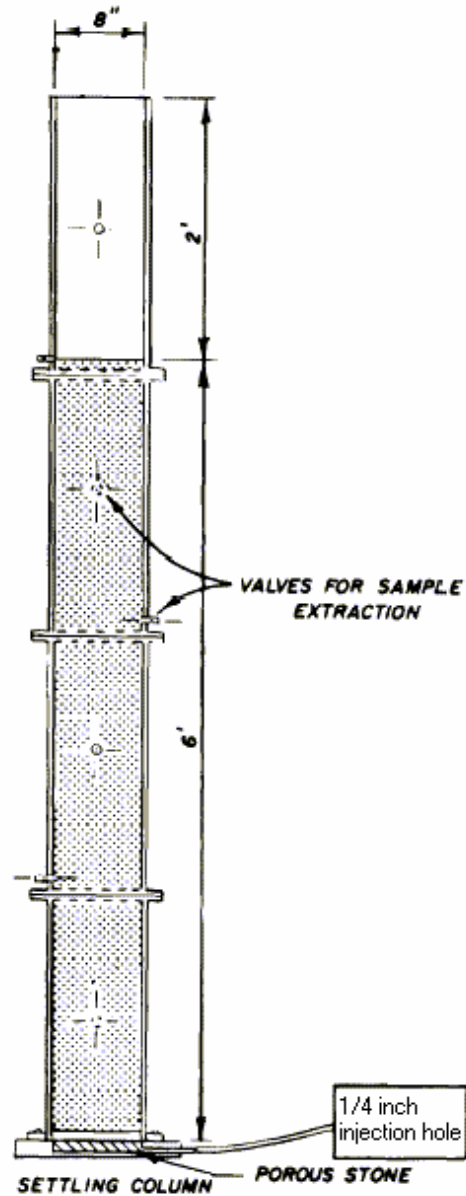


Figure 3.3
Schematic of apparatus for column tests [U.S. Army Corps of Engineers 1987]

2-D Aquarium

The 2-D aquarium was constructed of glass. It was constructed as a double-sided rectangular container whose dimensions on each side were 18-inches by 16-inches by 11-inches.

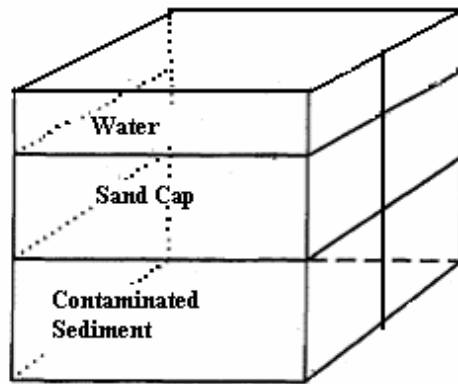


Figure 3.4
2-D aquarium schematic

Column Tests Procedures

Tests were performed using the fabricated columns previously described along with the sand, contaminated sediment and water described in the column test materials section. During the column tests, consolidation was studied in order to determine the effect that consolidation had on the migration of contaminants into the capping layer. Then, air and water injections were performed on some columns to simulate the gas migration and groundwater migration that occurs in the field, in order to determine what effects these have on ISC. After the consolidation or air and water migrations were performed, selected columns were cored and the core extruded and sliced for chemical analysis.

Consolidation Test

Consolidation tests were performed on all of the columns and the 2-D aquarium in order to observe the amount of consolidation due to a cap and the effect consolidation had on the movement of NAPL and contaminated pore water into the capping layer. The procedure for these tests included setting up the material in the columns, and then measuring the contaminated sediment consolidation over time.

Set Up Procedure

The 4-inch and 6-inch columns already contained undisturbed contaminated sediment cores. In order to simulate cap placement, water was added to represent the lagoon or surge pond water, and then a sand cap was poured into the column. Water was poured into the column very slowly and carefully to not disturb the contaminated sediment already in the column. A 7-foot long piece of ½-inch diameter plastic tubing was connected to a tap water hose at one end. The other end was placed in the column until the end touched the top of the contaminated sediment. Once the water stream was turned on, the end of the tube was placed so that the water stream would hit the inside glass before rolling down the glass wall on to the contaminated sediment. The water flow rate was 0.06 liters per minute for the first 2 liters, and then this was increased to about 0.2 liters per minute until the water was 1-foot from the top of the column. Then, the column was left to sit for 72 hours to allow any suspended solids to settle. Finally, an initial water sample was taken for analysis.

After the 72 hour period, the sand cap was poured. This was done by using a metal scoop to pour the sand into the top of each column at a rate of approximately 20 grams per second until the entire cap was in place. Table 3.2 shows the cap heights for

each column tested in these experiments. Once the capping layer was poured, then the columns were allowed to consolidate between 30-45 days. For the 8-inch diameter columns that contained lagoon and surge pond sample sediment, the above set up procedure was used after placement of 5 gallons of sediment in the bottom of the column.

Table 3.2
Poured Cap Heights

<u>Column Name</u>	<u>Cap Height (inches)</u>
L-29-1 (4")	17.5
L-29-2 (4")	18.5
L-29-4 (6")	18
L-29-5 (6")	18.25
L-28-1 (8")	11
L-29-6 (8")	11
aquarium left	6
aquarium right	6
SP-3B (4")	18
SP-2A (4")	18
SP-1 (8")	12 (4inch sacrificial cap)*

*Due to the weakness of the disturbed surge pond sediment in the 8" column, a 4 inch cap was placed to intermix with underlying sediment and then a 12 inch cap placed.

For the 8-inch diameter columns, named SP-1, that contained surge pond sample sediment, a dry cap was poured. This procedure included adding the contaminated sediment and water to the 8-inch diameter column as previously described. Then, an initial 4-inches of cap material was placed as a "sacrificial" capping layer to provide a better surface foundation for the subsequent cap. After pouring the "sacrificial" capping layer, then all of the overlying water was drained from the 8-inch column. Next, a 1-foot dry cap was poured over the contaminated sediment. This capping layer was allowed to settle for 5 days, and then water was re-added into the 8-inch column. Due to the

weakness of the sludge pond sediment, it was felt that this procedure might become necessary to implement a cap in the field to

- 1) provide a solid support layer for a cap layer
- 2) allow drainage of the sludge pond for easier cap placement without exposing contaminated sediment directly to the air

The consolidation test for the 2-D aquariums was conducted just as it was for the 4-inch and 6-inch diameter columns, but in this case the experiment was continued for 6 months as opposed to the 30-45 days for the other experiments. This was done to observe the long-term effects consolidation had on contaminant migration.

Consolidation Measurement Procedure

Prior to cap placement, contaminated sediment properties such as the initial height, volume, and bulk density were measured and recorded. The height of the water column was measured and recorded. Consolidation measurements were taken at increasing intervals due to the substantial reduction of consolidation over time. The intervals were 12, 24, 48, 96 hours, etc., until the end of the test (USACE 1987). These tests spanned between 30 to approximately 45 days. The consolidation measurements were taken with a tape measure that measured the distance from the column base to the sediment/contaminated sand interface. At the end of the consolidation and prior to coring, a sample of water above the cap was collected for HPLC analysis.

Air and Water Injections

The air and water injections were performed to simulate air bubble migration and water migration through the contaminated sediment. In the field this type of behavior naturally occurs due to CO₂ produced by benthic organisms in the sediment and

advective movement of pore water respectively (Palermo 1998). The purpose of these experiments was to test the effect of the air or water migration on contaminant migration into the capping layer.

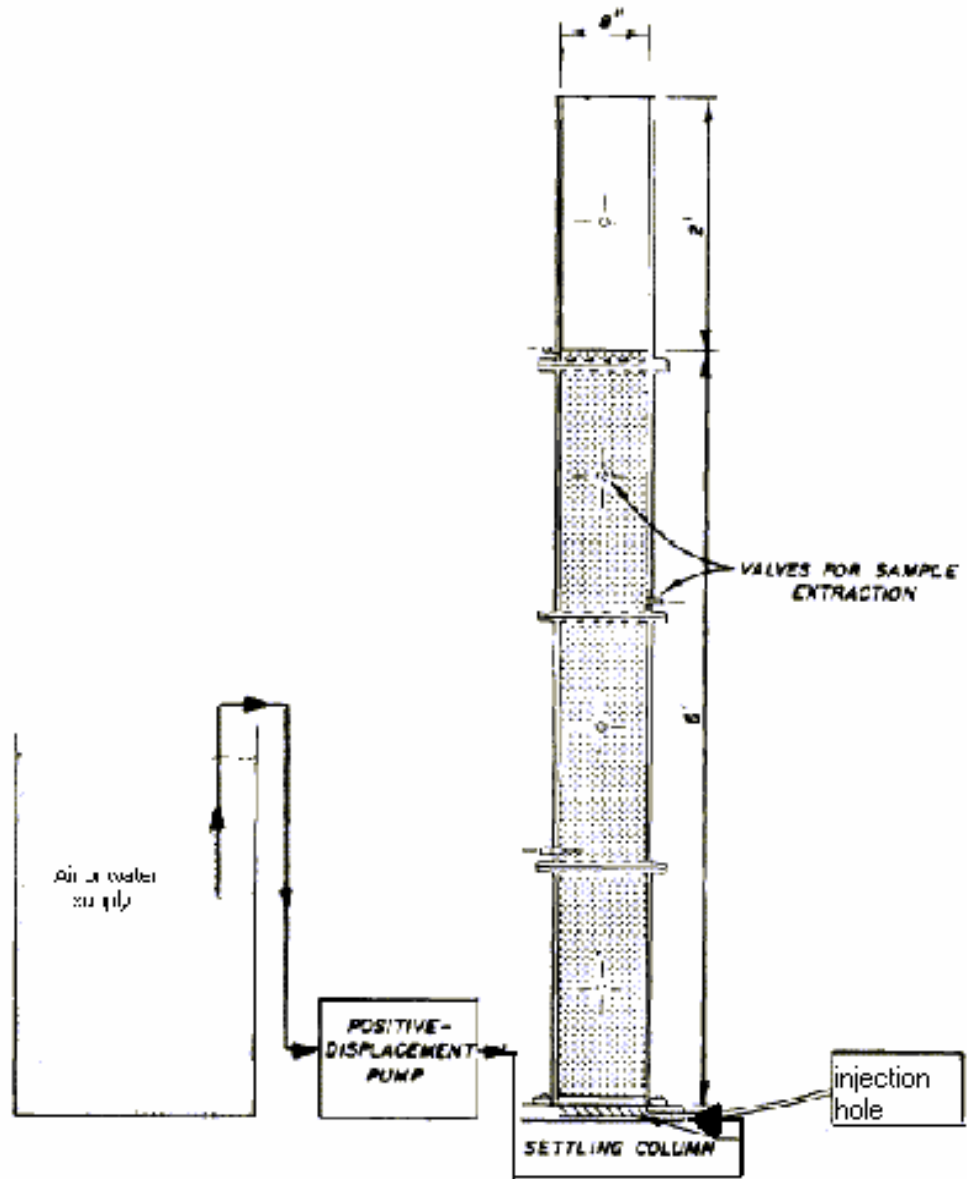


Figure 3.5
Air/Water injection set up

In the laboratory column experiments air injections were performed on columns L-29-6 and SP-1. The 8-inch diameter columns were made with a ¼-inch injection hole at their base along with a porous plate that would evenly spread the air and water as seen in Figure 3.5. The air and water were continuously injected into the settling column system using a low flow control volume pump, FMI model QG6-1SSY. Teflon tubing was attached to the outside air or the water supply and then to one side of the control volume pump. Then the other side of the control volume pump was connected to a second piece of Teflon tubing, and the tubing was connected to the column through the ¼ injection hole using a Teflon nut and farrel. The water was injected at a rate of 1.74 milliliters per minute, and the air was injected at a rate of 1.56 milliliters per minute for 37 days in column L-29-6 and for 57 days in column SP-1. The schematic diagram of the experimental setup is illustrated in Figure 3.4.

Column Coring

After approximately 30 to 45 days, the ISC test columns were cored so that contaminant migration could be analyzed. This coring procedure was necessary to remove a sample from the column to be analyzed. Before coring could take place, the water was siphoned from the column using ½-inch diameter plastic tubing. Once the water was drained, then the top acrylic column addition was removed. After the removal of the top acrylic column, the coring was performed.

For the coring procedure, a 2-inch diameter by 1-foot long split core sampler was used along with a plastic eggshell core catcher addition used to hold the sludge sample inside the corer. This coring device, shown in Figure 3.5, contained an inside sleeve that was inserted. The top 6-inches of cap material was removed with a ladle because that

upper region of the cap layer would not have significant contamination levels. The coring device was assembled, and then placed on top of the remaining 1-foot of sand. The coring device's handle was pounded, with a rubber mallet, straight down into the sand cap layer. Once the corer was pounded down into the 1-foot section of sand, it was removed by pulling the corer's handle straight up and out of the sand.



Figure 3.6
AMS Split Core Sampler

Core Extrusion and Slicing

In order to obtain contaminant migration data from the core sample, the sample had to be sliced into small sections of equal thickness for analysis. The core extruder used in this experiment was borrowed from, and designed by Libbers (1998). The only

changed made with the extruder was that it was mounted horizontally on a work bench for these experiments, as opposed to vertically on a wall. This did not affect the equipment performance, but made it easier to load the extruder with core samples. The piston-type extruder is shown in Figure 3.6. After coring, the inside sleeve that contained

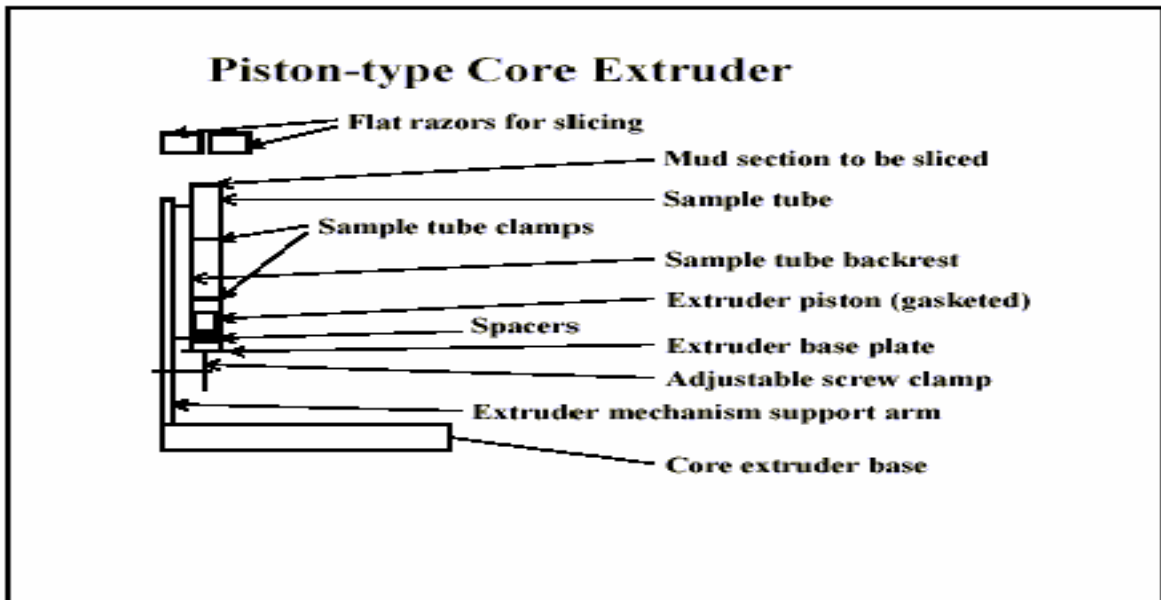


Figure 3.7
Piston-Type Extruder Diagram [Libbers 1998]

the sand sample was removed with the intact sand sample, and this sleeve was then placed into the core extruder. The extruder had a piston at its end, which was positioned at the bottom of the sediment sample. Once the lever was turned in a clockwise motion, the piston moved forward and forced the sand sample up through the core extruder's tube. When the sediment reached the opening of the sample tube, one centimeter slices of

sediment were cut. To ensure that there was no contamination between samples of the sediment due to the inside tube wall, the outside 1/4-inch circumference of each sample was removed. Then the cut sample slice was placed into a 140-milliliter jar for analysis.

Analysis

Analysis Preparation

In order to determine the amount of contaminants that migrated into the cap layer, the polycyclic aromatic hydrocarbons (PAHs) were measured using high performance liquid chromatography (HPLC). The specific PAHs measured were purchased from SUPELCO and named EPA 610 Polynuclear Aromatic Hydrocarbons Mix. Sixteen PAHs were in the mix with some chemical properties found in Table 3.3 that come from Thibodeaux [1996] and McGroddy [1995].

Table 3.3
Standard PAHs Mix

	<u>Mol.</u> <u>Formula</u>	<u>Num.</u> <u>of</u> <u>Rings</u>	<u>Mol.</u> <u>Weight</u> <u>(g/mol)</u>	<u>Percent</u> <u>Purity</u>	<u>Density</u> <u>(20/4)</u> <u>(kg/L)</u>	<u>Vapor</u> <u>Pressure</u> <u>at 25C</u> <u>(mg/L)</u>	<u>Water</u> <u>Solubilit</u> <u>y at 25C</u> <u>(mg/L)</u>	<u>K_{oc}</u> <u>(L/kg)</u>	<u>log</u> <u>K_{oc}</u>
Naphthalene	C ₁₀ H ₈	2	128	99.9	1.14	1.14E-04	34.4	1258	3.10
Acenaphthylene	C ₁₂ H ₈	3	152	99.9	0.899	9.12E-04	3.9	1470	3.17
Phenanthrene	C ₁₄ H ₁₀	3	178	98.5	0.98	4.53E-06	1.18	25118	4.40
Anthracene	C ₁₄ H ₁₀	3	178	99.1	1.24	1.40E-07	0.075	23493	4.37
Fluoranthene	C ₁₆ H ₁₀	4	202	98.2		9.22E-06	0.265	49096	4.69
Pyrene	C ₂₂ H ₁₂	4	202	98.0	1.27	1.60E-07	0.15	63095	4.80
Benzo(a)anthracene	C ₁₈ H ₁₂	4	228	99.9		1.90E-06	0.0094	357537	5.55
Chrysene	C ₁₈ H ₁₂	4	228	99.0	1.274	6.30E-09	0.002	45800	4.66
Benzo(b)fluoranthene	C ₂₀ H ₁₀	5	252	99.9		5.00E-07	0.0015	1450000	6.16
Benzo(k)fluoranthene	C ₂₀ H ₁₂	5	252	99.7			5.5E-05	1530000	6.18
Benzo(a)pyrene	C ₂₀ H ₁₂	5	252	97.3	1.35	7.00E-12	0.004	968774	6.00

Standards were prepared to accompany the contaminated sediment samples in the HPLC. The HPLC standards were prepared by diluting the standards into parts of 1/1000, 1/250, 1/50, 1/10 of the initial concentration.

The core samples were prepared using the Ultrasonic extraction method (EPA method 3550, 1986) to extract PAHs from the sediment matrix. The extraction method used in this study was slightly modified from the EPA method (EPA method 3550, 1986) and involved the following sample preparation steps. First, 1 gram to 2 gram wet sediment samples were placed in the extraction vessel (140 milliliter glass jar). Then, the sediment samples were mixed with about 30 gram (depending on sediment weight and moisture content) of anhydrous sodium sulfate to dry the sediment. Next, 60 milliliters of a 50/50 hexane/acetone mixture was added to the glass jars. The jars were then sealed and allowed to sonicate for about 20 minutes in a water-bath. After sonication, a 2 milliliter sub-sample was put into a 2 milliliter volumetric tube and concentrated under nitrogen flow to approximately 0.2 milliliter. Then, 1.8 milliliters of acetonitrile was added to the 0.2mL sample tube and mixed by hand. Finally, 0.5 milliliter to 1 milliliter of extraction solvent was transferred to 1.5 milliliter glass HPLC vials and analyzed immediately or stored in the refrigerator at 4°C for later analysis.

The water analysis was done similarly to the contaminated sand analysis, but there were a few differences in the preparation procedure. First, a 50 milliliter liquid sample was taken and poured it into a 140 milliliter glass jar. Then the sample was mixed with 5 milliliters of dichloromethane (DCM), and placed in a shaker for about 2 hours. Next, 2 milliliters of DCM from the bottom of the sample jar was transferred to a 2 milliliter volumetric tube. The DCM was blown away from the sample with nitrogen until

there was about 0.2 milliliter remaining in the volumetric tube. About 1.8 milliliter of acetonitrile was added to the volumetric tube sample in order to bring the volume up to 2mL. Finally, 0.5 milliliter to 1 milliliter extraction solvent was transferred to 1.5 ml glass HPLC vials and analyzed immediately or stored in the refrigerator at 4°C for later analysis.

HPLC

A Hewlett Packard 1100 series high performance liquid chromatography (HPLC, Hewlett Packard, Palo Alto, CA, USA) with UV-Diode array detector and fluorescence detector was used to measure the concentration of the extraction solvent (EPA method 8310, 1986). Sediment concentration of the contaminant tracers was calculated from the concentration of the extraction solvent. Additional information on the chromatographic analysis is located in Appendix B [Lu 2003].

Conclusion

In this study, ISC was simulated in laboratory column experiments to determine the effectiveness of ISC on the lagoon and surge pond sediments. The main experiments used for the laboratory testing were the consolidation test, gas and water injection test and HPLC analysis, which were discussed in this section. This work was done to examine the problems that could arise when using ISC on oil contaminated sediments.

Chapter 4. Results and Discussion

This chapter is focused on discussing the results obtained from the In-Situ Capping (ISC) experiments. The goal of this research was to evaluate the use of ISC as a remediation method for the lagoon and surge pond, which contained sediment contaminated by refinery wastewater solids. The experiments were used to determine the contaminant migration due to excessive consolidation, the migration of nonaqueous phase liquid (NAPL) and polycyclic aromatic hydrocarbons (PAHs) enriched in the contaminant, the amount of significant gas generation and migration, and the migration of groundwater via active seeps. Based on the research findings, the feasibility of an ISC design for the chosen site was discussed.

Studies on Lagoon Sediment

Consolidation

Contaminant migration due to excessive consolidation was studied through the column tests described in Chapter 3. The results of the column test show that there was an initial intermixing of the cap material and the upper layer of contaminated sediment during cap placement of about 1-inch for a 12-inch cap. After the initial intermixing, no other intermixing was observed during cap placement. The cap layer was supported by the contaminated sediment sample. During the consolidation tests, the independent variables were the various column diameters, and the two collection methods (reconstituted sediment samples and intact core samples). These independent variables were taken into consideration when analyzing the data.

Consolidation rates were taken for the two 4-inch columns named L-29-1 and L-29-2; for the two 6-inch columns named L-29-4 and L-29-5; for the two 8-inch columns

L-28-1 and L-29-6; and for the two 18-inch by 16-inch by 11-inch 2-D aquariums named aquarium 1 and aquarium 2. All of the curves for the consolidation rate versus time for these columns are all shown in graphs located in Appendix C. Figure 4.1 shows that the consolidation rate of the contaminated sediment reaches steady state

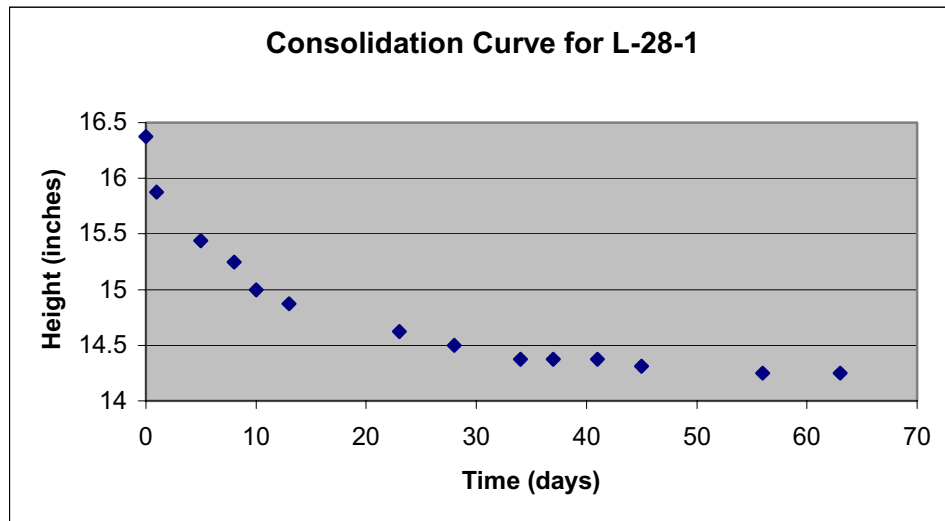


Figure 4.1
Consolidation Curve for L-28-1

after about one month of settling for the 8-inch column L-28-1. This was the same trend seen in all of the other columns tested during this experiment, which suggest that there would not be continual consolidation occurring after the contaminated sediment has reached the point of steady state.

In order to examine consolidation as a function of column diameter, the total percentage of consolidation (based on the initial height for each column) is located in table 4.1 shown below. The error was determined to be +/- 0.125-inches for the measured consolidation values. Also, the total percent loading for each column was approximately 30% sand cap, for each aquarium it was approximately 65% sand cap. For all columns, day one measurements were not taken into account as part of the total consolidation rate

because this consolidation was a result of only the upper layer of contaminated sediment settling quickly. This upper layer was not a representation of the consolidation of the

Table 4.1
Lagoon Total Consolidation Percentages

<u>Column Name</u>	<u>Collection method</u>	<u>Initial Sediment Thickness on day 2 (inches)</u>	<u>Final sediment Thickness (inches)</u>	<u>Change in height (inches)</u>	<u>Num. of Days</u>	<u>Total Consolidation (%) (minus day 1)</u>
L-29-1 (4")	intact core	39.13	37.81	1.31	30	3.35
L-29-2 (4")	intact core	39.38	38.94	0.44	32	1.11
L-29-4 (6")	intact core	39.75	38.50	1.25	30	3.14
L-29-5 (6")	intact core	37.25	33.44	3.81	32	10.23
L-28-1 (8")	reconstituted	15.88	14.38	1.50	33	9.45
L-29-6 (8")	intact core	20.06	19.44	0.63	33	3.12
aquarium left	reconstituted	5.75	5.38	0.38	28	6.52
aquarium right	reconstituted	5.63	5.00	0.63	28	11.11

contaminated sediment as a whole. Column diameter did not cause a significant difference in consolidation rates between the 4-inch columns, 6-inch columns, 8-inch columns, and aquarium despite the varying degree of wall effects on the contaminated sediment. It is important to note that column L-29-5 was the first column tested, thus there was an excess disturbance made on the contaminated sediment in this column during the initial adding of the overlying water. This excess in disturbance explains the difference in consolidation seen for this column when it is compared to the other 6-inch column, L-29-4. The lack of difference in consolidation due to wall effects is seen when comparing all of the intact cores in Table 4.1. All of consolidation ranges of the intact cores are between 1% to 3%, except for L-29-5 because of the initial excess disturbance. The wall effects proved to be small among the column test, but they still exist. Thus, the wall effects must be taken into consideration when scaling this project up for a field site

because the wall effects will be much less in the field site, consequently an increase in consolidation should be expected.

The core samples showed differences in consolidation rates due to the various collection methods used to retrieve the samples. As mentioned earlier, the collection methods were reconstituted sediment samples, and intact core samples. Table 4.1 shows the total consolidation data for all samples and differentiates between the two collection methods. As seen in Table 4.1, the percent of total consolidation of the 8-inch reconstituted column L-28-1 and the 8-inch intact core column L-29-6 were 9.45% and 3.12% respectively. This difference in total consolidation percentage is most likely due to the difference in collection methods.

All samples were not taken from the exact same location in the body of water sampled. As a result, this may be one cause for the slight differences seen in total consolidation rates between columns that shared the same diameter or collection method. An example of this is demonstrated in columns L-29-1 and L-29-2, and aquarium left and aquarium right. The difference in sample location caused a variation in sediment characteristics due to the differences in physical properties of the contaminated sediment at each location.

Although there was an intermixing between the cap and contaminated sediment during cap placement, after cap placement there was no further intermixing beyond the lower inch of cap material. Additional intermixing should be expected during placement under field conditions. The settling tests showed that there was minimal consolidation once the consolidation reached a steady state after approximately a one month period, and the contaminated sediment was able to fully support the cap layer. Since the

consolidation rate slows down to a steady state of almost zero, it can be assumed that contaminant migration due to consolidation would not be a factor once this occurs. One must also consider the effects of the two independent variables: column diameter, and collection method when using this data. It is important to remember that under field conditions there will be almost no wall effect, thus consolidation would increase when compared to the laboratory data. Also, behavior in field conditions would more closely resemble the intact core data. Overall, the data shows that the problems occurring due to consolidation do not prevent ISC as being feasible when used on the lagoon sediment.

Chemical Migration

The chemical migration seen in these experiments were NAPL and PAHs migration into the capping layer. NAPL migration was only observed during the initial intermixing that took place during cap placement. The NAPL migration observed was determined to be on the order of a few centimeters into each of the caps tested. After the initial cap pouring, no subsequent NAPL migration was observed.

The chemical measurements used to determine PAHs migration were collected by sampling the overlying water column above the cap, and by coring the cap to obtain vertical chemical profiles.

Overlying Water PAHs Measurements

The measurements of the PAHs located in the water column indicated that there was no significant change in concentration before and after capping as shown in Table 4.2 for column L-29-6. The overlying water column PAH concentrations were in the low 0 to 10 ppb range before and after capping. The contaminants located in the water can be attributed to the small amount of intermixing that occurs between the water and the

contaminated sediment during water placement. The overlying water PAH data for additional columns is located in Appendix D.

Table 4.2
PAH concentrations of the overlying water for L-29-6

Chemicals	concentration in water (ppb)	
	initial	final
Naphthalene	2.56	
Acenaphthene	4.96	
Phenanthrene	0.051	0
Anthracene		
Fluoranthene	20.38	0.33
Pyrene	0.45	
Benzo(a)anthracene	2.70	
Chrysene	1.40	
Benzo(b) fluoranthene	16.42	0.92
Benzo(k)fluoranthene		
Benzo(a)pyrene	0.22	

Vertical PAHs Profiles

The columns used for the consolidation tests were also used to examine the vertical PAH profiles in the cap layer. The tests show that there was some penetration of contaminants into the lower layers of the cap, which can be attributed to the initial intermixing during cap placement, the migration of pore water into the base of the cap layer due to consolidation (a relatively short term effect taking place over about one month), and finally diffusion (a long term effect taking place over many years). Heights above the lower few inches of the cap show that the concentrations of PAHs detected are either considered background or below the detectable limits of 10ppb.

PAHs were tested for 11 chemical compounds as stated in the Chapter 3. When considering the data for the 11 chemical compounds, it is important to note that the more

hydrophobic PAHs (representing four- and five- ring chemical compounds) are more sorbing. This means that more highly sorbing chemical compounds will migrate through the cap layer at a slower velocity than, the two- and three- ring counterparts. The less sorbing compounds that have the ability to more easily migrate into the cap include: Naphthalene, Acenaphthene and Phenanthrene. Thus, when considering chemical migration, the above three chemical compounds will be discussed. The effect of retardation occurred for the sorbing PAHs compounds in all column experiments and retardation factors will show this.

Naphthalene, Acenaphthene and Phenanthrene (as shown in Figure 4.2, Figure 4.3 and Figure 4.4) were used to detect the migration of chemicals into the cap layer for the columns tested. The vertical concentration profiles shown in these Figures become consistently low after a height of about 4 to 5cm from the sediment/cap interface. The low concentrations of PAHs are considered background due to the equilibrium partitioning between the water and sand cap.

Figure 4.2, Figure 4.3 and Figure 4.4 both show that all three compounds have migrated up to about 4cm for Naphthalene and about 3cm for Acenaphthylene and Phenanthrene. This amount is approximately one half of what would be expected from calculations as a result of pore water migration due to consolidation. Total consolidation for column L-29-4, including day one, was about 5.4cm, and the contamination migrated about 3 to 4cm up into the column, depending on the compound, as shown by Figure 4.2, 4.3 and 4.4. The porosity of the play sand was 42%. When the ultimate depth of

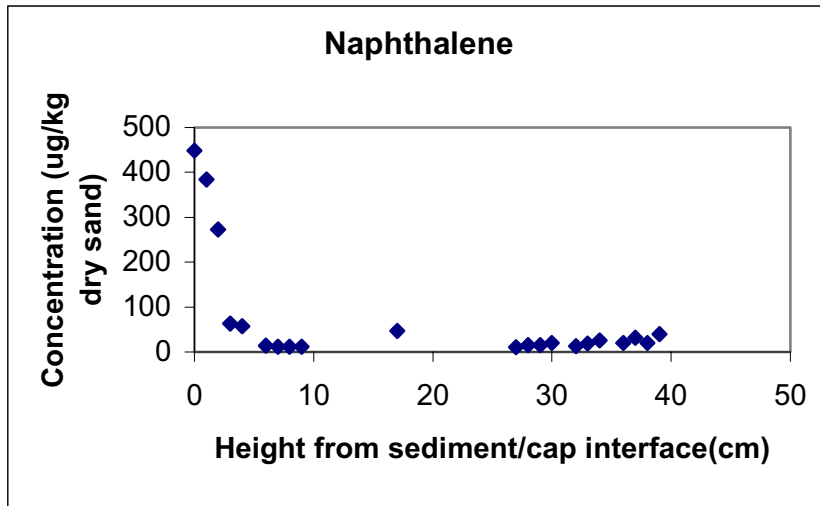


Figure 4.2
Naphthalene vertical PAH profile of column L-29-4

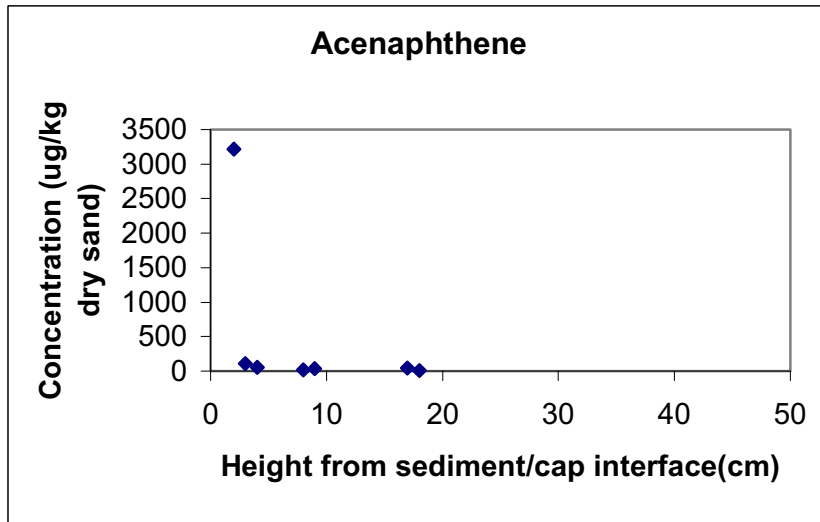


Figure 4.3
Acenaphthene vertical PAH profile of column L-29-4

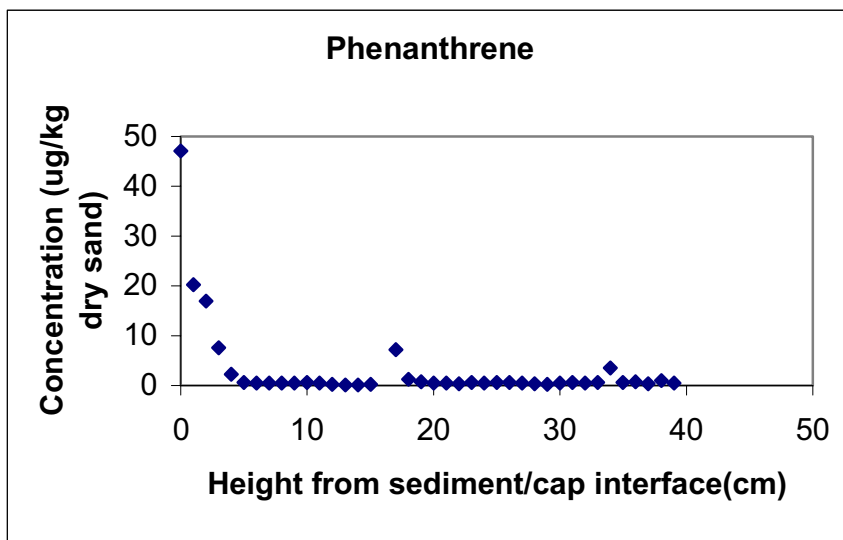


Figure 4.4
Phenanthrene vertical PAH profile of column L-29-4

consolidation of the underlying contaminated sediment due to cap placement equals ΔL_{sed} , then the depth of the cap affected by this porewater (or non-sorbing contaminant), ΔL_{sedpw} is given by

$$\Delta L_{sedpw} \approx \Delta L_{sed} / \varepsilon \quad (4-1)$$

where ε is the porosity of the cap materials [Palermo et al 1998]. When this is calculated for the column L-29-4 data, the ΔL_{sedpw} should be about 12cm based on total consolidation. But in this case, the migration data for Naphthalene in L-29-4 it is about 1/4 of what was expected at about 4cm of Naphthalene migration. This shows that the advective pore water migration in this column's Naphthalene compound was only about 1/4 of what was expected, which shows that the PAHs in this type of contaminated sediment are not carried up into the cap layer as far as calculations may make one to believe. The ΔL_{sedpw} values were calculated for the other compounds in L-29-4 as shown in Table 4.3. The calculated results were compared to the experimental results determined from the PAHs migration curves. From the results it is can be seen that

Table 4.3
Pore Water Migration and Retardation Factors for L-29-4

<u>Column Name</u>	<u>Num. of Days</u>	<u>porosity</u>	<u>K_{oc}</u>	<u>ΔL_{sed} (cm)</u>	<u>ΔL_{sedpw} calculated (cm)</u>	<u>ΔL_{sedpw} exper. (cm)</u>	<u>R_f exper.</u>	<u>R_f calc.</u>
L-29-4 (6")	30	0.42		5.4	12.85			
Naphthalene			1258		12.85	4	3.21	4.76
Acenaphthylene			1470		12.85	3	4.28	5.49
Phenanthrene			25118		12.85	3	4.28	87.07
Anthracene			23493		12.85	UD		
Fluoranthene			49096		12.85	2	6.42	169.80
Pyrene			63095		12.85	UD		
Benzo(a)anthracene			357537		12.85	UD		
Chrysene			45800		12.85	UD		
Benzo(b)fluoranthene			1450000		12.85	3	3.21	5002.92
Benzo(k)fluoranthene			1530000		12.85	UD		
Benzo(a)pyrene			968774		12.85	UD		

* UD = under detection limits

ΔL_{sedpw} is dependent on the sorption of the compound for the experimental values. When looking at the K_{oc} values in Table 4.3, one will notice that as ΔL_{sedpw} decreases, then K_{oc} increases. This shows that migration into the capping layer is chemical dependent.

Further examination proves that the chemical dependence is only slight. This can be seen when looking at the retardation factors shown in Table 4.3. The retardation factors for the experimental results all remain in the same order of magnitude, while the retardation factors for the calculated values increase by a factor of 10 or more. This shows that while there is a slight chemical dependence when it comes to migration, the bulk of the migration is most likely due to the initial intermixing. A smaller portion of the chemical migration seen is due to the consolidation induced pore water advection.

Similar results can be seen for the other lagoon columns tested in Appendix F.

When only examining the calculated and experimental ΔL_{sedpw} values for each column while not taking into account the slight chemical dependence one can see that the advective pore water migration was about half of the expected value for all lagoon columns except for the one that received air injections. Table 4.4 shows the pore water

Table 4.4
Pore Water Migration Due to Consolidation

Column Name	Collection method	Number of Days	porosity	ΔL_{sed} (cm)	ΔL_{sedpw} calculated (cm)	ΔL_{sedpw} actual (cm)
L-29-1 (4")	undisturbed intact core	30	0.42	4.29	10.22	5
L-29-2 (4")	undisturbed intact core	32	0.42	2.22	5.29	3
L-29-4 (6")	undisturbed intact core	30	0.42	5.4	12.85	5
L-29-5 (6")	undisturbed intact core	32	0.42	11.59	27.59	UD
L-29-6 (8")	air injected intact core	33	0.42	4.29	10.21	10

migration due to consolidation for all lagoon columns with the ΔL_{sedpw} experimental being an average of migration over all compounds. The calculated retardation factors from Table 4.3 can not be used as an appropriate adjustment for ΔL_{sedpw} values based on these results.

These results show that PAHs migration into the cap layer during the consolidation tests did occur, but only into the lower few centimeters of the cap. This migration was small and primarily due to the initial intermixing and consolidation-induced advection of the contaminated sediment. After consolidation has occurred, contaminant migration is expected to continue at a very slow rate due to pore water diffusion. Additional figures containing the PAHs migration curves for all of the columns studied can be found in Appendix E.

Gas Migration

Gas migration experiments were conducted to determine if it caused additional PAH migration into the cap layer. In order to examine gas migration, air was injected into the columns L-29-6 and L-28-1 as described in Chapter 3. It was determined that gas migration does cause a slight increase in the PAH migration through the cap layer. In this laboratory procedure gas was introduced into the system for 37 days continuously. Air at the rate of 1.5 mL/min, as mentioned in Chapter 3, From this, one would expect 1332 mL of pore water to be expressed from the contaminated sediment into the capping layer due to the air injection. This would be equivalent to 10cm of additional contaminant migration due to pore water expression.

Figure 4.5 and Figure 4.6 show that from the vertical chemical profile of Naphthalene and Acenaphthene for column L-29-6, the contaminants migrate up to about 9cm into the capping layer. Based on equation 4-1, the total consolidation is 4.2cm, and the porosity is again 42% for column L-29-6. When ΔL_{sedpw} is calculated for L-29-6, it is 10cm which equals the actual pore water migration value measured as shown in Table 4.4. The value of 10cm also coincides with the distance of migration expected due to the pore water expression due to the air injection.

The columns with out gas migration (discussed in the previous section) only showed migration lengths of about ½ of the calculated value. When comparing the columns with out gas injection to the column with gas injection, it is seen that the contaminants migrate higher up into the capping layer due to the gas injections. Thus, the assumption can be made that the gas migration introduced in this test caused an increase in PAHs migration.

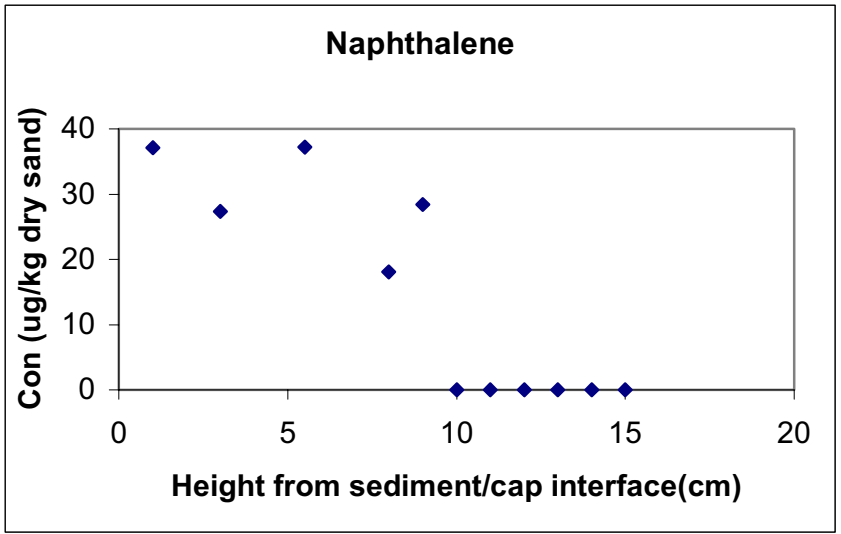


Figure 4.5
Naphthalene vertical PAH profile of column L-29-6

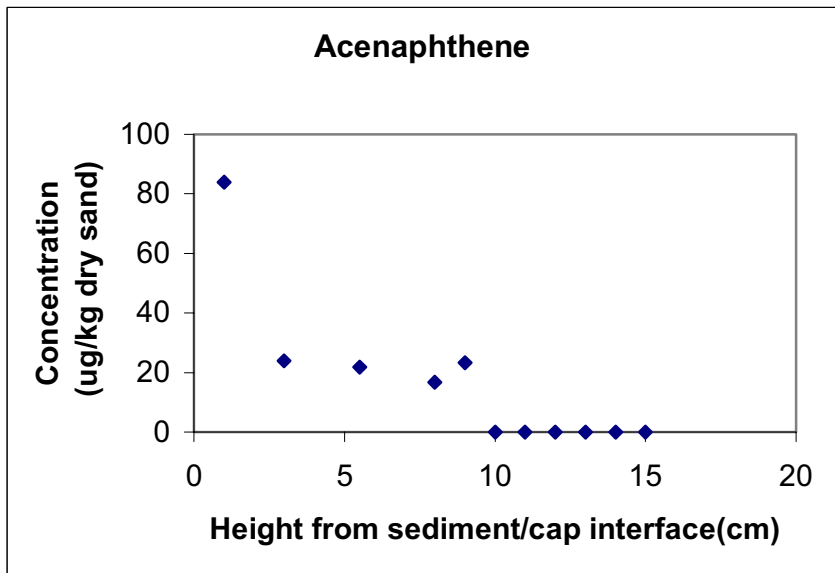


Figure 4.6
Acenaphthene vertical PAH profile of column L-29-6

The air injection experiment failed for column L-28-1 due to a build up of the air at the base of the column underneath the contaminated sediment as seen in Figure 4.7. This air build up at the base of the column could have possibly occurred in L-28-1

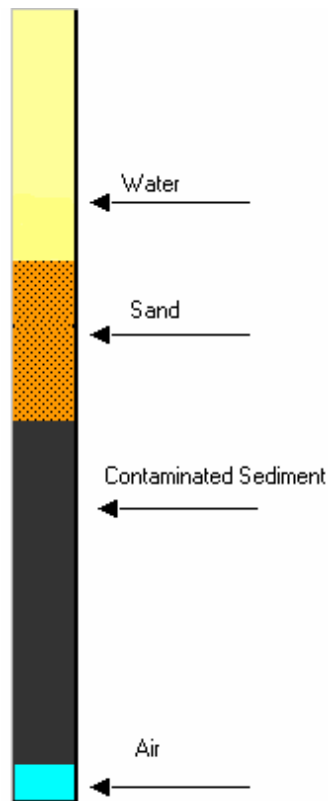


Figure 4.7
Column experiencing air build up at the base

and not L-29-6 because of the differences in physical properties between the two samples of contaminated sediment. Although these samples both came from the lagoon, each sample was collected differently. L-29-6 was collected as an intact core, and L-28-1 was collected as reconstituted sediment. It appears that the surface area created by L-28-1 was large enough to prevent any of the air bubbles from flowing up into the contaminated sediment.

Migration of Groundwater

The migration of groundwater was tested by injecting water into the settling columns as described in Chapter 3. This procedure proved to be unsuccessful in injecting water up through the contaminated sediment because just as in Figure 4.7, the same type of accumulation at the base of the column occurred for the water. Thus, the effect of water flow into the sediment could not be studied. It appears that the water flowing through the porous plate at the base of the column could not get past the surface tension created by the contaminated sediment.

2-D Aquarium Experiment

NAPL migration into the cap layer was studied in the 2-D aquarium. In this case, it was observed that the cap was slowly sinking into the contaminated sediment over a period of 6 months. The contaminated sediment sank into the cap at a rate of approximately .0096 inches per day. It appeared that this sinking effect was beginning to slow considerably after about a 6 month period. This result is important because it shows that contaminant migration can occur over an extended period of time due to the weight of the cap sinking into the contaminated sediment. This effect was more apparent in the 2-D aquarium because there were less wall effects in this vessel as opposed to the columns tested. The sinking effect of the sand cap layer should not be a cause for concern because it tapered off significantly after a few months. It would be important to account for this sinking effect when determining the height of the ISC layer.

Studies on Surge Pond Sediment

When compared to the samples taken from the lagoon, the surge pond samples were an oilier, softer, and wetter sediment. This sediment had a stronger odor and was

much harder to deal with because of these differences in physical properties. Based upon the overlying water contaminant concentrations, the surge pond sediment had higher concentrations of contaminants than the lagoon sediment. This sediment also generated gas bubbles, which had the potential to carry contaminants up into the overlying water when disturbed. The same types of experiments were performed on the surge pond sediment as the lagoon sediment, but the surge pond sediment proved to be more problematic during ISC because of its differences in physical properties. These issues are discussed in the following sections.

Consolidation

Contaminant migration due to excessive consolidation was studied for the samples taken from the surge pond with the column settling tests described in Chapter 3. The results of the settling test show that there was a significant amount of initial intermixing of the cap material and the upper layer of contaminated sediment of about two inches during cap placement for an 18 inch cap in columns SP-2A and SP-3B. Also, during cap placement contaminated sediment was kicked up into the water column so that it settled on top of the entire cap layer. Thus, this delayed settling of contaminated sediment caused there to be a thin layer of contaminated sediment present at the top of the cap layer placed. After the initial intermixing, no other intermixing was observed. For column SP-1, there was little to no intermixing because the cap was poured dry (with out the overlying water column) as described in the Materials and Method section.

The 4-inch columns SP-2A and SP-3B showed similar percentages of total consolidation rates versus time as shown in Table 4.5. This value was calculated by omitting the first day of consolidation as was done for the lagoon sediments also. For

SP-2A total consolidation was 5.56% and SP-3B was 6.11% over a 21 day period. Figure 4.8 shows the total consolidation curve for SP-3A. This column was approaching a

Table 4.5
Total Consolidation Percentages

<u>Column Name</u>	<u>Collection method</u>	<u>Initial Sediment Thickness on day 2 (inches)</u>	<u>Final sediment Thickness(inches)</u>	<u>Change in height (inches)</u>	<u>Number of Days</u>	<u>Total Consolidation (%) (minus day 1)</u>
SP-3B (4")	intact core	32.35	30.38	1.98	21	6.11
SP-2A (4")	intact core	58.50	55.25	3.25	21	5.56
SP-1 (8")	reconstituted	21.00	18.00	3.00	14	14.29

steady-state consolidation rate of zero as seen also seen for the lagoon sediments. Column SP-1 was an 8-inch diameter column taken from a reconstituted sample. These differing variables cause the consolidation rate of SP-1 to be significantly greater than that of the two 4-inch surge pond columns.

The consolidation tests showed that there was minimal consolidation once the consolidation reached a steady state, and the contaminated sediment was able to fully support the cap layer. Since the consolidation rate slows down to a steady state of almost zero, it can be assumed that contaminant migration due to consolidation would not be problematic in the long term for ISC, once this occurs. When comparing the surge pond sediment to the lagoon sediment, there was more consolidation observed. Overall, consolidation for the surge pond sediment is more problematic than the lagoon sediment, but the ISC layer was still able to hold and contain the contaminated sediment.

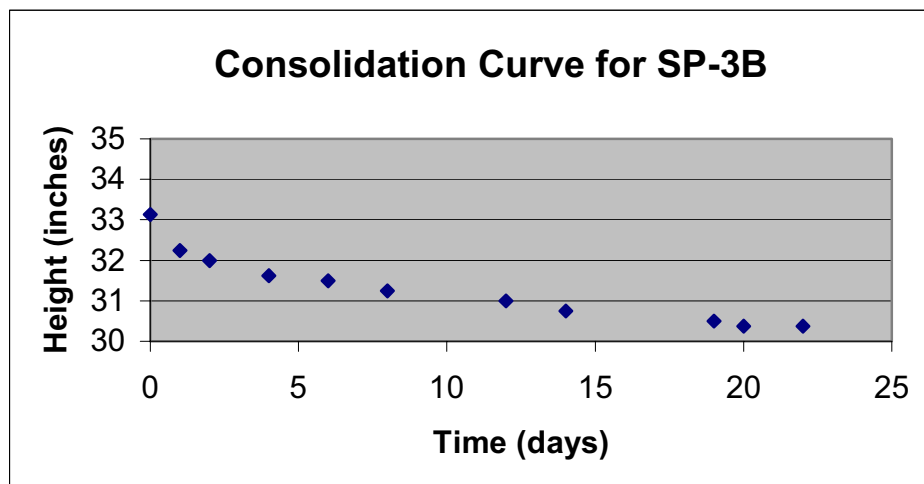


Figure 4.8
Consolidation Curve for SP-2A

Chemical Migration

The surge pond sediment, like the lagoon sediment, had chemical measurements taken that were used to determine PAHs migration with the samples collected from the overlying water column above the cap, and by coring the cap to obtain vertical chemical profiles. NAPL migration was only observed during the initial cap placement and went up only a few centimeters into the capping layer.

Overlying water PAHs measurements

The overlying water PAH proved to contain higher concentrations than that in the previous lagoon sediments discussed. The water concentrations were between 10 ppm to 50 µg/L as shown in Table 4.6 for the 4-inch column SP-3B. This shows that higher levels of contaminants are present in the surge pond sediment samples. Consequently, higher contaminant concentrations were expected in the background of the PAHs migration profiles. As shown in Table 4.6 for column SP-3B, the measurements of the PAHs located in the water column indicated that there was a decrease in the contaminant

Table 4.6
PAH Concentrations of the Overlying Water for SP-3B

Chemicals	Concentration in water (ppb)	
	initial	final
Naphthalene		
Acenaphthene	12.96	4.49
Phenanthrene	0.74	0.31
Anthracene		0.38
Fluoranthene	52.96	9.01
Pyrene	15.20	1.27
Benzo(a)anthracene	34.09	1.77
Chrysene	0.26	
Benzo(b) fluoranthene	30.02	2.46
Benzo(k)fluoranthene	0.083	
Benzo(a)pyrene	0.26	0.15

concentrations measured before and after capping. This is attributed to the prolonged undisturbed settling that took place once the cap layer was poured, which allowed any suspended solids to settle out.

Vertical PAHs Profiles

SP-3B was cored and extruded to obtain vertical PAHs profiles of the capping layer in the column. The tests showed that there was some penetration of contaminants into the lower layers of the cap and the top layer shows contaminants also. The contaminants in the lower layers of the cap can be attributed to the initial intermixing during cap placement and the migration of pore water into the base of the cap layer due to consolidation. The remaining contaminants present through the middle and upper portion of the column are attributed to gas migration into the cap. The surge pond intact cores had a substantial amount of gas generation that moved up into the capping layer. It is

assumed that the gas bubbles migrating up into the capping layer carried contaminants up through the capping layer as seen in Figures 4.9, 4.10 and 4.11.

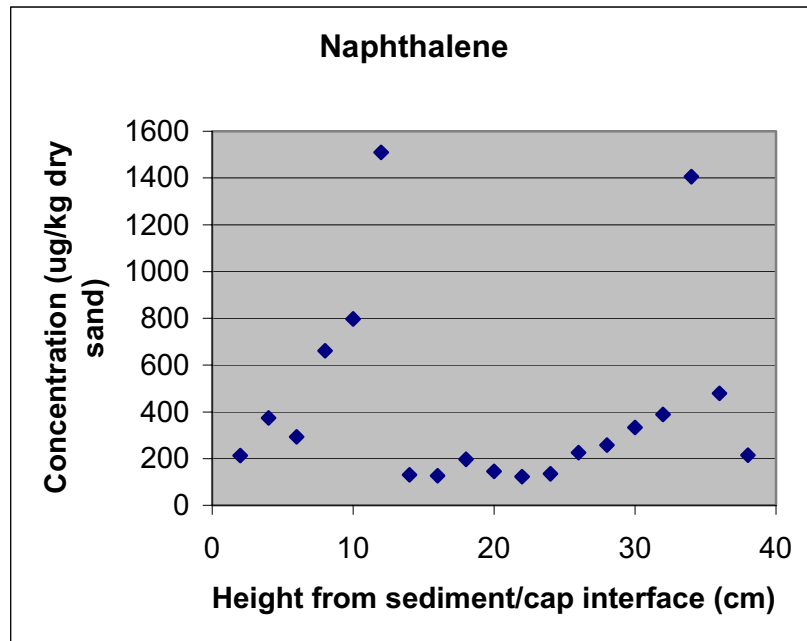


Figure 4.9
Naphthalene vertical PAH profile of column SP-3B

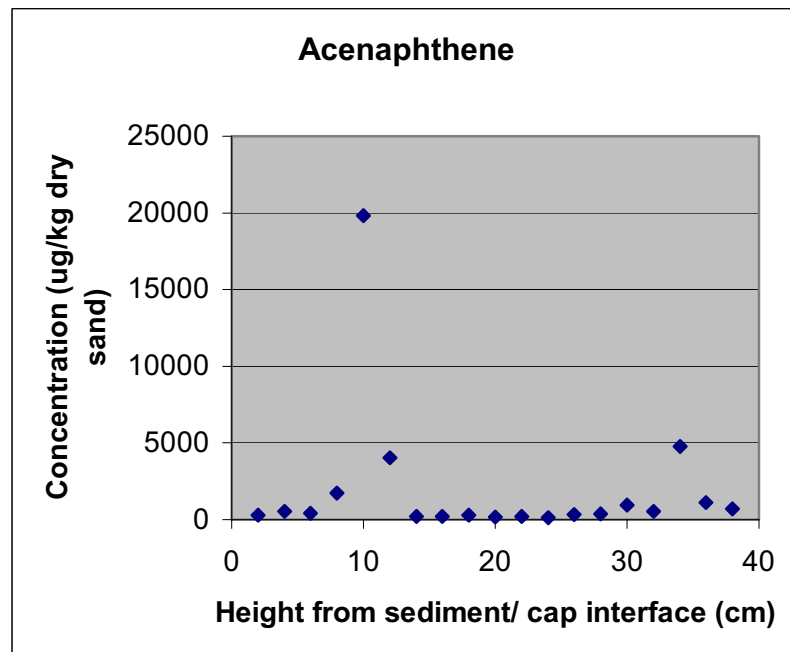


Figure 4.10
Acenaphthene vertical PAH profile of column SP-3B

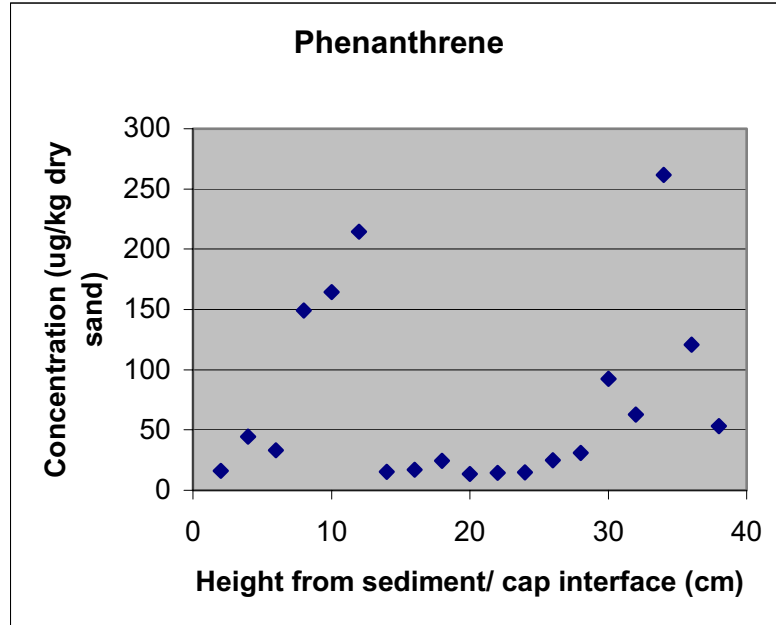


Figure 4.11
Phenanthrene vertical PAH profile of column SP-3B

Figure 4.9, Figure 4.10, and Figure 4.11 show the curves of the three non-sorbing compounds used to determine NAPL migration. All of the curves for these compounds have two peaks. The second peak, located at a height of about 34 cm, is considered an outlier due possible contamination from the coring procedure. This point outlying point does not occur in column SP-2A, as seen in Appendix E. Column SP2A show a similar curve when compared to SP-3B. Thus, it is believed that the contaminants in the lower layers are due to the initial intermixing and migration of pore water into the capping layer as seen in the lagoon samples. But unlike the lagoon samples, there is a higher level of contaminants seen through the entire capping layer for the surge pond columns. This is due the gas generation from the contaminated sediment, which carried contaminilants up into the capping layer.

When considering ΔL_{sedpw} for SP-3B, the total consolidation was about 7cm with a porosity of 42%, gives a ΔL_{sedpw} of 16.6cm. The actual value found from the data

averaged across all contaminants, about 10cm, is 60% of the expected pore water migration expected. When compared to lagoon data, the pore water migration is only slightly higher.

Examining ΔL_{sedpw} for SP-3B for each compound, it appears that migration of the contaminants have a minimal chemical dependence. Table 4.7 shows the relationship between the ΔL_{sedpwa} and retardation factors of the experimental and calculated values for the column SP-3B data. From the data one can see that the retardation factors for the calculated are increase by order 10, while the retardation factors for the experimental values remain on the same order for all compounds. Thus, chemical dependence is minimal when it comes to migration of contaminants into the capping layer. This trend was seen in all of the surge pond data and it can be reviewed in Appendix F.

Table 4.7
Pore Water Migration and Retardation Factors for SP-3B

<u>Column Name</u>	<u>Num. of Days</u>	<u>porosity</u>	<u>Koc</u>	<u>ΔL_{sed} (cm)</u>	<u>ΔL_{sedpw} calculate d (cm)</u>	<u>ΔL_{sedpw} exper. (cm)</u>	<u>R_f exper.</u>	<u>R_f calc.</u>
SP-3B (4")	38	0.42		7	16.6			
Naphthalene			1258		16.6	13		
Acenaphthylene			1470		16.6	12	1.38	5.49
Phenanthrene			25118		16.6	18	0.92	87.08
Anthracene			23493		16.6	8	2.08	81.47
Fluoranthene			49096		16.6	18	0.92	169.80
Pyrene			63095		16.6	21	0.79	218.10
Benzo(a)anthracene			357537		16.6	22	0.75	1233.92
Chrysene			45800		16.6	14	1.19	158.43
Benzo(b)fluoranthene			1450000		16.6	14	1.19	5002.92
Benzo(k)fluoranthene			1530000		16.6	UD		5278.92
Benzo(a)pyrene			968774		16.6	UD		3342.69

Column SP-2, the reconstituted sample, demonstrated a similar result when compared to the intact cores. The all had contaminants present through the entire cap at a

higher level than the lagoon samples. Finally, the level of contamination seen in the middle of the cap is due to a combination of background, and gas migration into the cap layer as a result of the sediment generated gas bubbles.

This increased amount of contamination in the ISC layer in the surge pond sediment samples due to the gas generation caused an additional release of contaminants into the capping layer. When operating in field conditions this must be considered because additional cap height, and multiple cap lifts would probably be necessary.

Gas Migration and Generation

The sediment sample SP-1, taken from the surge pond, generated gas bubbles. It was observed that without a cap layer the gas bubbles, carrying up oil, would bubble up to the surface of the contaminated sediment and overlying water. This resulted in the overlying water of the 8-inch column to change to an opaque color. Quantitative measurements of the gas bubbles being generated were not taken in this experiment. But, through observation it was seen that once the ISC layer had been placed, that no further NAPL contaminated gas bubbles escaped through the cap layer into the overlying water. In addition to the gas bubbles generated by the SP-1 sample, air bubbles were injected into the sediment to explore the worst-case scenario of gas generation. The PAHs versus height data can be found in Figure 4.12 and 4.13. The curves were similar to the SP-3B data shown in Figures 4.9, 4.10 and 4.11. But, there was a slight decrease in the order of magnitude of contaminants present in the middle and upper capping layer. This is probably due to the fact that reconstituted sediment was used. Thus, much of the gas generated by the contaminated sediment was able to escape prior to the start of the experiment. So, there was less generated gas (containing the contaminants) to move up

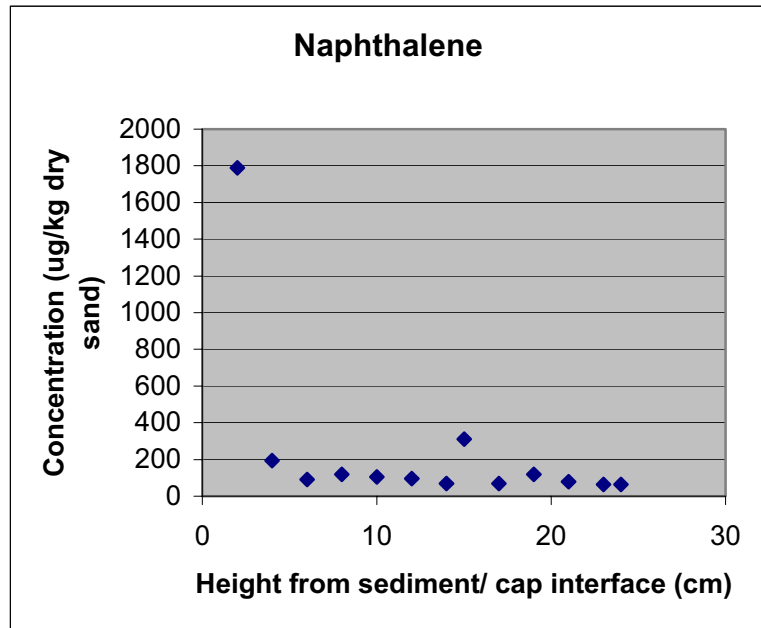


Figure 4.12
Naphthalene vertical PAH profile of column SP-1

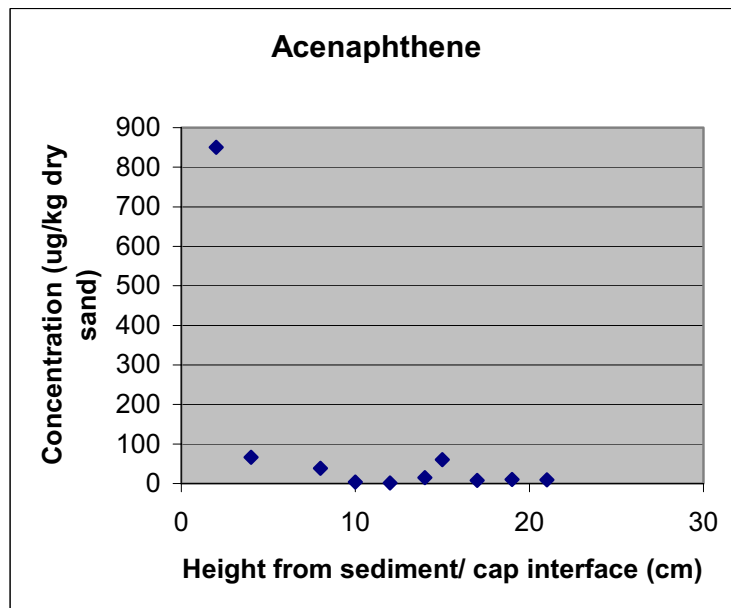


Figure 4.13
Acenaphthene vertical PAH profile of column SP-1

into the capping layer. Where as the intact cores were pretty much undisturbed, thus causing the gas to remain in the contaminated sediment. One would expect that contaminants would move up higher in SP-1 (because of air injection) than in SP-3B or SP-2A. But, this was not the case possibly because the air injected into the column was clean air, and not the contaminant filled gas generated by the contaminant sediment. Thus, the clean air didn't carry contaminants up into the capping layer.

This experiment proved that the ISC layer was able to contain the contaminants carried by the gas bubbles generated from entering the overlying water column. This was visually seen by observing gas bubbles escaping from the capping layer, but there was no sign of NAPL or oily residue left in the overlying water as previously seen in the test without a capping layer. Also, the water data in Appendix D proved this result.

Chapter 5. Conclusions and Recommendations

Overall, the results proved that In-Situ Capping (ISC) could be an effective remediation method for the oil contaminated sediments tested. However, some adjustments are necessary for the cap design to fully contain contaminant migration.

Conclusions

Consolidation was seen in all of the oil contaminated sediments tested during this experiment. The rate of consolidation significantly decreases after about one month following cap placement, which should be expected to occur in a field site as well. During cap placement intermixing of the contaminated sediment and capping material was observed. This intermixing played an even bigger role for the surge pond sediment. Nonaqueous phase liquid (NAPL) migration occurred due to intermixing up into the first few centimeters of the capping layer, but once the initial intermixing occurred there was no further intermixing on the undisturbed sediment.

The wall effects between the 4-inch, 6-inch, 8-inch, and 2-D aquarium vessels did not significantly affect the consolidation results. Thus, when performing laboratory experiments on ISC, one can use any of the column diameters tested and expect similar results.

Polycyclic aromatic hydrocarbons (PAHs) did migrate up into the capping layers of the lagoon and surge pond sediment due to the consolidation-induced advection of pore water into the capping layer. It was determined that pore water migration was only minimally chemical dependent. For the intact lagoon cores tested, the experimental value for the average (across all contaminants) height of pore migration was about one half of what the expected value would be. This indicates that the standard equation for

calculating this migration (Eqn 4-1) seems to be conservative. Thus, making a cap more effective at containing the contaminated sediments. The surge pond sediment had a contaminant migration up into the capping layer that was 60% of the expected value. Thus, the surge pond contaminant migration for an undisturbed core was effectively equaled to that of the lagoon sediment.

It appears that, gas migration did increase the contaminant migration into the capping layer. This effect was seen when comparing the results of column L-29-6 to the other intact columns that did not receive air injections. The gas migration up into the cap was twice that of the columns without air injections. The distance that the contaminants migrated, were found to approximately equal the expected value that was calculated based on the consolidation divided by the porosity (Eqn 4-1). This shows that in the lagoon sediment, gas migration had an impact on contaminant migration. This effect was even greater for the surge pond sediment due to the gas generated by the contaminated sediment. The effect of ground water migration could not be tested in these experiments.

Recommendations

When performing ISC at the field site, it will be important to take into consideration all of the problems seen in the bench-scale laboratory experiments in order to produce the most effective ISC design for the specific site. These problems have led to the following recommendations and future research work.

1. Overall, the problems seen in working with the lagoon sediment were magnified when working with the surge pond sediment. Thus, two site-specific cap designs are critical for each body of water.

2. The caps should be placed in numerous lifts when poured at the field sites. This would help to contain most of the contaminant released during the prior lifts, until contaminants are no longer disturbed during intermixing.

3. When performing bench-scale laboratory tests, the difference between the consolidation data for the 4-inch, 6-inch, and 8-inch cores was not significant. Hence, any of these diameters would be sufficient for future testing. It is necessary to note that wall effects will not be present in the field locations, thus an increase in consolidation will take place in the field site when compared to the laboratory experiments.

4. Further experiments should be done on various placement techniques in order to assure the least amount of disturbance during cap placement. Efficient placement techniques are an important area to study in order to reduce the amount of contaminants released into the overlying water during cap placement.

5. Future experiments should be conducted that use a variety of capping materials. This experiment only used one type of medium grade sand. The use of other materials could possibly improve the containment ability of the capping layer. Also, the use of innovative capping materials such as commercial sorbents should be studied because these materials could decrease contaminant migration even further.

6. Finally, computer modeling should be performed for this ISC model in order to predict long-term behavior of this ISC project.

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Appendix A
Chromatographic Analysis

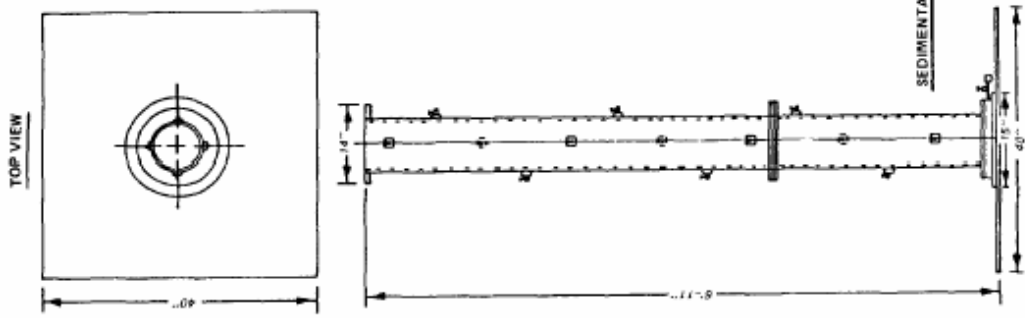
Chromatographic Analysis

All chemical concentrations were analyzed using a Hewlett Packard 1100 series high-performance liquid chromatography (HPLC, Hewlett Packard, Palo Alto, CA, USA) equipped with a UV-visible Diode array detector and fluorescence detector, an auto sampler and vacuum degasser. Samples were separated by a guard column (C-18 reverse phase column, Envirosep-pp, 30 x 3.2 mm, Phenomenex, Torrance, CA, USA) and a main column (C-18 reverse phase column, Envirosep-pp, 125 x 3.2 mm, Phenomenex, Torrance, CA, USA). All extracts ready for analysis were in acetonitrile except for the partition coefficient measurement, where direct water samples were injected without transfer to acetonitrile.

The HPLC conditions are isocratic elution and the injection volume is 25 μ l. The flow rate of the mobile phase was set at 0.5 ml/min with 70% acetonitrile and 30% water. The temperature of the column was set at 40°C and was very stable for all measurements. The pressure of the column changed a little bit for different measurements, but was around 80 bars. UV absorbance was measured for each compound (sample signal at 250 nm and reference signal at 360 nm). Fluorescence was also available with adjustable signal gains depending upon the expected sample concentrations and higher settings were employed when greater sensitivity was needed. The excitation and emission wavelengths were set for phenanthrene ($\lambda_{\text{exc}}=244$ nm, $\lambda_{\text{emiss}}=360$ nm) and Benzo[*a*]pyrene ($\lambda_{\text{exc}}=255$ nm, $\lambda_{\text{emiss}}=420$ nm). External calibration was used to establish response factors (ratio of peak area for a specific volume of the calibration standard to the concentration of the

standard) for UV and fluorescence and to correct for non-linearities. The response factor used in this study was the average of several response factors for individual standard or the slope of the response (peak area) to the standard concentration curve. The standards were prepared in the laboratory and all chemicals were in acetonitrile. One or two standards were run with each sample analysis to verify that significant deviations (i.e. greater than 15%) in response factor have not occurred and one “blank” (pure water) was run for each batch to check if the machine was free of contaminants. All concentration measurements from HPLC analysis were reported in either $\mu\text{g/L}$ (parts per billion) or mg/L (parts per million) in this study.

Appendix B
Column Specifications



BILL OF MATERIAL

QTY	MATERIAL	SIZE
1	AIR COUPLER	1/4" I.D.
1	BALL VALVE (STAINLESS STEEL)	1/4" I.D.
1	BALL VALVE ASSEMBLY (STAINLESS STEEL)	3/4" I.D.
13	SAMPLING VALVE ASSEMBLIES (STAINLESS STEEL)	3/8" I.D.
2	PIPE (STAINLESS STEEL)	1/4" I.D., 2'-0" LONG
1	SINTERED STEEL FILTER DISK	1/4" THICK
1	50-80 MICRON PORE DIAMETER	8.23 DIAMETER
1	MATERIAL FOR AT LEAST 2-10" DIAMETER O-RINGS	1/4" DIA., 12" LONG
1	WATERPROOF PLYWOOD	4' x 4' x 1/2"
1	WATERPROOF PLYWOOD PLATE FOR COLUMN BASE	16" DIAMETER
8	HEX HEAD BOLT W/WASHER AND NUT	1/4" -20 UNC x 1-1/2"
8	CARRIAGE HEAD BOLT W/WASHER AND NUT	1/4" x 3"
14	PLEXIGLASS REINFORCEMENT FOR COLUMN HOLES	3" x 3" x 1/4"
2	PLEXIGLASS FLANGE FOR BOTTOM COLUMN	1/2" THICK, 14" O.D., 8-1/2" I.D.
2	PLEXIGLASS FLANGE FOR TOP COLUMN	1/2" THICK, 14" O.D., 8-1/2" I.D.
1	PLEXIGLASS PLATE FOR COLUMN BOTTOM	1" THICK, 14" DIA
1	PLEXIGLASS CYLINDER	29" LONG, 1/4" THICK
1	PLEXIGLASS CYLINDER	8" I.D., 8-1/2" O.D.
1	PLEXIGLASS CYLINDER	14" LONG, 1/4" THICK
		8" I.D., 8-1/2" O.D.

SUPPLIES

MATERIAL	COMPANY
FILTER DISK	MOTT METALLURGICAL CORPORATION FARMINGTON INDUSTRIAL PARK FARMINGTON, CT 06032
O-RING	BRISBROTHERS AND SPECIALTY COMPANY 819 SOUTH CONGRESS JACKSON, MS 39201
PLEXIGLASS	CADILLAC PLASTIC COMPANY/FALKNER PLASTICS, INC. 4504 E. HILSBORO AVE. P.O. BOX 1128 TAMPA, FL 33681

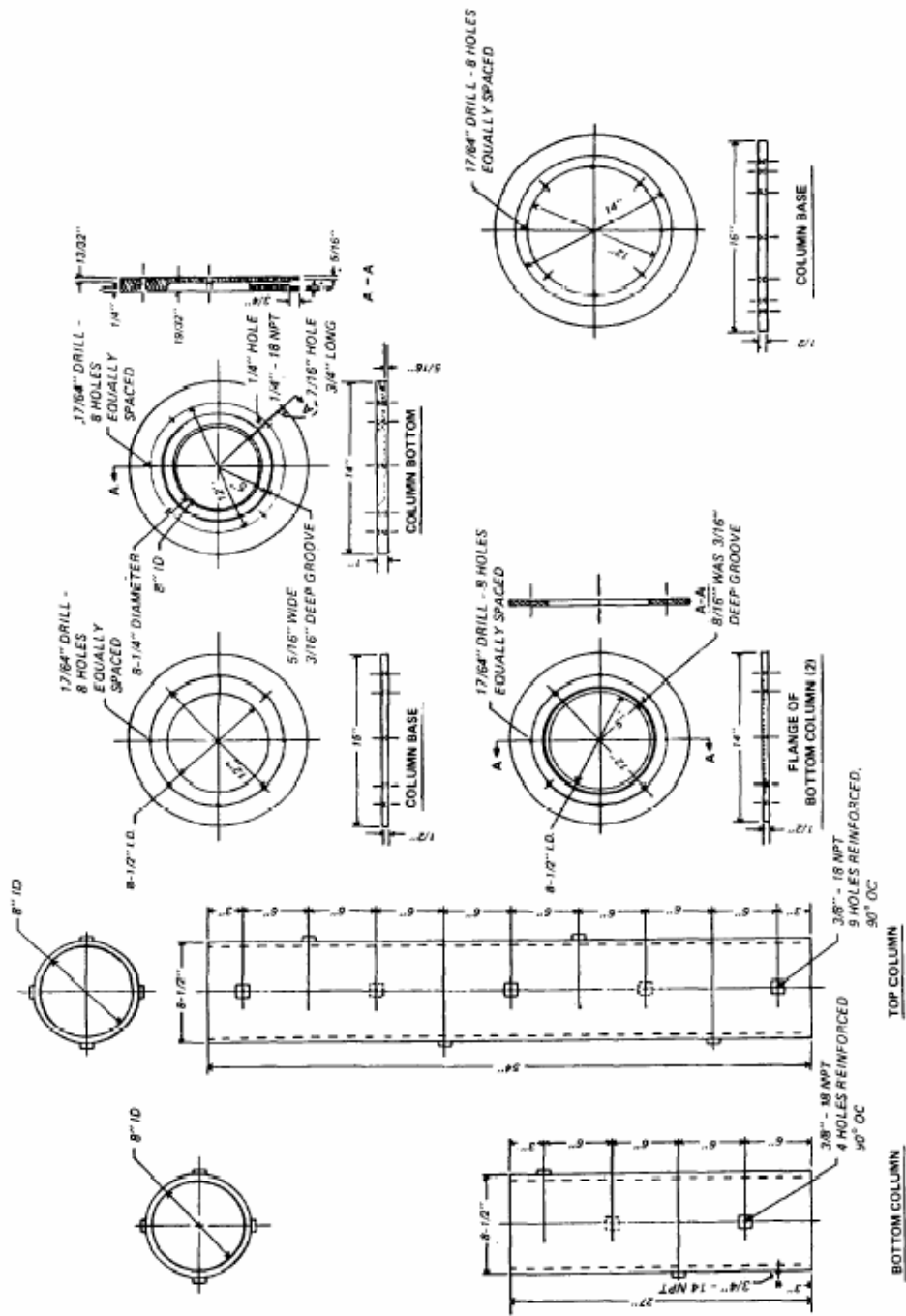
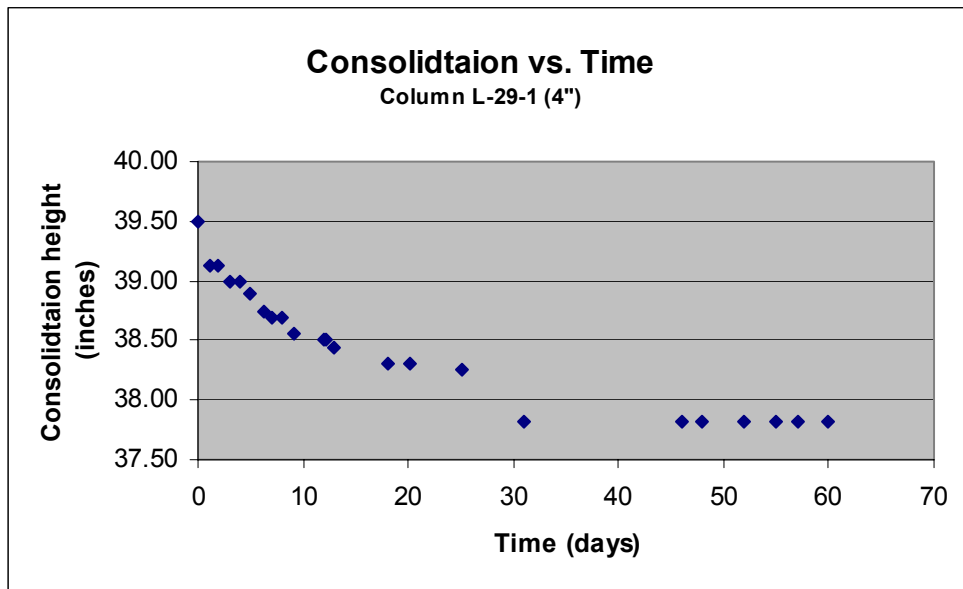


Figure B-2. Plans for top and bottom columns

Appendix C
Consolidation Curves

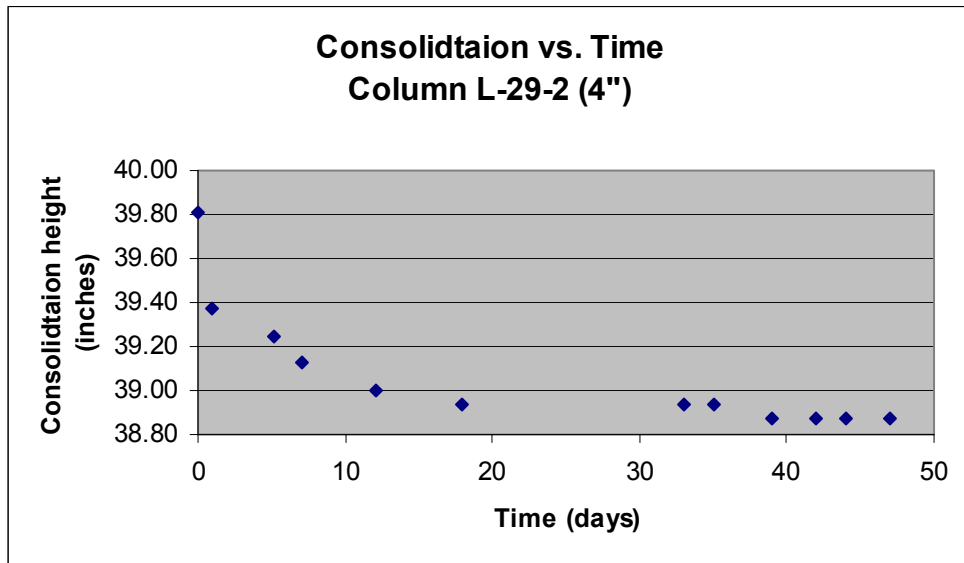
Column L-29-1

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	39.50
1	39.13
2	39.13
3	39.00
4	39.00
5	38.90
6	38.75
7	38.69
8	38.69
9	38.56
12	38.50
12	38.50
13	38.44
18	38.31
20	38.31
25	38.25
31	37.81
46	37.81
48	37.81
52	37.81
55	37.81
57	37.81
60	37.81



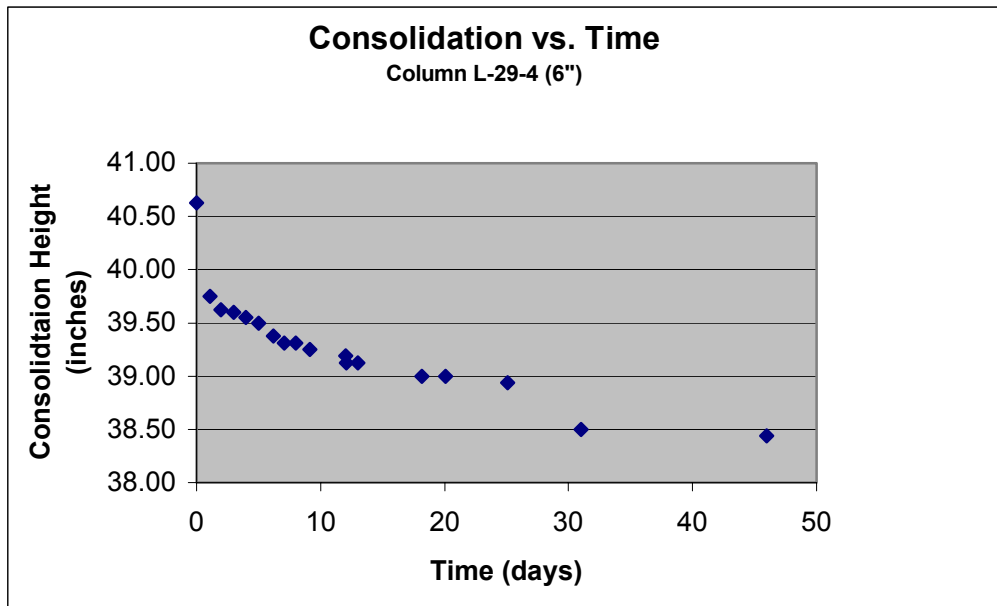
Column L-29-2

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	39.81
1	39.38
5	39.25
7	39.13
12	39.00
18	38.94
33	38.94
35	38.94
39	38.88
42	38.88
44	38.88
47	38.88



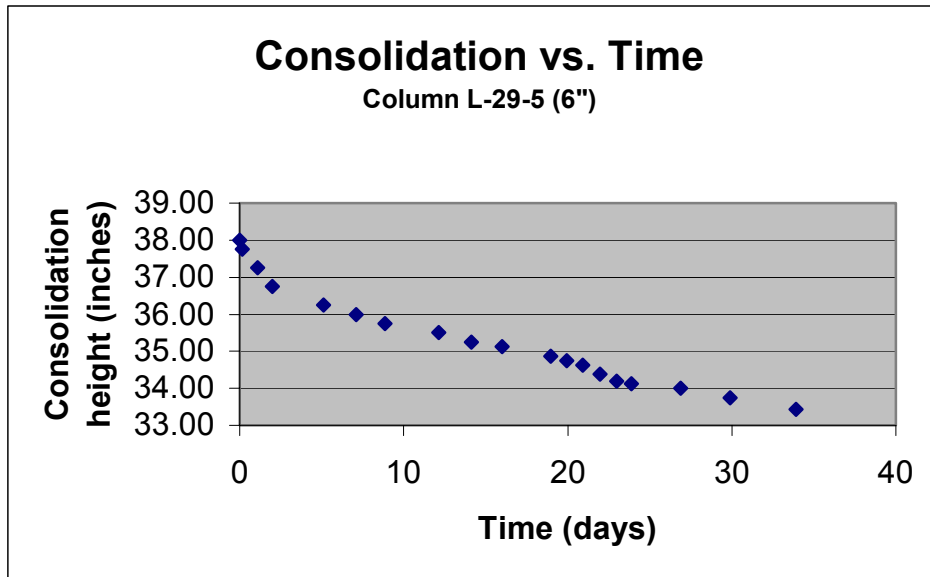
Column L-29-4

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	40.63
1	39.75
2	39.63
3	39.60
4	39.55
5	39.50
6	39.38
7	39.31
8	39.31
9	39.25
12	39.19
12	39.13
13	39.13
18	39.00
20	39.00
25	38.94
31	38.50
46	38.44



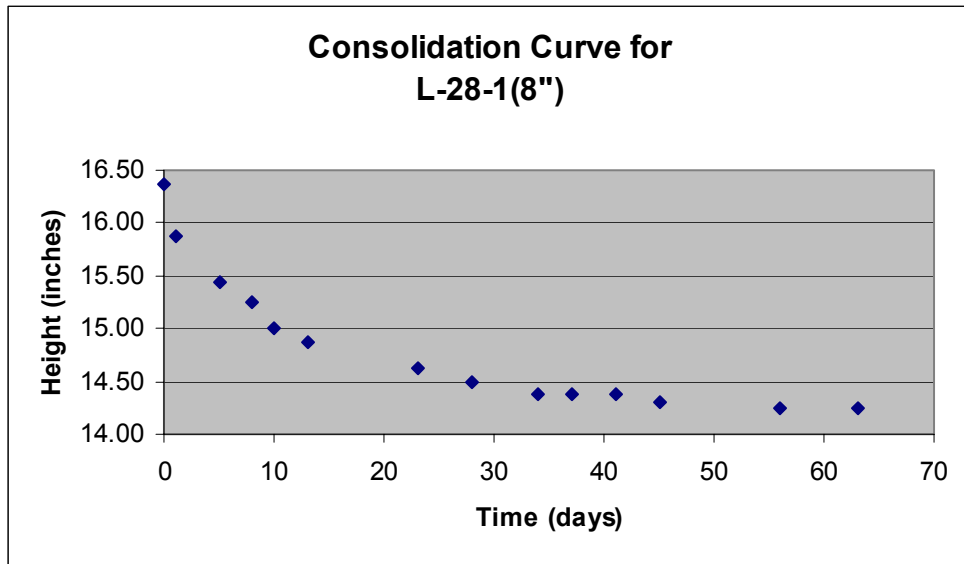
Column L-29-5

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	38.00
0	37.75
1	37.25
2	36.75
5	36.25
7	36.00
9	35.75
12	35.50
14	35.25
16	35.13
19	34.88
20	34.75
21	34.63
22	34.38
23	34.19
24	34.13
27	34.00
30	33.75
34	33.44



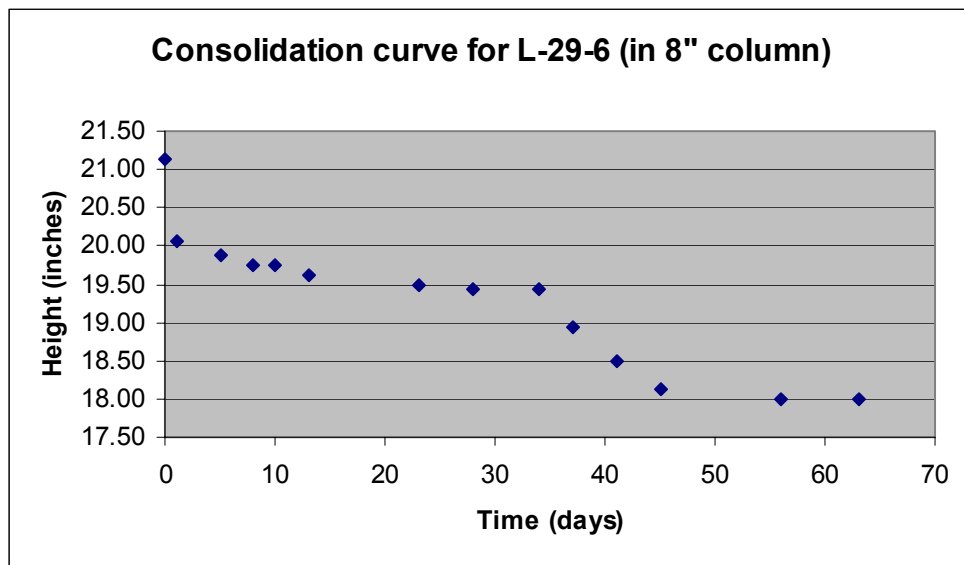
Column L-28-1

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	16.38
1	15.88
5	15.44
8	15.25
10	15.00
13	14.88
23	14.63
28	14.50
34	14.38
37	14.38
41	14.38
45	14.31
56	14.25
63	14.25



Column L-29-6

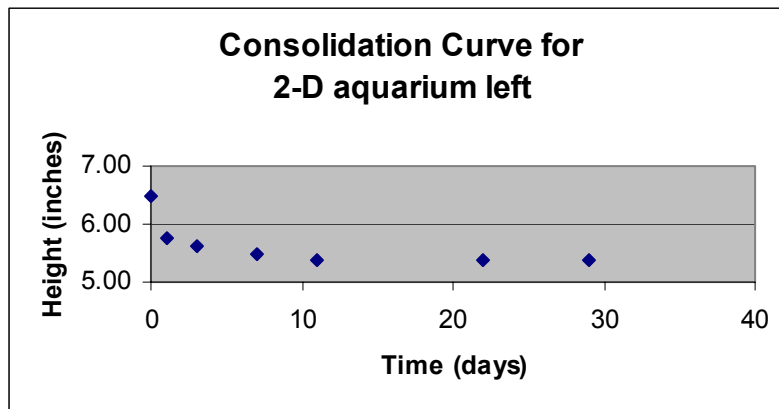
<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	21.13
1	20.06
5	19.88
8	19.75
10	19.75
13	19.63
23	19.50
28	19.44
34	19.44
37	18.94
41	18.50
45	18.13
56	18.00
63	18.00



***Note: The drop from day 34 to day 45 was the point when I opened up the bottom valve on the column to begin the air injection experiment. Since the experiment wasn't working properly, water was draining out of the column instead of air being injected into the column. Thus, causing the increase in consolidation until the air injection hole was sealed.**

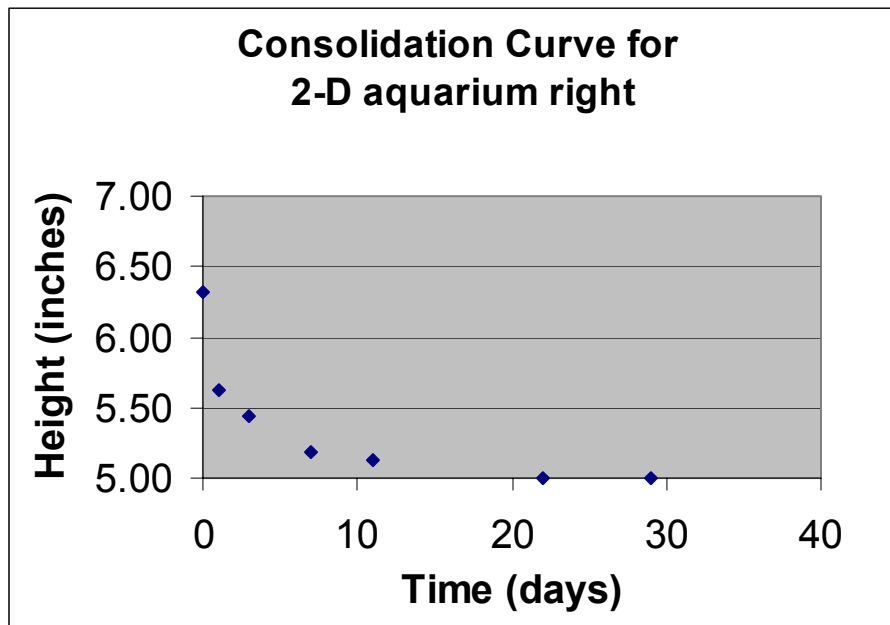
2-D Aquarium left

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	6.50
1	5.75
3	5.63
7	5.50
11	5.38
22	5.38
29	5.38



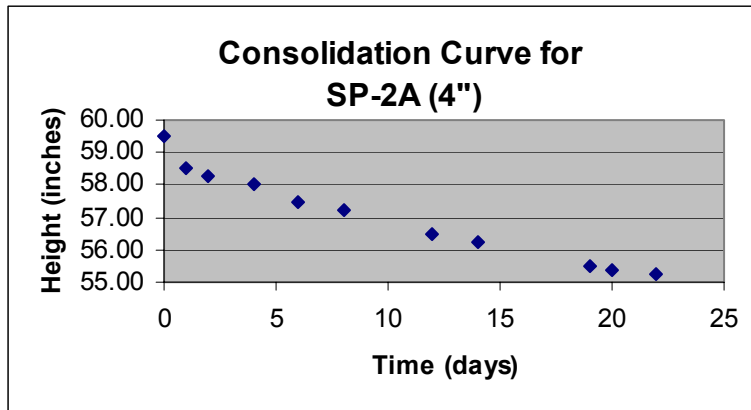
2-D Aquarium right

<u>time (days)</u>	<u>contaminated sediment depth (inches)</u>
0	6.31
1	5.63
3	5.44
7	5.19
11	5.13
22	5.00
29	5.00



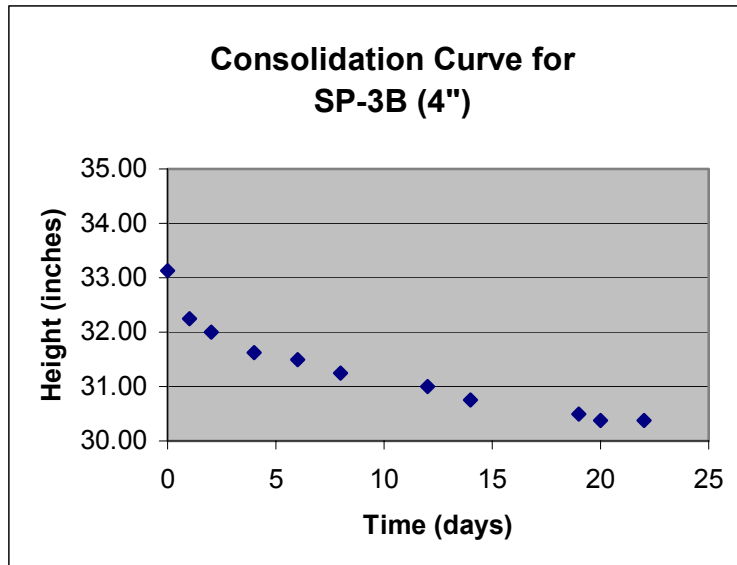
Column SP-2A

<u>time (days)</u>	<u>contaminated sediment height (inches)</u>
0	59.50
1	58.50
2	58.25
4	58.00
6	57.50
8	57.24
12	56.50
14	56.25
19	55.50
20	55.38
22	55.25



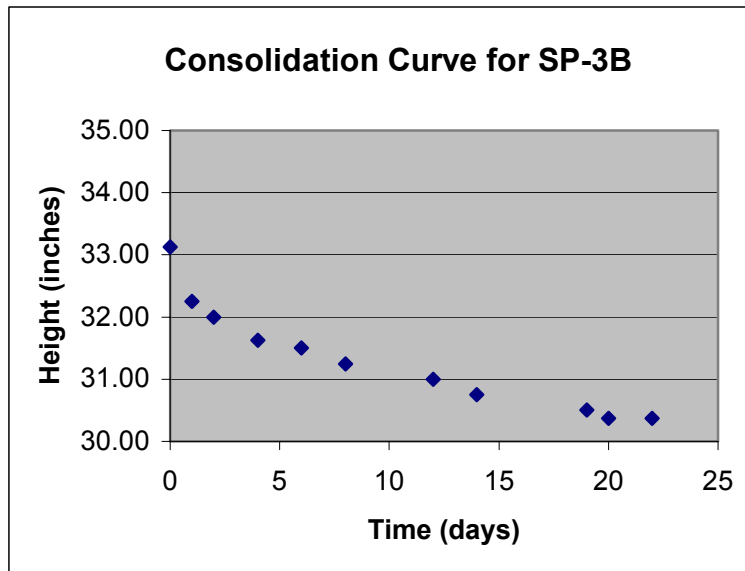
Column SP-2A

<u>time (days)</u>	<u>contaminated sediment height (inches)</u>
0	33.13
1	32.25
2	32.00
4	31.63
6	31.50
8	31.25
12	31.00
14	30.75
19	30.50
20	30.38
22	30.38



Column SP-1

<u>time (days)</u>	<u>contaminated sediment height (inches)</u>
0	22.25
1	21.00
3	20.50
7	18.88
8	18.75
9	18.50
15	18.00



Appendix D
PAHs concentrations of the Overlying Water

L-29-5 (6"column) final values

Chemicals	area			Concentration in water (ppb)		
	1	2	3	1	2	3
Naphthalene	24.03	5.49	6.08	10.09	2.46	2.70
Acenaphthylene		19.33		0.00	16.65	
Acenaphthene	67.88	41.13	46.00	9.65	5.65	6.38
Phenanthrene		85.00			0.65	
Anthracene	74.13	85.17		0.83	0.98	
Pyrene	37.18	3.40		1.04		
Benzo(a)anthracene						
Chrysene	36.10	2.21	4.66	0.54	UD	UD
Benzo(b) fluoranthene						
Benzo(k)fluoranthene	218.11	11.59	29.05	0.08	UD	UD
Benzo(a)pyrene	179.81	8.53	21.63	0.29	UD	UD
Dibenzo(a,h) anthracene	21.82	2.10	3.26	1.51	UD	UD
Benzo(g,h,i) perylene	64.88	3.55	10.14	1.02	UD	UD

L-29-4 (6"column) final values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene	11.85	6.32	3.65	2.73	1.61	1.07
Acenaphthene		20.87	11.71		3.04	2.09
Phenanthrene	53.33	16.49	12.83	0.11	-0.05	-0.07
Anthracene						
Fluoranthene	11.67	12.26	4.41	3.11	3.29	0.83
Pyrene	14.25			2.95		
Benzo(a)anthracene	13.98	6.67		1.16	0.31	
Chrysene			4.49			0.13
Benzo(b) fluoranthene	41.21	11.33	2.11	9.96	3.07	0.94
Benzo(k)fluoranthene	6.26	2.09		0.05	0.03	
Benzo(a)pyrene						

L-29-6 (8"column) initial values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene	11.07	5.14	5.69	2.57	1.37	1.48
Acenaphthene	39.24			4.96		
Phenanthrene	39.25	8.94	11.70	0.05	-0.08	-0.07
Anthracene						
Fluoranthene	66.64	10.29		20.38	2.67	
Pyrene				0.45		
Benzo(a)anthracene	27.26	4.50	6.07	2.70	0.06	0.24
Chrysene	159.63	4.96	3.17	1.40	0.14	0.12
Benzo(b) fluoranthene	69.24	6.63	10.77	16.42	1.98	2.94
Benzo(k)fluoranthene						
Benzo(a)pyrene	48.22			0.23		

L-29-6 (8"column) final values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene						
Acenaphthene						
Phenanthrene	19.45	17.06		0.00	0.00	
Anthracene						
Fluoranthene	2.84	1.63		0.33	0.00	
Pyrene						
Benzo(a)anthracene						
Chrysene						
Benzo(b) fluoranthene		2.00			0.92	
Benzo(k)fluoranthene						
Benzo(a)pyrene						

L-28-1 (8"column) initial values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene	4.54	6.67	1.12	1.25	1.68	0.56
Acenaphthene		12.43	13.03		2.16	2.22
Phenanthrene	11.55	6.75	21.59	-0.07	-0.09	-0.03
Anthracene			26.91			0.28
Fluoranthene	2.93	3.65	4.00	0.36	0.59	0.70
Pyrene	2.16			0.83		
Benzo(a)anthracene	4.11	3.36	3.37	0.01	-0.08	-0.08
Chrysene	2.33	1.19		0.12	0.11	
Benzo(b) fluoranthene	4.82	5.50	9.39	1.57	1.73	2.62
Benzo(k)fluoranthene	26.78			0.12		
Benzo(a)pyrene	3.04			0.15		

SP-3B (4"column) initial values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene						
Acenaphthene	115.87			12.96		
Phenanthrene	197.13			0.75		
Anthracene						
Fluoranthene	170.33			52.97		
Pyrene	84.10			15.21		
Benzo(a)anthracene	297.20			34.09		
Chrysene	20.34			0.26		
Benzo(b) fluoranthene	128.23			30.02		
Benzo(k)fluoranthene	17.03			0.08		
Benzo(a)pyrene	66.65			0.26		

SP-3B (4" column) final values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene						
Acenaphthene	34.78			4.49		
Phenanthrene	99.54			0.32		
Anthracene	15.39			0.39		
Fluoranthene	30.47			9.01		
Pyrene	4.71			1.27		
Benzo(a)anthracene	19.29			1.78		
Chrysene						
Benzo(b) fluoranthene	8.71			2.47		
Benzo(k)fluoranthene						
Benzo(a)pyrene	7.71			0.15		

SP-2A (4" column) initial values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene						
Acenaphthene	97.36			11.03		
Phenanthrene	223.34			0.86		
Anthracene						
Fluoranthene	82.29			25.30		
Pyrene	36.51			6.86		
Benzo(a)anthracene	452.07			52.10		
Chrysene	44.15					
Benzo(b) fluoranthene	183.19			42.69		
Benzo(k)fluoranthene	14.76					
Benzo(a)pyrene	81.07			0.29		

SP-2A (4" column) final values

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene	57.58096	31.1493		11.96	6.62	
Acenaphthene	76.00872	108.7098		8.80	12.21	
Phenanthrene	109.9295	272.1709		0.36	1.08	
Anthracene	72.94179			8.13		
Fluoranthene	398.8925	559.5232		124.79	175.27	
Pyrene						
Benzo(a)anthracene	100.5016			11.22	-0.47	
Chrysene	213.3906			1.84	0.10	
Benzo(b) fluoranthene	199.944			46.56	0.46	
Benzo(k)fluoranthene	265.4318			0.90		
Benzo(a)pyrene	90.81155			0.30	0.14	

SP-1 initial values (8" column with black water) on 3/3/05

Chemicals	area			concentrations in water (ppb)		
	1	2	3	1	2	3
Naphthalene	2390.821	182.0375		482.97		
Acenaphthene	2976.7	224.2269		311.66		
Phenanthrene	3765.236	282.9876		16.52		
Anthracene						
Fluoranthene	2036.191	609.7645		639.31		
Pyrene	382.5698	63.10723		67.59		
Benzo(a)anthracene		54.38778				
Chrysene		77.78848				
Benzo(b) fluoranthene		65.61311				
Benzo(k)fluoranthene						
Benzo(a)pyrene		31.38834				

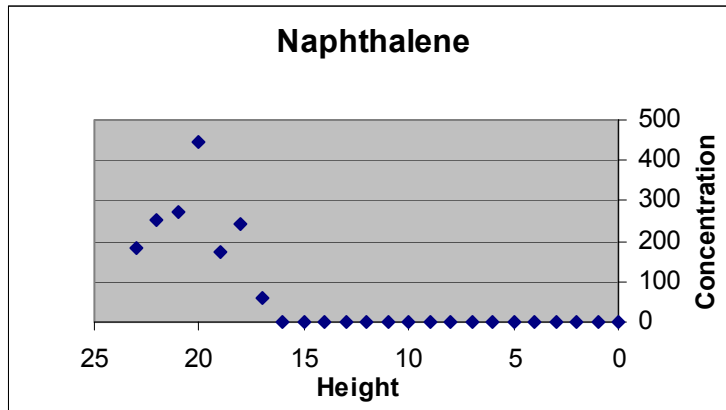
SP-1 final values (8" column dry cap)

Chemicals	area			concentrations in water (ppb)		
	bot	mid	top	1	2	3
Naphthalene	4.71558	66.01165		1.29	13.66	0.33
Acenaphthene						
Phenanthrene	143.4256	230.0534	39.28382	0.51	0.89	0.05
Anthracene		9.8037				
Fluoranthene	5.03097	273.4815	43.69557	1.02	85.38	13.17
Pyrene	12.12022	44.94	45.88364	2.58	8.33	8.50
Benzo(a)anthracene		151.6589			17.17	
Chrysene		32.81918	49.12604	0.10	0.37	0.50
Benzo(b) fluoranthene						
Benzo(k)fluoranthene						
Benzo(a)pyrene						

Appendix E
PAHs Migration Profiles

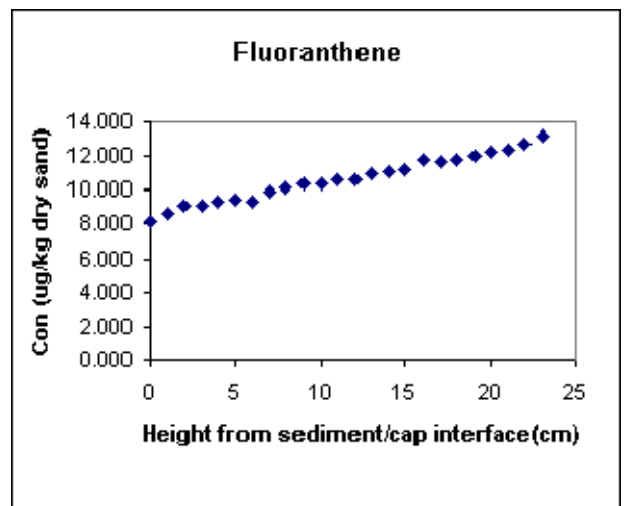
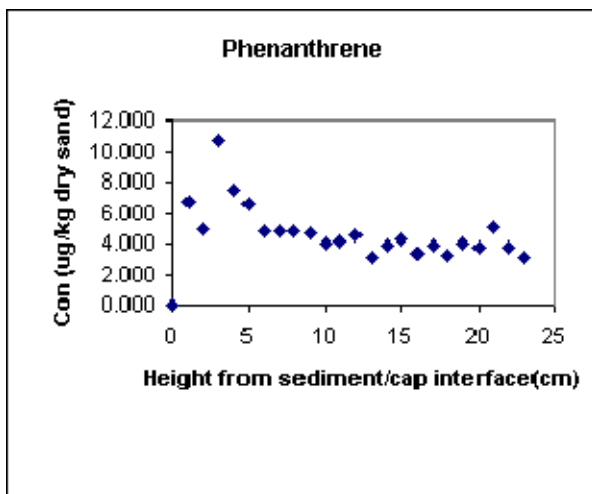
L-29-1 (4")

<u>Height (cm)</u>	<u>Dry weight (kg)</u>	<u>Naphthalene(ppb)</u>	<u>Naphthalene (ug)</u>	<u>Con (ug/kg dry sand)</u>
23	0.026521223	184.653	7.386	278.499
22	0.02265902	251.653	10.066	444.244
21	0.016871652	273.653	10.946	648.789
20	0.02265902	443.593	17.744	783.076
19	0.021481928	173.944	6.958	323.889
18	0.026418304	240.666	9.627	364.393
17	0.022293513	60.889	2.436	109.250
16	0.024454118	0.000	0.000	0.000
15	0.01983828	0.000		
14	0.022097094	0.000		
13	0.027165777	0.000		
12	0.018897932	0.000		
11	0.020374333	0.000		
10	0.021555454	0.000		
9	0.018307372	0.000		
8	0.01741745	0.000		
7	0.017811065	0.000		
6	0.018401487	0.000		
5	0.012890881	0.000		
4	0.011414826	0.000		
3	0.007960026	0.000		
2	0.017099315	0.000		
1	0.012873622	0.000		
0	0.005994587	0.000		



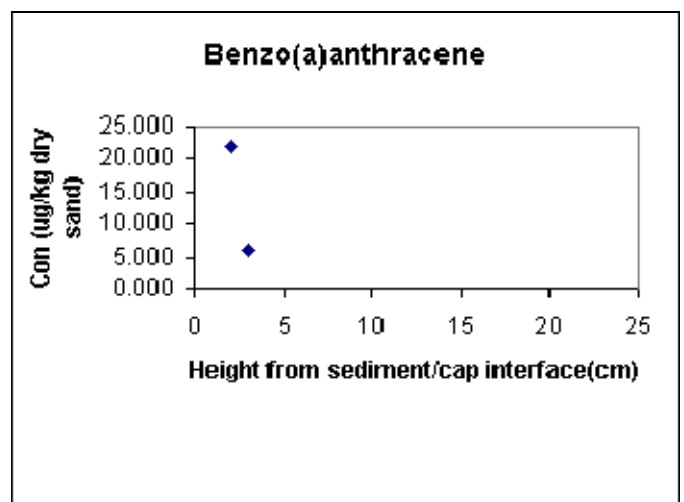
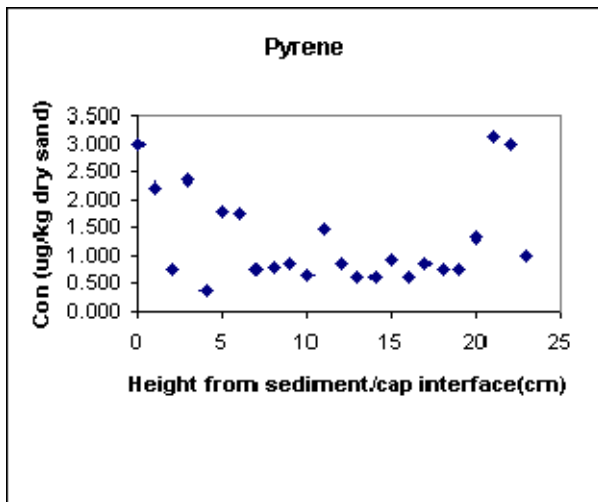
L-29-1 (4")

	<u>Phenanthrene</u> Concentration			<u>Fluoranthene</u> Concentration		
<u>Phenanthrene(ppb)</u>	<u>Phenanthrene(ug)</u>	<u>(ug/kg dry sand)</u>	<u>Fluoranthene(ppb)</u>	<u>Fluoranthene(ug)</u>	<u>(ug/kg dry sand)</u>	
2.056	0.082	3.102	27.121	1.085	13.189	
2.112	0.084	3.728	26.734	1.069	12.661	
2.124	0.085	5.036	26.346	1.054	12.402	
2.125	0.085	3.751	25.959	1.038	12.217	
2.125	0.085	3.956	25.571	1.023	12.034	
2.129	0.085	3.224	25.184	1.007	11.828	
2.134	0.085	3.828	24.796	0.992	11.621	
2.072	0.083	3.390	24.409	0.976	11.779	
2.140	0.086	4.315	24.021	0.961	11.225	
2.132	0.085	3.859	23.634	0.945	11.086	
2.129	0.085	3.135	23.246	0.930	10.917	
2.142	0.086	4.534	22.859	0.914	10.672	
2.127	0.085	4.175	22.471	0.899	10.566	
2.136	0.085	3.964	22.084	0.883	10.339	
2.098	0.084	4.584	21.696	0.868	10.341	
2.099	0.084	4.820	21.309	0.852	10.154	
2.099	0.084	4.713	20.921	0.837	9.969	
2.201	0.088	4.785	20.534	0.821	9.327	
2.133	0.085	6.617	20.146	0.806	9.447	
2.123	0.085	7.438	19.759	0.790	9.309	
2.129	0.085	10.698	19.371	0.775	9.099	
2.095	0.084	4.900	18.984	0.759	9.063	
2.164	0.087	6.723	18.596	0.744	8.595	
2.225	0.089	0.000	18.209	0.728	8.185	



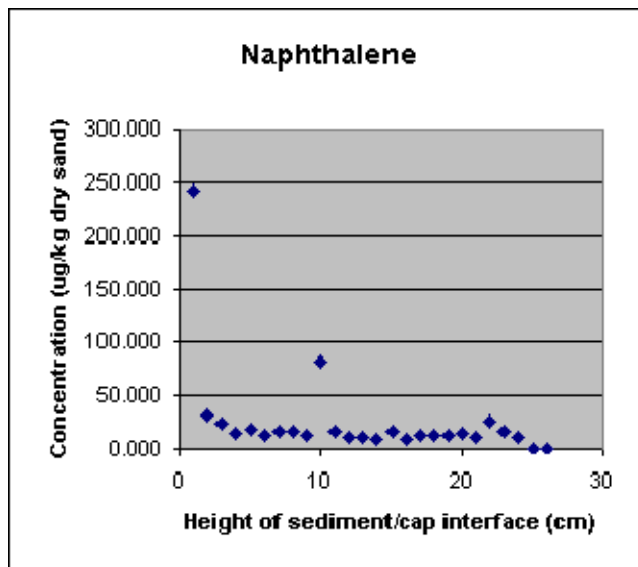
L-29-1 (4'')

<u>Pyrene</u>			<u>Benzo(a)anthracene</u>		<u>Benzo(a)anthracene</u>
<u>Pyrene(ppb)</u>	<u>Pyrene(ug)</u>	<u>Concentration (ug/kg dry sand)</u>	<u>Benzo(a)anthracene (ppb)</u>	<u>Benzo(a)anthracene (ug)</u>	<u>Concentration (ug/kg dry sand)</u>
0.669	0.027	1.009			-1.788
1.709	0.068	3.017	14.561	0.582	
1.318	0.053	3.125	4.062	0.162	
0.740	0.030	1.307			
0.410	0.016	0.763			
0.490	0.020	0.743			
0.469	0.019	0.842			
0.363	0.015	0.594			
0.465	0.019	0.937	-2.014	-0.081	
0.339	0.014	0.614			
0.407	0.016	0.599			
0.408	0.016	0.864			
0.752	0.030	1.477			
0.341	0.014	0.632			
0.400	0.016	0.873			-3.037
0.336	0.013	0.772			
0.336	0.013	0.755			
0.802	0.032	1.744			
0.581	0.023	1.803			
0.103	0.004	0.362			
0.466	0.019	2.342			
0.313	0.013	0.733			6.127
0.708	0.028	2.201			21.961
0.449	0.018	2.995	-1.185	-0.047	



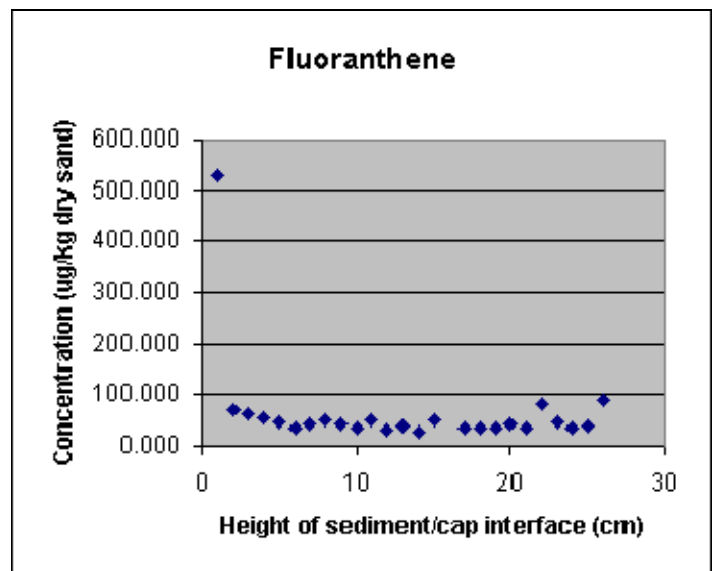
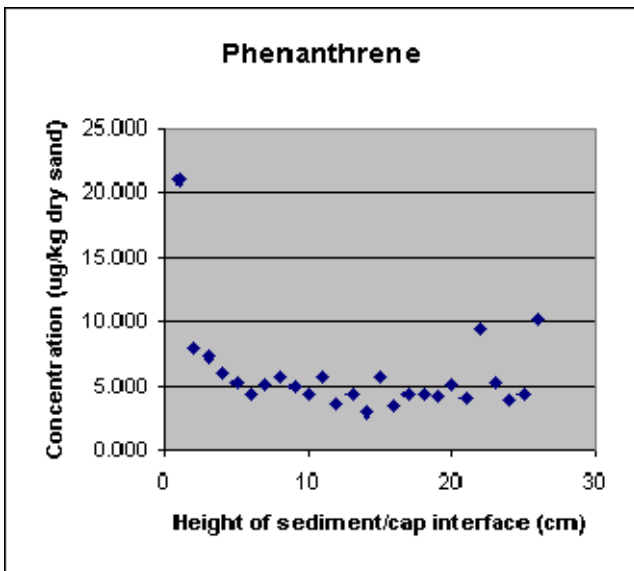
L-29-2 (4")

<u>Sample #</u>	<u>Height (cm)</u>	<u>Dry weight (kg)</u>	<u>Naphthalene(ppb)</u>	<u>Naphthalene (ug)</u>	<u>Naphthalene Concentration (ug/kg dry sand)</u>
1	1	0.005	28.053	1.122	242.941
2	2	0.012	9.042	0.362	31.190
3	3	0.012	7.401	0.296	24.294
4	4	0.014	5.424	0.217	15.227
5	5	0.017	7.368	0.295	17.750
6	6	0.021	6.259	0.250	12.135
7	7	0.017	7.177	0.287	16.889
8	8	0.015	6.726	0.269	17.442
9	9	0.017	5.747	0.230	13.295
10	10	0.020	41.038	1.642	81.106
11	11	0.015	6.496	0.260	17.259
12	12	0.024	6.185	0.247	10.287
13	13	0.020	5.822	0.233	11.734
14	14	0.029	6.400	0.256	8.786
15	15	0.015	6.138	0.246	16.395
16	16	0.025	5.925	0.237	9.533
17	17	0.020	6.323	0.253	12.668
18	18	0.021	6.906	0.276	13.313
19	19	0.020	6.237	0.249	12.314
20	20	0.016	6.347	0.254	15.499
21	21	0.020	6.080	0.243	11.864
22	22	0.009	5.840	0.234	26.173
23	23	0.016	6.444	0.258	16.123
24	24	0.021	5.647	0.226	10.516
25	25	0.020		0.000	0.000
26	26	0.008		0.000	0.000



L-29-2 (4")

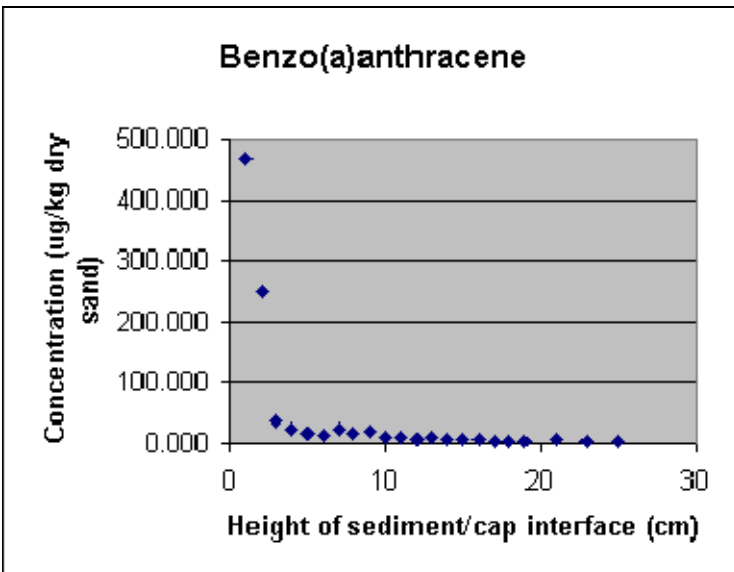
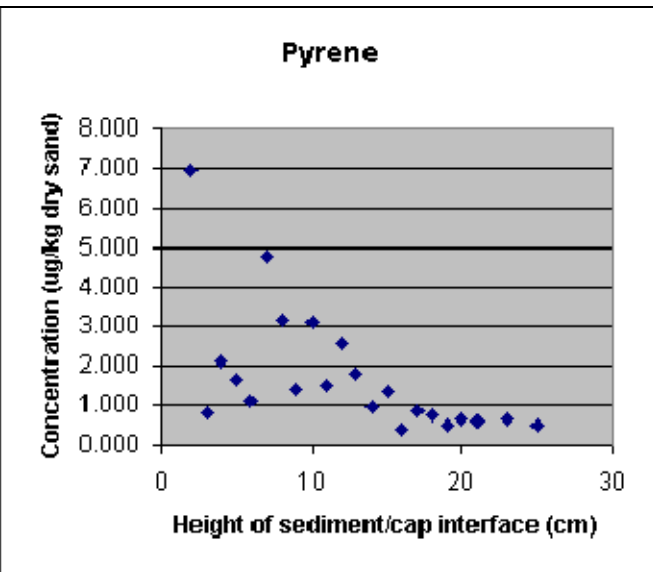
<u>Phenanthrene</u> (ppb)	<u>Phenanthrene</u> (ug)	<u>Phenanthrene</u> Concentration (ug/kg dry sand)	<u>Fluoranthene</u> (ppb)	<u>Fluoranthene</u> (ug)	<u>Fluoranthene</u> Concentration (ug/kg dry sand)
2.432	0.097	21.060	61.173	2.447	529.764
2.284	0.091	7.878	20.146	0.806	69.491
2.193	0.088	7.200	19.572	0.783	64.246
2.145	0.086	6.022	19.187	0.767	53.858
2.167	0.087	5.220	19.234	0.769	46.337
2.199	0.088	4.264	19.004	0.760	36.844
2.195	0.088	5.165	18.854	0.754	44.370
2.202	0.088	5.711	18.812	0.752	48.782
2.117	0.085	4.897	18.920	0.757	43.766
2.178	0.087	4.304	18.510	0.740	36.582
2.130	0.085	5.658	18.989	0.760	50.447
2.138	0.086	3.556	18.847	0.754	31.344
2.145	0.086	4.324	18.786	0.751	37.862
2.151	0.086	2.954	18.702	0.748	25.676
2.132	0.085	5.694	18.508	0.740	49.438
2.141	0.086	3.445			
2.155	0.086	4.318	18.310	0.732	36.682
2.213	0.089	4.265	18.571	0.743	35.802
2.129	0.085	4.203	18.474	0.739	36.473
2.117	0.085	5.169	18.281	0.731	44.644
2.078	0.083	4.055	18.298	0.732	35.707
2.092	0.084	9.375	18.270	0.731	81.880
2.120	0.085	5.304	18.539	0.742	46.386
2.076	0.083	3.867	18.307	0.732	34.093
2.116	0.085	4.302	18.371	0.735	37.348
2.085	0.083	10.141	18.317	0.733	89.104



L-29-2
(4")

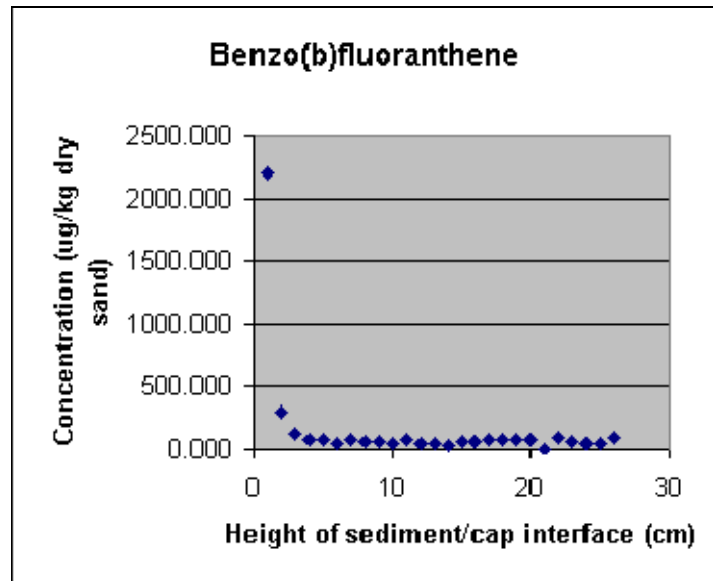
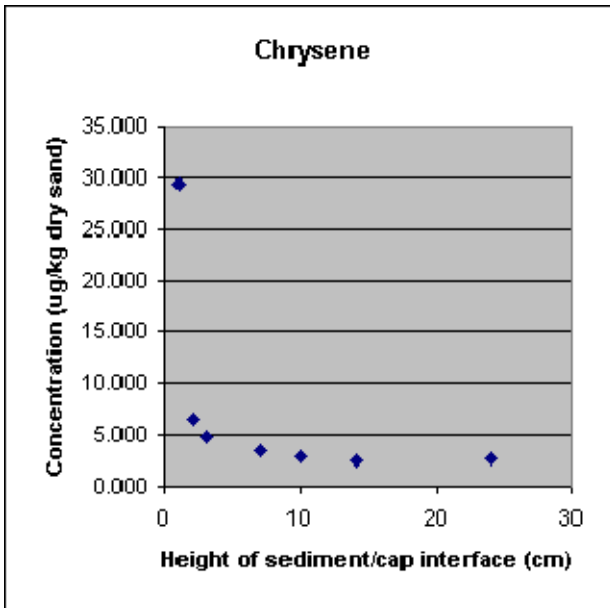
Benzo(a)anthracene

<u>Pyrene</u> (ppb)	<u>Pyrene(ug)</u> (ug/kg dry sand)	<u>Concentration</u> (ug/kg dry sand)	<u>Benzo(a)anthracene</u> (ppb)	<u>Benzo(a)anthracene</u> (ug)	<u>Concentration</u> (ug/kg dry sand)
			54.142	2.166	468.880
2.014	0.081	6.948	71.544	2.862	246.782
0.251	0.010	0.823	10.770	0.431	35.353
0.755	0.030	2.120	7.846	0.314	22.023
0.686	0.027	1.652	6.609	0.264	15.921
0.582	0.023	1.128	6.413	0.257	12.433
2.025	0.081	4.765	10.194	0.408	23.991
1.217	0.049	3.157	5.943	0.238	15.411
0.612	0.024	1.415	7.984	0.319	18.469
1.571	0.063	3.106	5.174	0.207	10.226
0.577	0.023	1.532	3.920	0.157	10.414
1.529	0.061	2.542	4.476	0.179	7.444
0.896	0.036	1.805	4.565	0.183	9.201
0.710	0.028	0.975	4.934	0.197	6.773
0.503	0.020	1.343	2.589	0.104	6.916
0.257	0.010	0.414	3.436	0.137	5.528
0.423	0.017	0.848	2.198	0.088	4.403
0.379	0.015	0.730	2.540	0.102	4.896
0.259	0.010	0.511	0.866	0.035	1.709
0.269	0.011	0.658			
0.297	0.012	0.579	3.156	0.126	6.159
0.261	0.010	0.652	1.365	0.055	3.416
0.241	0.010	0.489	1.763	0.071	3.583



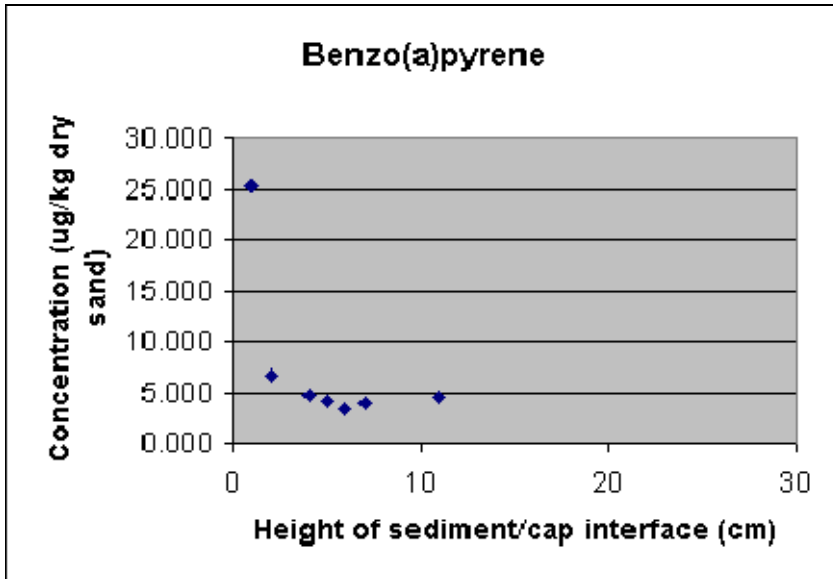
L-29-2 (4")

<u>Chrysene</u>			<u>Benzo(b)fluoranthene</u>		
Chrysene (ppb)	Chrysene (ug)	Con (ug/kg dry sand)	Benzo(b)fluoranthene (ppb)	Benzo(b)fluoranthene (ug)	Con (ug/kg dry sand)
3.405	0.136	29.484	254.200	10.168	2201.411
1.925	0.077	6.642	89.310	3.572	308.064
1.477	0.059	4.847	37.295	1.492	122.420
			27.962	1.118	78.493
			34.944	1.398	84.182
			28.395	1.136	55.050
1.470	0.059	3.459	32.428	1.297	76.315
			24.202	0.968	62.761
			26.104	1.044	60.386
1.448	0.058	2.862	27.883	1.115	55.108
			27.153	1.086	72.138
			26.098	1.044	43.404
			26.243	1.050	52.892
1.812	0.072	2.488	17.687	0.707	24.283
			24.796	0.992	66.234
			36.275	1.451	58.367
			36.833	1.473	73.791
			39.085	1.563	75.348
			38.941	1.558	76.883
			31.154	1.246	76.082
				0.000	0.000
			20.446	0.818	91.633
			24.222	0.969	60.606
1.481	0.059	2.757	25.982	1.039	48.386
			22.064	0.883	44.855
			20.220	0.809	98.362



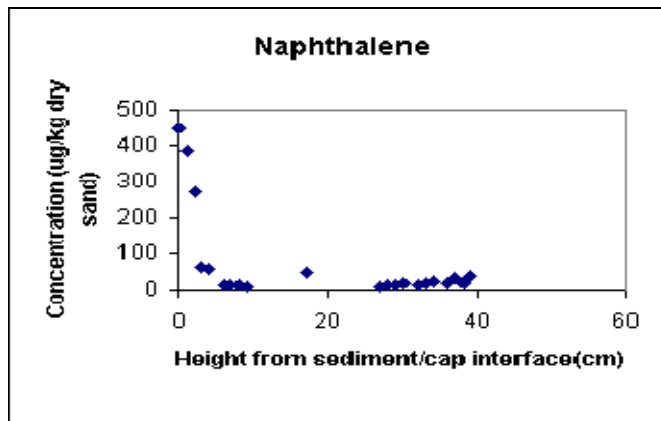
L-29-2 (4")

<u>Benzo(a)pyrene (ppb)</u>	<u>Benzo(a)pyrene (ug)</u>	<u>Benzo(a)pyrene Con (ug/kg dry sand)</u>
2.914	0.117	25.238
1.905	0.076	6.569
1.711	0.068	4.802
1.685	0.067	4.059
1.684	0.067	3.265
1.695	0.068	3.990
1.691	0.068	4.492



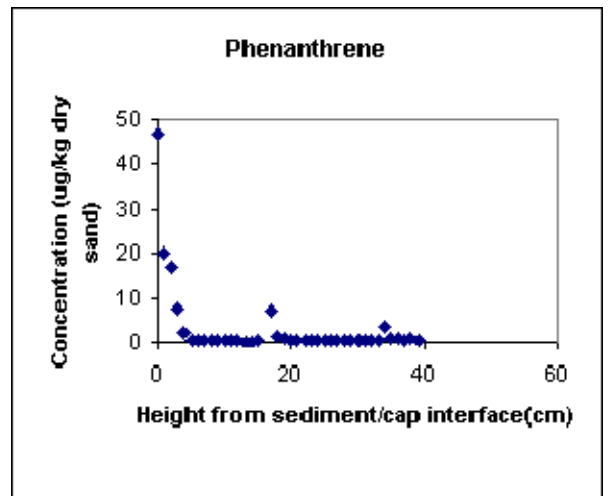
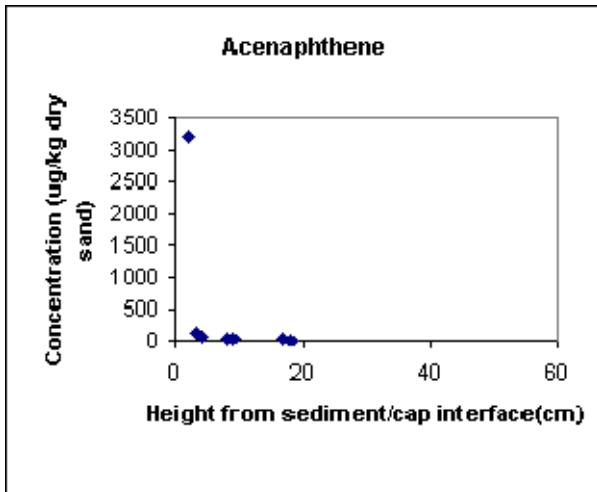
L-29-4 (6")

Sample #	Height (inches)	Dry weight (kg)	Naphthalene(ppb)	Naphthalene (ug)	Naphthalene Con (ug/kg dry sand)
1	39	0.009	8.621	0.345	39.620
2	38	0.014	6.711	0.268	19.325
3	37	0.010	7.525	0.301	31.218
4	36	0.011	5.465	0.219	20.376
5	35	0.010			
6	34	0.014	8.961	0.358	25.949
7	33	0.017	7.971	0.319	19.020
8	32	0.022	7.422	0.297	13.328
9	31	0.021			
10	30	0.026	12.437	0.497	19.435
11	29	0.030	11.599	0.464	15.721
12	28	0.030	11.087	0.443	14.898
13	27	0.036	9.885	0.395	10.968
14	26	0.033			
15	25	0.030			
16	24	0.039			
17	23	0.025			
18	22	0.048			
19	21	0.023			
20	20	0.037			
21	19	0.025			
22	18	0.051			
23	17	0.017	19.671	0.787	47.284
35	9	0.026	7.405	0.296	11.602
36	8	0.022	6.542	0.262	12.147
37	7	0.023	7.089	0.284	12.171
38	6	0.027	9.677	0.387	14.291
39	5	0.023			
40	4	0.016	23.368	0.935	57.342
41	3	0.010	16.123	0.645	63.346
42	2	0.023	155.729	6.229	273.334
43	1	0.013	127.537	5.101	383.841
44	0	0.008	92.222	3.689	448.595



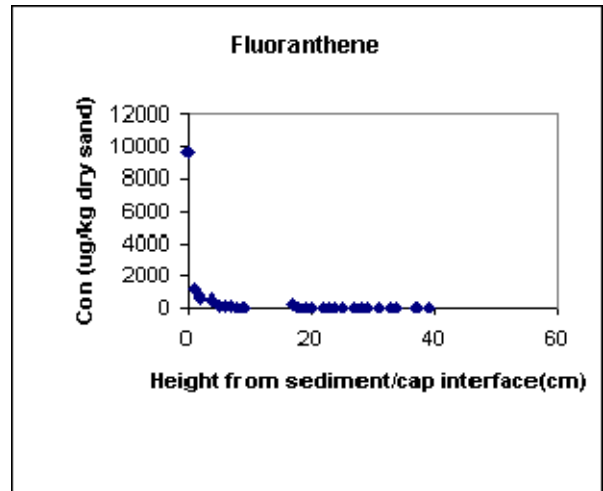
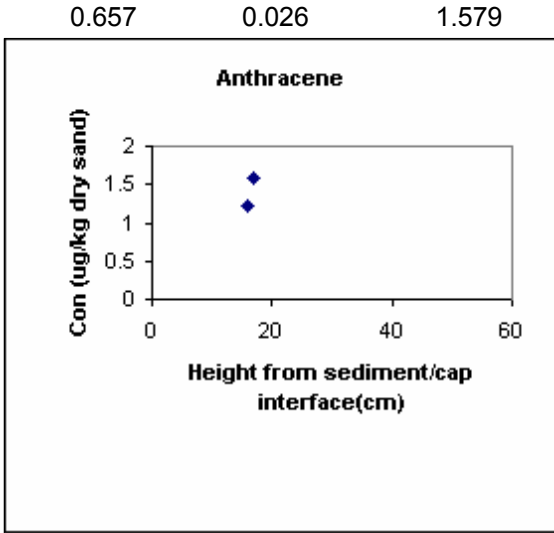
L-29-4 (6")

<u>Acenaphthene</u> (ppb)	<u>Acenaphthene</u> (ug)	<u>Acenaphthene</u> Con (ug/kg dry sand)	<u>Phenanthrene</u> (ppb)	<u>Phenanthrene</u> (ug)	<u>Phenanthrene</u> Con (ug/kg dry sand)
			0.108	0.004	0.495
			0.341	0.014	0.982
			0.101	0.004	0.419
			0.210	0.008	0.784
			0.169	0.007	0.686
			1.223	0.049	3.540
			0.248	0.010	0.592
			0.254	0.010	0.456
			0.334	0.013	0.650
			0.322	0.013	0.503
			0.183	0.007	0.249
			0.244	0.010	0.328
			0.483	0.019	0.536
			0.504	0.020	0.616
			0.428	0.017	0.570
			0.499	0.020	0.513
			0.416	0.017	0.654
			0.501	0.020	0.422
			0.300	0.012	0.518
			0.437	0.017	0.476
			0.452	0.018	0.726
12.089	0.484	9.498	1.644	0.066	1.291
18.050	0.722	43.388	2.981	0.119	7.165
20.688	0.828	32.411	0.312	0.012	0.488
10.152	0.406	18.849	0.303	0.012	0.562
			0.305	0.012	0.524
			0.313	0.013	0.462
			0.338	0.014	0.597
21.933	0.877	53.822	0.914	0.037	2.242
28.698	1.148	112.753	1.932	0.077	7.591
1831.179	73.247	3214.075	9.633	0.385	16.908
			6.729	0.269	20.251
			9.677	0.387	47.073



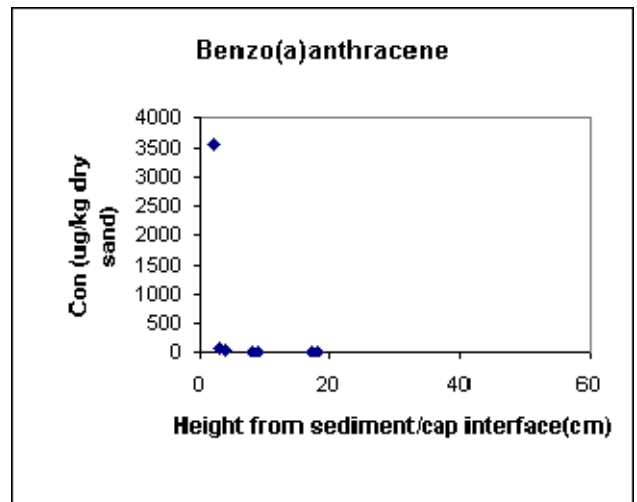
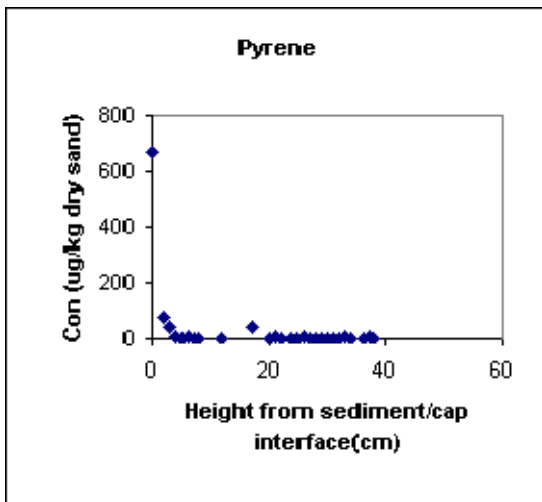
L-29-4 (6")

<u>Anthracene</u> (ppb)	<u>Anthracene</u> (ug)	<u>Anthracene</u> Con (ug/kg dry sand)	<u>Fluoranthene</u> (ppb)	<u>Fluoranthene</u> (ug)	<u>Fluoranthene</u> Con (ug/kg dry sand)
			2.445	0.098	11.238
			-5.601	-0.224	
			2.002	0.080	8.305
			-0.090	-0.004	
			-1.169	-0.047	
			0.391	0.016	1.132
			1.286	0.051	3.068
			-1.520	-0.061	
			5.732	0.229	11.164
			-0.179	-0.007	
			1.285	0.051	1.742
			4.118	0.165	5.534
			6.002	0.240	6.659
			-5.601	-0.224	
			6.630	0.265	8.819
			8.455	0.338	8.684
			6.400	0.256	10.061
			2.283	0.091	1.922
			-5.601	-0.224	
			12.411	0.496	13.532
			4.627	0.185	7.441
			30.806	1.232	24.203
0.657	0.026	1.579	79.903	3.196	192.064
			1.375	0.055	2.154
			32.517	1.301	60.374
			44.878	1.795	77.047
			86.397	3.456	127.589
			76.957	3.078	135.866
			208.201	8.328	510.899
			-5.601	-0.224	
			329.163	13.167	577.746
			377.632	15.105	1136.539
			1992.781	79.711	9693.474



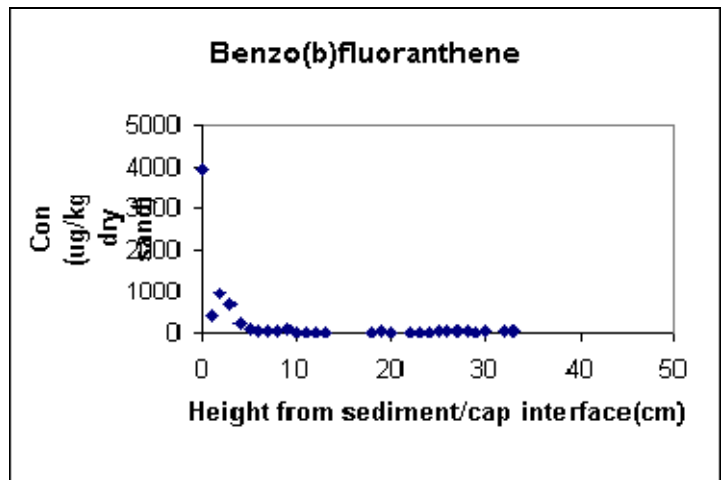
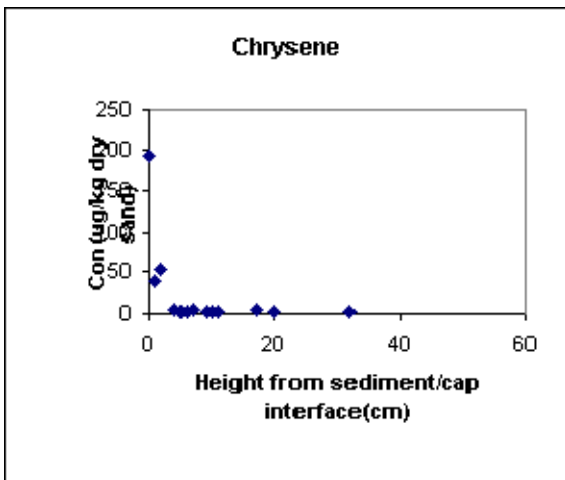
L-29-4 (6")

<u>Pyrene</u> (ppb)	<u>Pyrene</u> (ug)	<u>Pyrene</u> Con (ug/kg dry sand)	<u>Benzo(a)anthracene</u> (ppb)	<u>Benzo(a)anthracene</u> (ug)	<u>Benzo(a)anthracene</u> Con (ug/kg dry sand)
0.914	0.037	2.632			
1.175	0.047	4.872			
0.903	0.036	3.367			
0.983	0.039	2.848			
2.469	0.099	5.891			
1.044	0.042	1.875			
1.635	0.065	3.184			
1.592	0.064	2.488			
1.689	0.068	2.290			
1.109	0.044	1.491			
2.079	0.083	2.307			
5.154	0.206	6.301			
0.987	0.039	1.313			
3.176	0.127	3.262			
1.080	0.043	0.909			
4.988	0.200	8.626			
1.005	0.040	1.096			
17.110	0.684	41.128	-0.825	-0.033	-0.648
			5.814	0.233	13.975
			8.751	0.350	13.711
0.938	0.038	1.742	-2.982	-0.119	-5.537
0.982	0.039	1.685		0.000	
4.776	0.191	7.053		0.000	
0.880	0.035	1.553		0.000	
3.619	0.145	8.881	10.139	0.406	24.879
10.015	0.401	39.348	17.672	0.707	69.434
43.141	1.726	75.721	2025.071	81.003	3554.393
138.062	5.522	671.576		0.000	
				0.000	



L-29-4 (6")

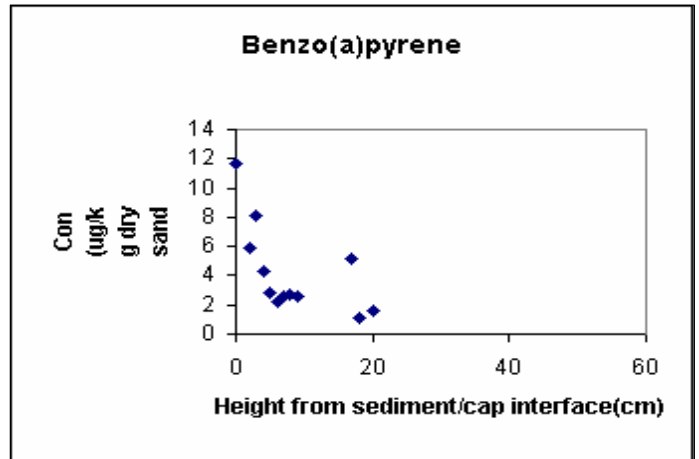
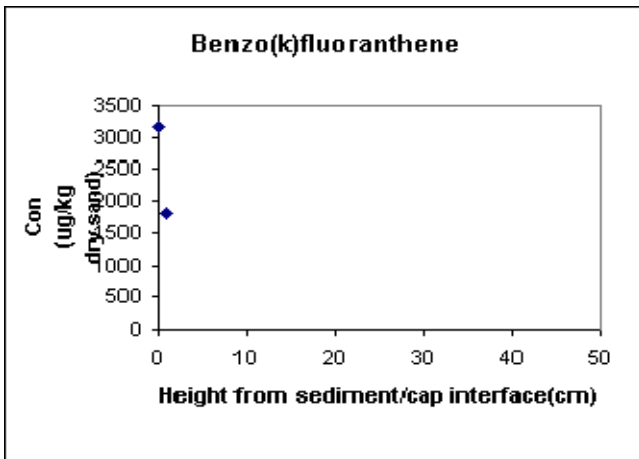
<u>Chrysene</u> (ppb)	<u>Chrysene</u> (ug)	<u>Chrysene</u> Con (ug/kg dry sand)	<u>Benzo(b)fluoranthene</u> (ppb)	<u>Benzo(b)fluoranthene</u> (ug)	<u>Benzo(b)fluoranthene</u> Con (ug/kg dry sand)
1.073	0.043	1.928	15.720	0.629	37.508
	0.000		20.720	0.829	37.210
	0.000			0.000	
	0.000		19.791	0.792	30.926
	0.000		15.717	0.629	21.304
	0.000		17.696	0.708	23.779
	0.000		39.755	1.590	44.111
	0.000		49.348	1.974	60.333
	0.000		19.906	0.796	26.477
	0.000		18.038	0.722	18.527
	0.000		13.922	0.557	21.884
	0.000		18.106	0.724	15.245
	0.000			0.000	
1.413	0.057	1.541	15.778	0.631	17.203
	0.000		17.374	0.695	27.940
	0.000		27.623	1.105	21.702
1.445	0.058	3.474			
2.010	0.080	3.148	72.358	2.894	113.364
	0.000		19.621	0.785	36.431
2.588	0.104	4.443	27.482	1.099	47.182
1.319	0.053	1.948	35.009	1.400	51.700
1.685	0.067	2.975	50.650	2.026	89.421
1.817	0.073	4.460	89.075	3.563	218.578
	0.000		178.770	7.151	702.374
30.588	1.224	53.688	543.980	21.759	954.791
12.728	0.509	38.306	134.501	5.380	404.801
39.614	1.585	192.693	813.806	32.552	3958.591



L-29-4 (6")

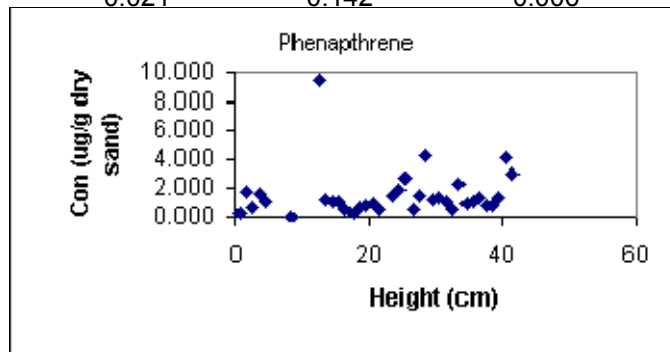
<u>Benzo(k)fluoranthene</u> (ppb)	<u>Benzo(k)fluoranthene</u> (ug)	<u>Benzo(k)fluoranthene</u> Con (ug/kg dry sand)	<u>Benzo(a)pyrene</u> (ppb)	<u>Benzo(a)pyrene</u> (ug)	<u>Benzo(a)pyrene</u> Con (ug/kg dry sand)
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			1.449	0.058	1.580
				0.000	
			1.447	0.058	1.137
-19.216	-0.769	-46.189	2.151	0.086	5.170
	0.000		1.624	0.065	2.544
	0.000		1.454	0.058	2.699
	0.000		1.484	0.059	2.547
	0.000		1.519	0.061	2.244
	0.000		1.628	0.065	2.874
	0.000		1.749	0.070	4.292
	0.000		2.057	0.082	8.082
	0.000		3.337	0.133	5.858
601.761	24.070	1811.088		0.000	
652.105	26.084	3172.030	2.393	0.096	11.642



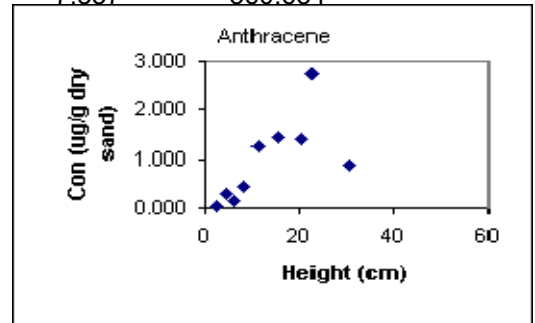
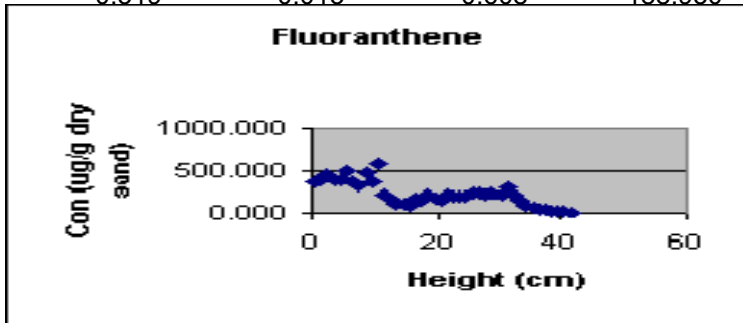
L-29-5 (6")

Sample #	Height (cm)	Dry weight (kg)	Phenapthrene (ppb)	Phenapthrene (ug)	Phenapthrene Con (ug/kg dry sand)
1	41.5	0.017	1.265	0.051	3.042
2	40.5	0.019	1.925	0.077	4.145
3	39.5	0.025	0.805	0.032	1.303
4	38.5	0.026	0.494	0.020	0.764
5	37.5	0.025	0.501	0.020	0.813
6	36.5	0.026	0.914	0.037	1.412
7	35.5	0.021	0.553	0.022	1.067
8	34.5	0.017	0.407	0.016	0.978
9	33.5	0.011	0.622	0.025	2.313
10	32.5	0.008	0.109	0.004	0.552
30	31.5	0.018	0.484	0.019	1.088
29	30.5	0.023	0.768	0.031	1.332
28	29.5	0.024	0.763	0.031	1.278
27	28.5	0.020	2.100	0.084	4.294
26	27.5	0.020	0.757	0.030	1.477
25	26.5	0.019	0.274	0.011	0.580
24	25.5	0.018	1.259	0.050	2.746
23	24.5	0.021	1.052	0.042	1.964
22	23.5	0.021	0.774	0.031	1.487
21	22.5	0.020	-0.690	-0.028	-1.400
20	21.5	0.017	0.241	0.010	0.580
19	20.5	0.023	0.577	0.023	1.004
18	19.5	0.020	0.434	0.017	0.885
17	18.5	0.014	0.229	0.009	0.658
16	17.5	0.018	0.148	0.006	0.322
15	16.5	0.015	0.190	0.008	0.523
14	15.5	0.030	0.804	0.032	1.059
13	14.5	0.022	0.627	0.025	1.158
12	13.5	0.018	0.554	0.022	1.217
11	12.5	0.011	2.727	0.109	9.498
31	11.5	0.026	-0.690	-0.028	-1.060
32	10.5	0.010	-0.216	-0.009	-0.879
33	9.5	0.016	-0.036	-0.001	-0.090
34	8.5	0.013	0.005	0.000	0.016
35	7.5	0.019	-0.218	-0.009	-0.466
36	6.5	0.017	-0.272	-0.011	-0.637
37	5.5	0.013	-0.048	-0.002	-0.144
38	4.5	0.018	0.470	0.019	1.051
39	3.5	0.018	0.748	0.030	1.684
40	2.5	0.015	0.271	0.011	0.702
41	1.5	0.019	0.875	0.035	1.834
42	0.5	0.021	0.142	0.006	0.271



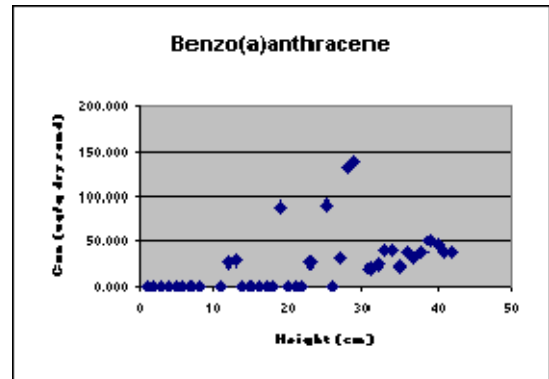
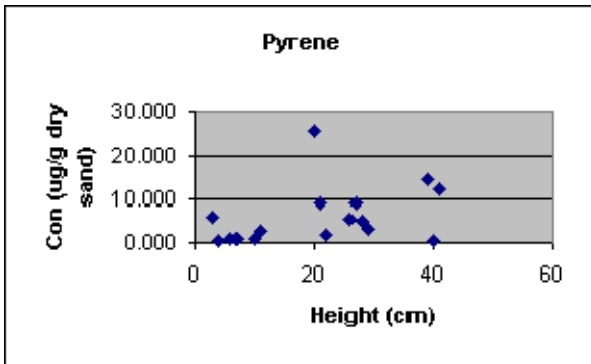
L-29-5 (6")

<u>Anthracene</u> (ppb)	<u>Anthracene</u> (ug)	<u>Anthracene</u> Con (ug/kg dry sand)	<u>Fluoranthene</u> (ppb)	<u>Fluoranthene</u> (ug)	<u>Fluoranthene</u> Con (ug/kg dry sand)
-0.319	-0.013	-0.766	3.388	0.136	8.146
-0.319	-0.013	-0.686	7.914	0.317	17.038
-0.319	-0.013	-0.516	12.439	0.498	20.123
-0.319	-0.013	-0.494	16.965	0.679	26.277
-0.319	-0.013	-0.517	21.490	0.860	34.830
-0.319	-0.013	-0.492	26.015	1.041	40.167
-0.319	-0.013	-0.615	30.541	1.222	58.973
-0.319	-0.013	-0.766	35.066	1.403	84.306
-0.319	-0.013	-1.185	39.592	1.584	147.160
-0.319	-0.013	-1.621	44.117	1.765	224.355
-0.319	-0.013	-0.716	134.625	5.385	302.546
0.509	0.020	0.883	130.100	5.204	225.640
-0.319	-0.013	-0.534	125.574	5.023	210.210
-0.319	-0.013	-0.652	121.049	4.842	247.541
-0.319	-0.013	-0.622	116.523	4.661	227.367
-0.319	-0.013	-0.676	111.998	4.480	237.466
-0.319	-0.013	-0.695	107.473	4.299	234.312
-0.319	-0.013	-0.595	102.947	4.118	192.163
-0.319	-0.013	-0.612	98.422	3.937	188.979
1.352	0.054	2.745	93.896	3.756	190.585
-0.319	-0.013	-0.765	89.371	3.575	214.652
0.793	0.032	1.380	84.846	3.394	147.717
-0.319	-0.013	-0.649	80.320	3.213	163.597
-0.319	-0.013	-0.915	75.795	3.032	217.585
-0.319	-0.013	-0.694	71.269	2.851	155.097
-0.319	-0.013	-0.877	66.744	2.670	183.587
1.072	0.043	1.412	62.219	2.489	81.919
-0.319	-0.013	-0.588	57.693	2.308	106.519
-0.319	-0.013	-0.700	53.168	2.127	116.836
-0.319	-0.013	-1.110	48.642	1.946	169.406
0.815	0.033	1.251	139.150	5.566	213.760
-0.319	-0.013	-1.294	143.676	5.747	583.465
-0.020	-0.001	-0.050	148.201	5.928	367.510
0.139	0.006	0.428	152.727	6.109	469.230
-0.040	-0.002	-0.085	157.252	6.290	336.455
0.066	0.003	0.154	161.777	6.471	379.169
-0.319	-0.013	-0.952	166.303	6.652	496.800
0.132	0.005	0.295	170.828	6.833	382.252
-0.319	-0.013	-0.717	175.354	7.014	394.747
0.018	0.001	0.048	179.879	7.195	466.071
-0.319	-0.013	-0.668	184.404	7.376	386.485
-0.319	-0.013	-0.608	188.930	7.557	360.654



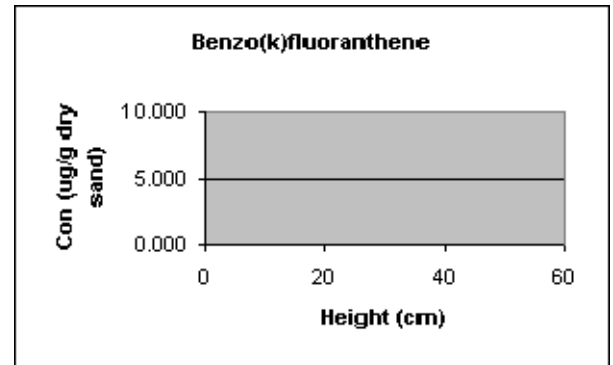
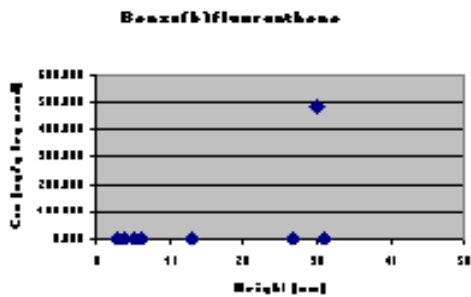
L-29-5 (6'')

<u>Pyrene</u> (ppb)	<u>Pyrene</u> (ug)	<u>Con (ug/kg dry</u> <u>sand)</u>	<u>Benzo(a)anthracene</u> (ppb)	<u>Benzo(a)anthracene</u> (ug)	<u>Con (ug/kg dry sand)</u>
-0.337	-0.013	-0.811	-0.393	-0.016	-0.944
-0.337	-0.013	-0.726	-0.393	-0.016	-0.845
3.638	0.146	5.885	-0.393	-0.016	-0.635
0.211	0.008	0.327	-0.393	-0.016	-0.608
-0.337	-0.013	-0.547	-0.393	-0.016	-0.636
0.553	0.022	0.854	-0.393	-0.016	-0.606
0.553	0.022	1.068	-0.393	-0.016	-0.758
-0.337	-0.013	-0.811	-0.393	-0.016	-0.944
-0.337	-0.013	-1.254	-0.393	-0.016	-1.459
0.202	0.008	1.025	-0.393	-0.016	-1.996
1.227	0.049	2.759	-0.393	-0.016	-0.882
-0.337	-0.013	-0.585	15.435	0.617	26.770
-0.337	-0.013	-0.565	17.053	0.682	28.547
-0.337	-0.013	-0.690	-0.393	-0.016	-0.803
-0.337	-0.013	-0.658	-0.393	-0.016	-0.766
-0.337	-0.013	-0.715	-0.393	-0.016	-0.832
-0.337	-0.013	-0.735	-0.393	-0.016	-0.856
-0.337	-0.013	-0.630	-0.393	-0.016	-0.733
-0.337	-0.013	-0.648	45.863	1.835	88.061
12.618	0.505	25.611	-0.393	-0.016	-0.797
3.802	0.152	9.131	-0.393	-0.016	-0.943
1.069	0.043	1.861	-0.393	-0.016	-0.683
-0.337	-0.013	-0.687	12.452	0.498	25.363
-0.337	-0.013	-0.968	-0.393	-0.016	-1.127
-0.337	-0.013	-0.734	41.703	1.668	90.754
1.914	0.077	5.265	-0.393	-0.016	-1.080
6.996	0.280	9.211	23.188	0.928	30.530
2.598	0.104	4.797	71.819	2.873	132.599
1.362	0.054	2.993	63.424	2.537	139.374
-0.337	-0.013	-1.175	284.992	11.400	992.539
-0.337	-0.013	-0.518	12.294	0.492	18.886
-0.337	-0.013	-1.370	6.207	0.248	25.206
-0.337	-0.013	-0.836	15.565	0.623	38.597
-0.337	-0.013	-1.036	12.914	0.517	39.676
-0.337	-0.013	-0.722	10.471	0.419	22.403
-0.337	-0.013	-0.791	16.299	0.652	38.200
-0.337	-0.013	-1.008	10.432	0.417	31.164
-0.337	-0.013	-0.755	16.270	0.651	36.406
6.407	0.256	14.422	22.906	0.916	51.565
0.176	0.007	0.455	17.777	0.711	46.062
5.759	0.230	12.070	17.498	0.700	36.673
-0.337	-0.013	-0.644	19.636	0.785	37.485



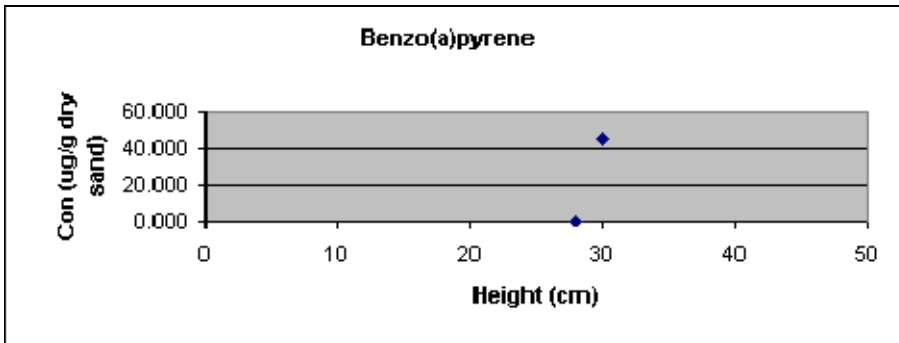
L-29-5 (6")

		<u>Benzo(b)fluoranthene</u>		<u>Benzo(k)fluoranthene</u>		<u>Benzo(k)fluoranthene</u>	
<u>Benzo(b)fluoranthene (ppb)</u>	<u>Benzo(b)fluoranthene (ug)</u>	<u>Con (ug/kg dry sand)</u>	<u>Benzo(k)fluoranthene (ppb)</u>	<u>Benzo(k)fluoranthene (ug)</u>			<u>Con (ug/kg dry sand)</u>
-2.304	-0.092	-5.539	-4.289	-0.172			-10.312
-2.304	-0.092	-4.960	-4.289	-0.172			-9.235
-2.304	-0.092	-3.727	-4.095	-0.164			-6.624
-2.304	-0.092	-3.568	-4.262	-0.170			-6.602
-2.304	-0.092	-3.734	-4.289	-0.172			-6.952
-2.304	-0.092	-3.557	-4.246	-0.170			-6.555
-2.304	-0.092	-4.449	-4.246	-0.170			-8.198
-2.304	-0.092	-5.539	-4.289	-0.172			-10.312
-2.304	-0.092	-8.563	-4.289	-0.172			-15.943
-2.304	-0.092	-11.716	-4.263	-0.171			-21.679
-2.304	-0.092	-5.177	-4.213	-0.169			-9.467
-2.304	-0.092	-3.996	-4.289	-0.172			-7.439
-2.304	-0.092	-3.857	-4.289	-0.172			-7.180
-2.304	-0.092	-4.711	-4.289	-0.172			-8.771
-2.304	-0.092	-4.495	-4.289	-0.172			-8.369
-2.304	-0.092	-4.885	-4.289	-0.172			-9.094
-2.304	-0.092	-5.023	-4.289	-0.172			-9.351
-2.304	-0.092	-4.300	-4.289	-0.172			-8.006
-2.304	-0.092	-4.424	-4.289	-0.172			-8.236
-2.304	-0.092	-4.676	-3.656	-0.146			-7.420
-2.304	-0.092	-5.533	-4.087	-0.163			-9.816
-2.304	-0.092	-4.011	-4.220	-0.169			-7.348
-2.304	-0.092	-4.692	-4.289	-0.172			-8.736
-2.304	-0.092	-6.614	-4.289	-0.172			-12.313
-2.304	-0.092	-5.014	-4.289	-0.172			-9.334
-2.304	-0.092	-6.337	-4.179	-0.167			-11.495
-2.304	-0.092	-3.033	-3.931	-0.157			-5.175
-2.304	-0.092	-4.254	-4.146	-0.166			-7.654
-2.304	-0.092	-5.063	-4.206	-0.168			-9.243
139.112	5.564	484.484	-4.289	-0.172			-14.938
-2.304	-0.092	-3.539	-4.289	-0.172			-6.589
-2.304	-0.092	-9.356	-4.289	-0.172			-17.418
-2.304	-0.092	-5.713	-4.289	-0.172			-10.636
-2.304	-0.092	-7.078	-4.289	-0.172			-13.178
-2.304	-0.092	-4.929	-4.289	-0.172			-9.177
-2.304	-0.092	-5.400	-4.289	-0.172			-10.053
-2.304	-0.092	-6.882	-4.289	-0.172			-12.813
-2.304	-0.092	-5.155	-4.289	-0.172			-9.598
-2.304	-0.092	-5.186	-3.959	-0.158			-8.913
-2.304	-0.092	-5.969	-4.264	-0.171			-11.048
-2.304	-0.092	-4.828	-3.991	-0.160			-8.365
-2.304	-0.092	-4.398	-4.289	-0.172			-8.188



L-29-5 (6")

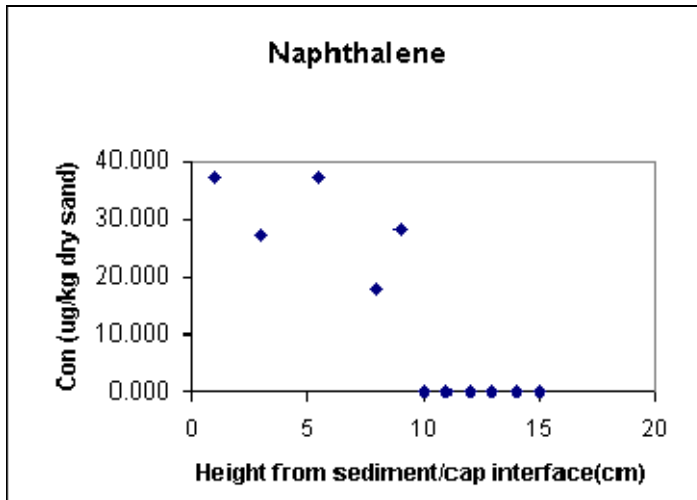
<u>Benzo(a)pyrene(ppb)</u>	<u>Benzo(a)pyrene(ug)</u>	<u>Con (ug/kg dry sand)</u>
-4.221	-0.169	-10.147
-4.221	-0.169	-9.087
-4.221	-0.169	-6.828
-4.221	-0.169	-6.537
-4.221	-0.169	-6.841
-4.221	-0.169	-6.516
-4.221	-0.169	-8.150
-4.221	-0.169	-10.147
-4.221	-0.169	-15.688
-4.221	-0.169	-21.464
-4.221	-0.169	-9.485
-3.274	-0.131	-5.678
-3.177	-0.127	-5.319
-4.221	-0.169	-8.631
-4.221	-0.169	-8.235
-4.221	-0.169	-8.949
-4.221	-0.169	-9.202
-4.221	-0.169	-7.878
-1.455	-0.058	-2.793
-4.221	-0.169	-8.567
-4.221	-0.169	-10.137
-4.221	-0.169	-7.348
-3.452	-0.138	-7.032
-4.221	-0.169	-12.116
-1.703	-0.068	-3.707
-4.221	-0.169	-11.609
-2.810	-0.112	-3.700
0.098	0.004	0.180
-0.404	-0.016	-0.889
12.845	0.514	44.737
-3.462	-0.138	-5.318
-3.826	-0.153	-15.537
-3.266	-0.131	-8.100
-3.425	-0.137	-10.522
-3.571	-0.143	-7.640
-3.222	-0.129	-7.553
-3.573	-0.143	-10.675
-3.224	-0.129	-7.215
-2.827	-0.113	-6.365
-3.134	-0.125	-8.120
-3.151	-0.126	-6.604
-3.023	-0.121	-5.770



L-29-6 (8")

Naphthalene

<u>Sample #</u>	<u>Height (cm)</u>	<u>Dry weight (kg)</u>	<u>Naphthalene (ppb)</u>	<u>Naphthalene (ug)</u>	<u>Con (ug/kg dry sand)</u>
1	1	0.034	31.692	1.268	37.123
2	3	0.039	27.033	1.081	27.390
3	5.5	0.048	44.154	1.766	37.172
4	8	0.055	24.716	0.989	18.075
5	9	0.039	27.516	1.101	28.411
6	10	0.019	0.000	0.000	0.000
7	11	0.029	0.000	0.000	0.000
8	12	0.024	0.000	0.000	0.000
9	13	0.024	0.000	0.000	0.000
10	14	0.025	0.000	0.000	0.000
11	15	0.033	0.000	0.000	0.000

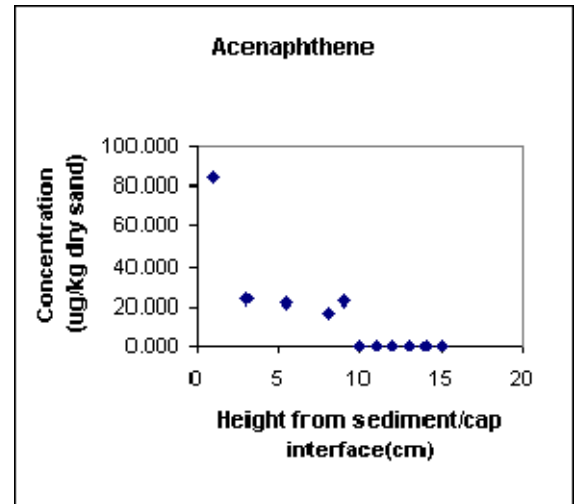
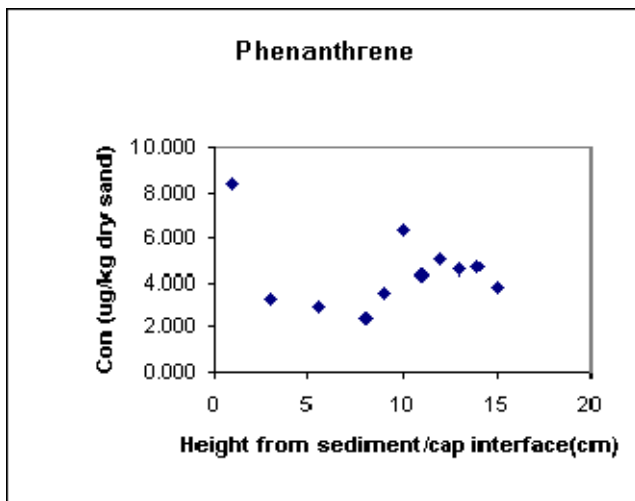


L-29-6 (8")

Acenaphthene

Phenanthrene

<u>Acenaphthene</u> (ppb)	<u>Acenaphthene</u> (ug)	<u>Con (ug/kg dry sand)</u>	<u>Phenanthrene</u> (ppb)	<u>Phenanthrene</u> (ug)	<u>Con (ug/kg dry sand)</u>
71.600	2.864	83.868	7.188	0.288	8.419
23.686	0.947	23.999	3.221	0.129	3.263
25.848	1.034	21.761	3.437	0.137	2.894
22.892	0.916	16.742	3.255	0.130	2.381
22.514	0.901	23.246	3.435	0.137	3.547
0.000	0.000	0.000	3.056	0.122	6.359
0.000	0.000	0.000	3.176	0.127	4.348
0.000	0.000	0.000	3.018	0.121	5.016
0.000	0.000	0.000	2.788	0.112	4.619
0.000	0.000	0.000	2.968	0.119	4.685
0.000	0.000	0.000	3.106	0.124	3.802

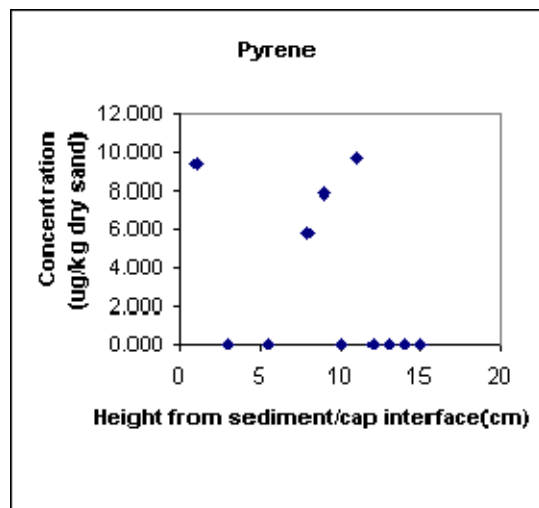
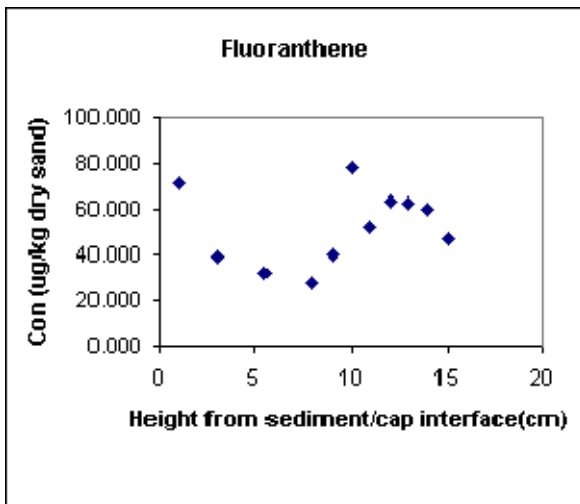


L-29-6 (8'')

Fluoranthene

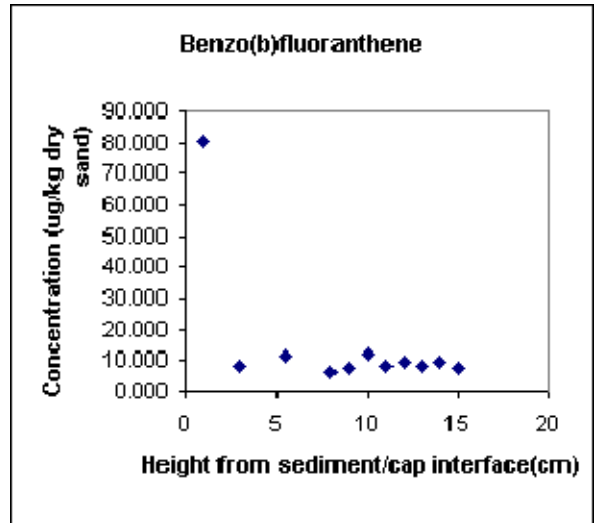
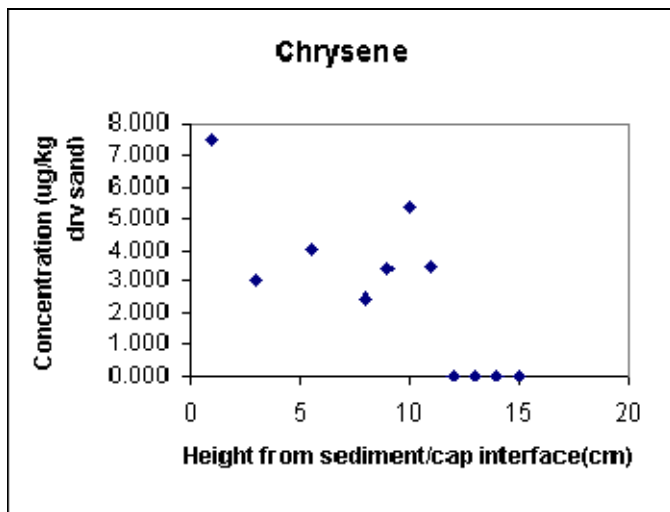
Pyrene

<u>Fluoranthene</u> (ppb)	<u>Fluoranthene</u> (ug)	<u>Con (ug/kg dry sand)</u>	<u>Pyrene</u> (ppb)	<u>Pyrene (ug)</u>	<u>Con (ug/kg dry sand)</u>
61.166	2.447	71.647	8.019	0.321	9.393
38.861	1.554	39.375	0.000	0.000	0.000
38.588	1.544	32.486	0.000	0.000	0.000
38.222	1.529	27.953	7.884	0.315	5.766
39.132	1.565	40.404	7.596	0.304	7.843
37.499	1.500	78.031	0.000	0.000	0.000
38.088	1.524	52.144	7.115	0.285	9.741
38.016	1.521	63.183	0.000	0.000	0.000
37.927	1.517	62.820	0.000	0.000	0.000
37.880	1.515	59.789	0.000	0.000	0.000
38.051	1.522	46.578	0.000	0.000	0.000



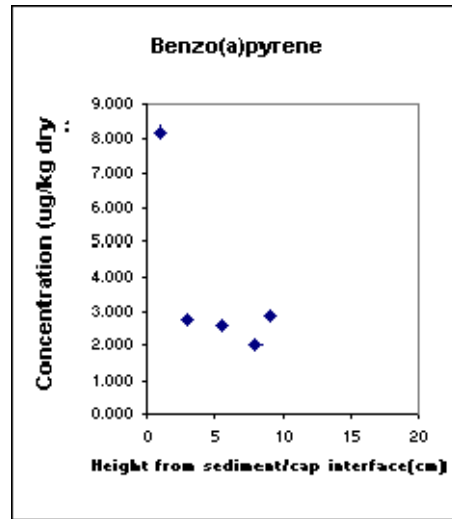
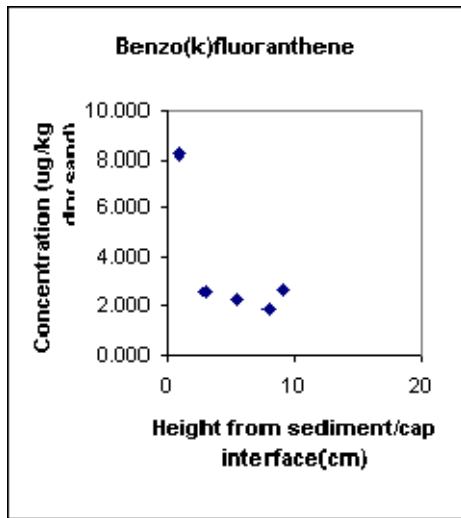
L-29-6 (8'')

<u>Chrysene</u>			<u>Benzo(b)fluoranthene</u>		
<u>Chrysene (ppb)</u>	<u>Chrysene (ug)</u>	<u>Con (ug/kg dry sand)</u>	<u>Benzo(b) fluoranthene (ppb)</u>	<u>Benzo(b) fluoranthene (ug)</u>	<u>Con (ug/kg dry sand)</u>
6.385	0.255	7.479	68.715	2.749	80.490
3.014	0.121	3.054	8.123	0.325	8.230
4.779	0.191	4.023	13.408	0.536	11.287
3.368	0.135	2.463	8.474	0.339	6.197
3.271	0.131	3.378	7.631	0.305	7.879
2.588	0.104	5.386	5.682	0.227	11.823
2.535	0.101	3.470	5.899	0.236	8.076
0.000	0.000	0.000	5.723	0.229	9.512
0.000	0.000	0.000	4.966	0.199	8.226
0.000	0.000	0.000	6.209	0.248	9.800
0.000	0.000	0.000	6.492	0.260	7.947
0.000	0.000	0.000			



L-29-6 (8'')

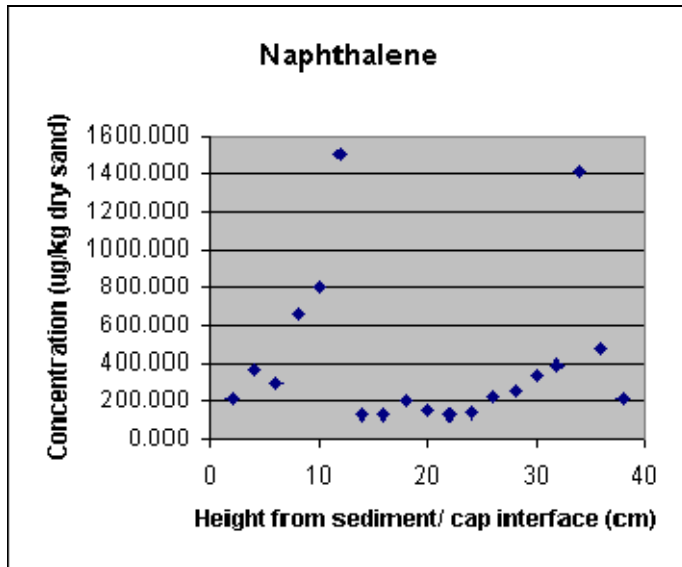
<u>Benzo(k)fluoranthene</u>			<u>Benzo(a)pyrene</u>		
<u>Benzo(k)</u> <u>fluoranthene</u>	<u>Benzo(k)</u> <u>fluoranthene</u>	Con (ug/kg dry sand)	<u>Benzo(a)</u> <u>pyrene</u>	<u>Benzo(a)</u> <u>pyrene</u>	Con (ug/kg dry sand)
(ppb)	(ug)		(ppb)	(ug)	
6.997	0.280	8.195	7.003	0.280	8.203
2.551	0.102	2.584	2.734	0.109	2.770
2.659	0.106	2.239	3.101	0.124	2.611
2.576	0.103	1.884	2.754	0.110	2.014
2.584	0.103	2.668	2.791	0.112	2.881



SP-3B (4")

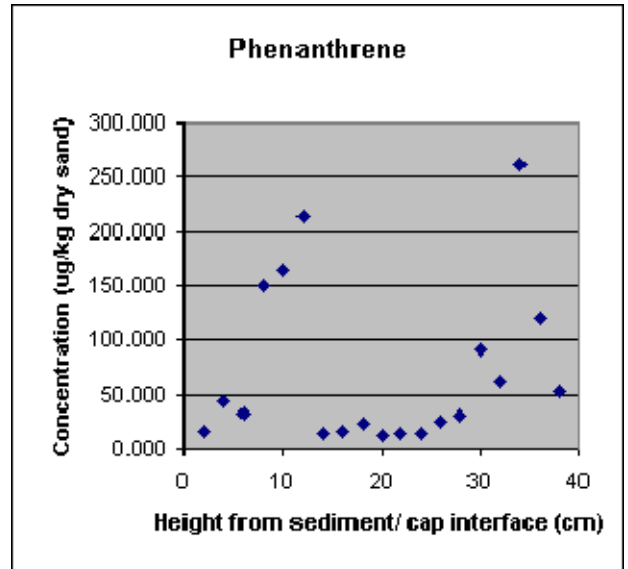
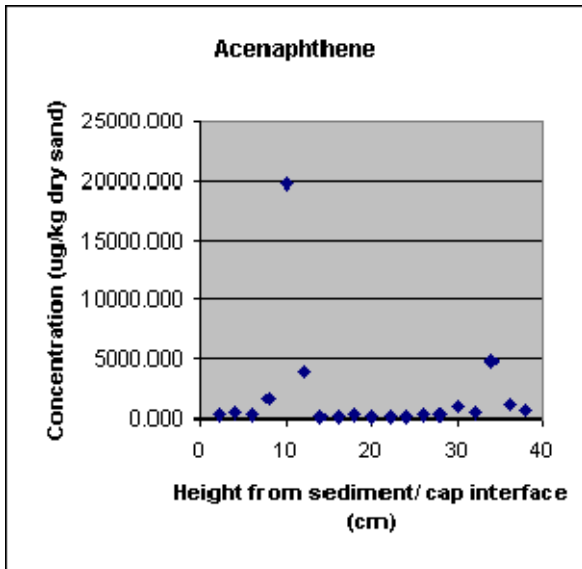
Naphthalene

Sample #	Height (cm)	Dry weight (kg)	Naphthalene(ppb)	Naphthalene (ug)	Con (ug/kg dry sand)
12	2	0.016	82.851	3.314	213.493
13	4	0.016	150.337	6.013	373.318
14	6	0.023	169.195	6.768	292.087
15	8	0.022	370.994	14.840	661.706
16	10	0.019	385.365	15.415	797.035
17	12	0.024	917.835	36.713	1510.238
18	14	0.030	97.708	3.908	130.299
19	16	0.021	68.168	2.727	127.019
20	18	0.020	99.678	3.987	196.500
21	20	0.019	70.112	2.804	146.349
22	22	0.023	71.481	2.859	122.970
23	24	0.029	95.825	3.833	134.484
24	26	0.027	154.794	6.192	225.814
25	28	0.019	119.675	4.787	257.540
26	30	0.022	184.788	7.392	332.946
27	32	0.021	207.426	8.297	388.747
28	34	0.016	551.087	22.043	1406.084
29	36	0.017	207.615	8.305	478.858
30	38	0.022	118.797	4.752	214.867



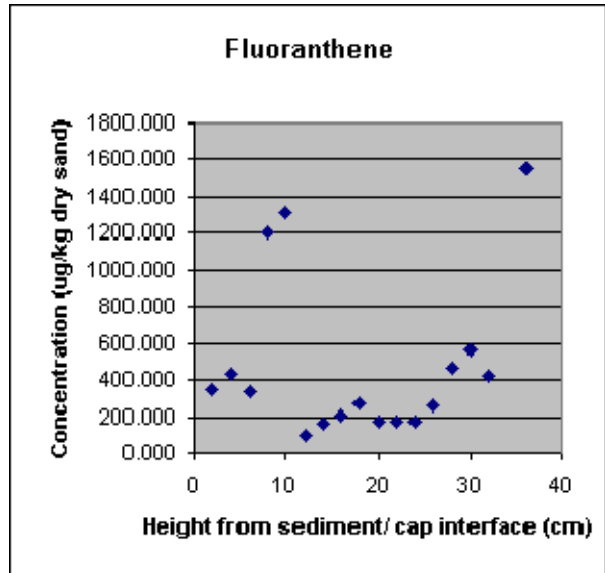
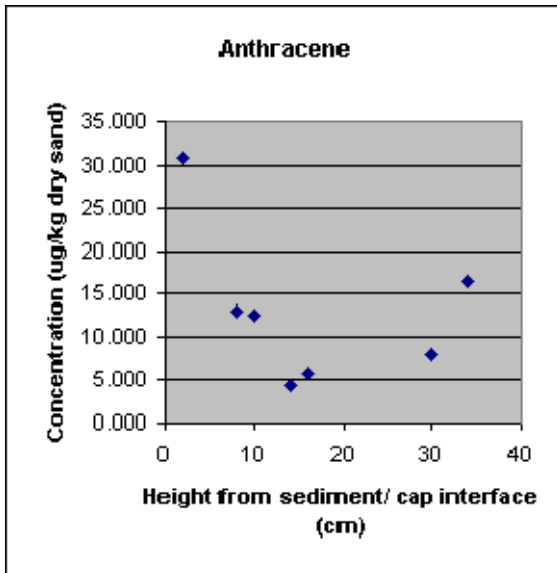
SP-3B (4")

<u>Acenaphthene</u>			<u>Phenanthrene</u>		
<u>Acenaphthene</u> (ppb)	<u>Acenaphthene</u> (ug)	<u>Con (ug/kg dry sand)</u>	<u>Phenanthrene</u> (ppb)	<u>Phenanthrene</u> (ug)	<u>Con (ug/kg dry sand)</u>
110.272	4.411	284.150	6.210	0.248	16.002
207.989	8.320	516.479	17.830	0.713	44.277
236.120	9.445	407.622	19.306	0.772	33.329
966.434	38.657	1723.732	83.693	3.348	149.275
9575.006	383.000	19803.613	79.379	3.175	164.176
2445.939	97.838	4024.634	130.472	5.219	214.684
146.940	5.878	195.952	11.362	0.454	15.151
111.699	4.468	208.132	9.091	0.364	16.939
144.587	5.783	285.031	12.280	0.491	24.208
84.002	3.360	175.341	6.400	0.256	13.359
119.630	4.785	205.799	8.469	0.339	14.569
94.831	3.793	133.090	10.677	0.427	14.984
230.661	9.226	336.490	16.938	0.678	24.709
172.601	6.904	371.435	14.372	0.575	30.928
526.377	21.055	948.412	51.204	2.048	92.257
285.152	11.406	534.416	33.459	1.338	62.707
1875.203	75.008	4784.534	102.586	4.103	261.745
476.289	19.052	1098.549	52.364	2.095	120.777
379.884	15.195	687.091	29.465	1.179	53.293



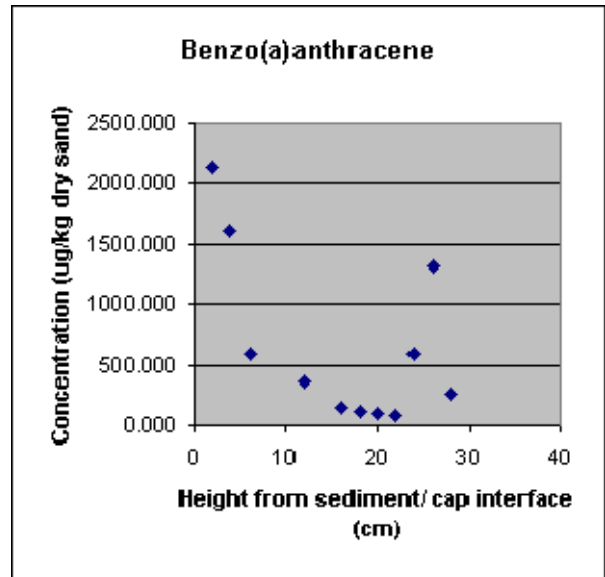
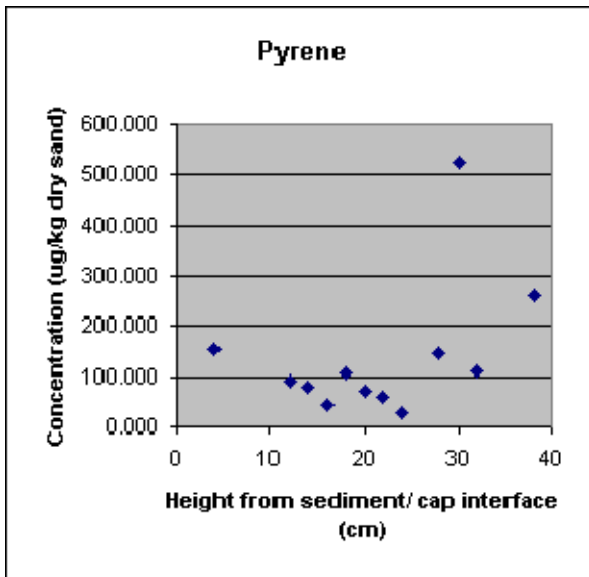
SP-3B (4")

<u>Anthracene</u>			<u>Fluoranthene</u>		
<u>Anthracene</u> (ppb)	<u>Anthracene</u> (ug)	<u>Con (ug/kg dry sand)</u>	<u>Fluoranthene</u> (ppb)	<u>Fluoranthene</u> (ug)	<u>Con (ug/kg dry sand)</u>
11.944	0.478	30.778	136.430	5.457	351.556
			175.640	7.026	436.150
			197.108	7.884	340.275
7.328	0.293	13.070	673.992	26.960	1202.133
6.073	0.243	12.560	635.145	25.406	1313.645
			61.917	2.477	101.880
3.263	0.131	4.351	124.481	4.979	166.002
3.104	0.124	5.783	109.292	4.372	203.646
			139.752	5.590	275.499
			83.048	3.322	173.350
			100.400	4.016	172.718
			127.373	5.095	178.760
			182.000	7.280	265.503
			215.713	8.629	464.212
4.317	0.173	7.778	314.221	12.569	566.155
			222.875	8.915	417.700
6.455	0.258	16.469			
			673.522	26.941	1553.462



SP-3B (4")

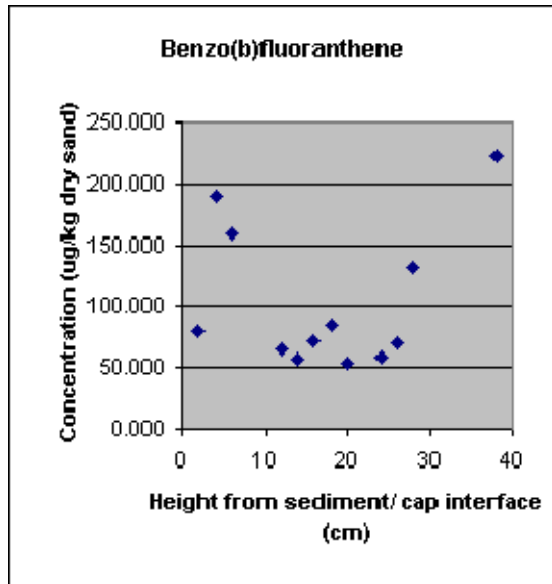
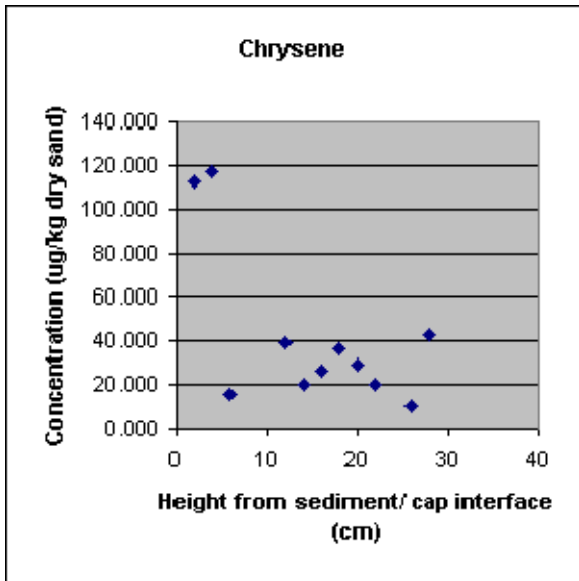
<u>Pyrene</u>			<u>Benzo(a)anthracene</u>		
<u>Pyrene</u> <u>(ppb)</u>	<u>Pyrene</u> <u>(ug)</u>	<u>Con (ug/kg dry</u> <u>sand)</u>	<u>Benzo(a)anthracene</u> <u>(ppb)</u>	<u>Benzo(a)anthracene</u> <u>(ug)</u>	<u>Con (ug/kg dry</u> <u>sand)</u>
62.214	2.489	154.490	827.329	33.093	2131.876
			652.113	26.085	1619.329
			343.366	13.735	592.764
54.519	2.181	89.708	216.236	8.649	355.803
58.406	2.336	77.888			
23.012	0.920	42.878	81.366	3.255	151.612
54.118	2.165	106.686	61.103	2.444	120.455
34.806	1.392	72.653	48.810	1.952	101.883
34.771	1.391	59.816	48.110	1.924	82.764
19.803	0.792	27.793	427.612	17.104	600.127
			896.967	35.879	1308.500
67.132	2.685	144.467	124.099	4.964	267.059
291.618	11.665	525.430			
57.941	2.318	108.589			
144.864	5.795	262.013	1284.873	51.395	



SP-3B (4")

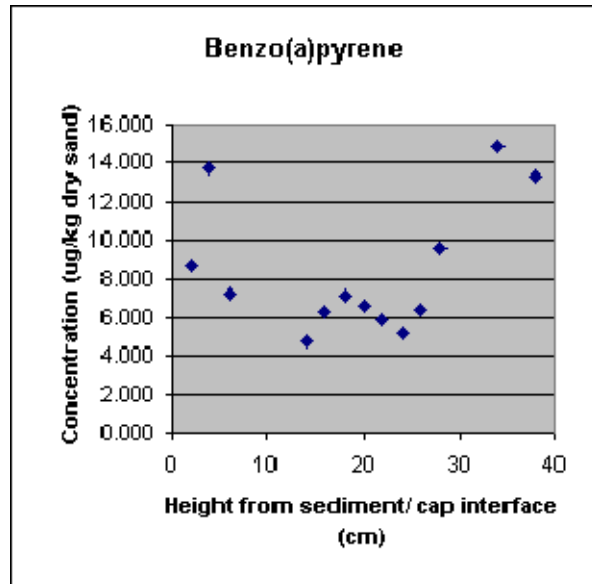
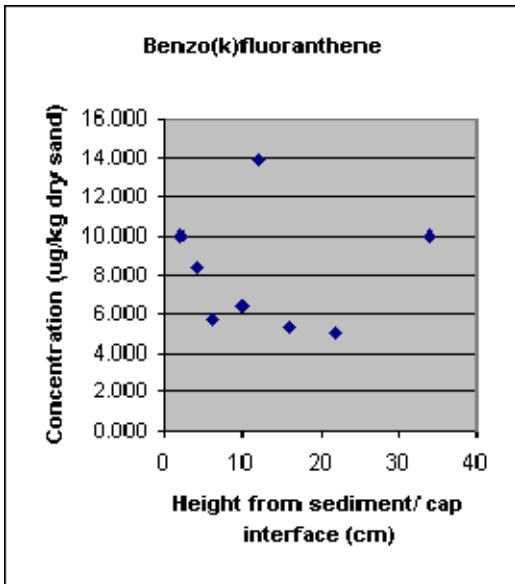
<u>Chrysene</u>			<u>Benzo(b)fluoranthene</u>		
<u>Chrysene</u> (ppb)	<u>Chrysene</u> (ug)	<u>Con (ug/kg dry sand)</u>	<u>Benzo(b)fluoranthene</u> (ppb)	<u>Benzo(b)fluoranthene</u> (ug)	<u>Con (ug/kg dry sand)</u>
43.770	1.751	112.786	31.164	1.247	80.304
47.104	1.884	116.969	76.292	3.052	189.447
8.915	0.357	15.390	91.758	3.670	158.404
23.870	0.955	39.276	39.885	1.595	65.627
15.183	0.607	20.247	42.336	1.693	56.458
13.936	0.557	25.967	38.570	1.543	71.868
18.379	0.735	36.231	42.729	1.709	84.233
13.908	0.556	29.031	25.642	1.026	53.524
11.513	0.461	19.806	42.184	1.687	59.202
6.669	0.267	9.729	47.965	1.919	69.971
19.661	0.786	42.309	61.351	2.454	132.027

122.536 4.901 221.630



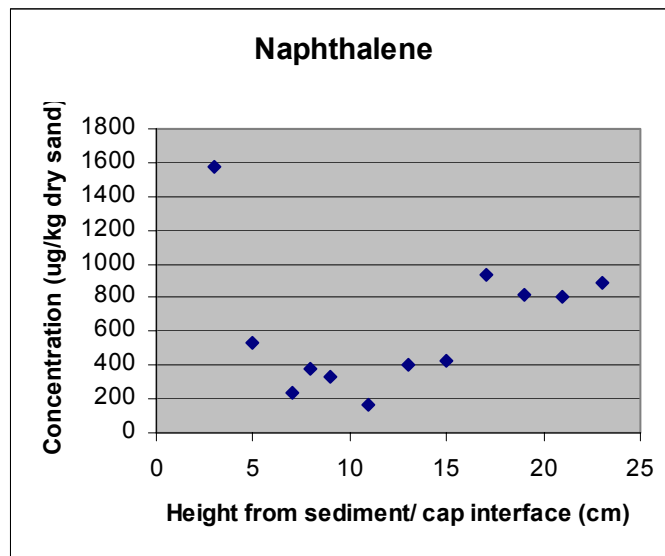
SP-3B (4")

<u>Benzo(k)fluoranthene</u>			<u>Benzo(a)pyrene</u>		
<u>Benzo(k)</u> <u>fluoranthene</u>	<u>Benzo(k)</u> <u>fluoranthene</u>	Con (ug/kg dry sand)	<u>Benzo(a)</u> <u>pyrene</u>	<u>Benzo(a)</u> <u>pyrene (ug)</u>	Con (ug/kg dry sand)
(ppb)	(ug)		(ppb)		
3.866	0.155	9.962	3.382	0.135	8.715
3.346	0.134	8.308	5.547	0.222	13.775
3.281	0.131	5.663	4.197	0.168	7.245
3.115	0.125	6.443			
8.441	0.338	13.889			
2.852	0.114	5.314	3.569	0.143	4.759
			3.388	0.136	6.312
			3.630	0.145	7.155
			3.180	0.127	6.638
2.886	0.115	4.965	3.446	0.138	5.928
			3.685	0.147	5.172
			4.395	0.176	6.411
			4.447	0.178	9.570
3.910	0.156	9.977	5.821	0.233	14.853
			7.365	0.295	13.322



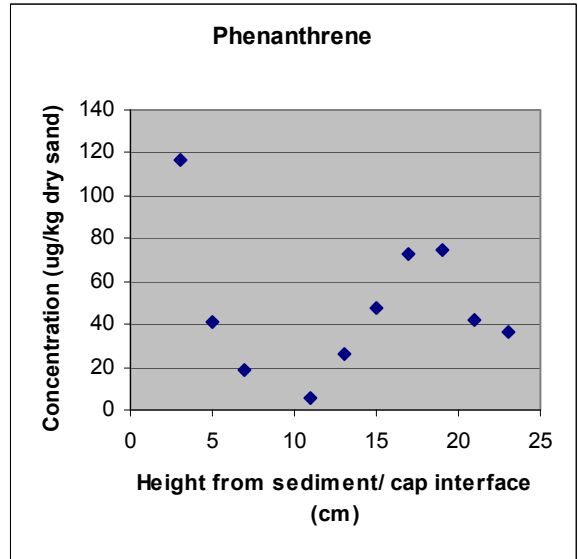
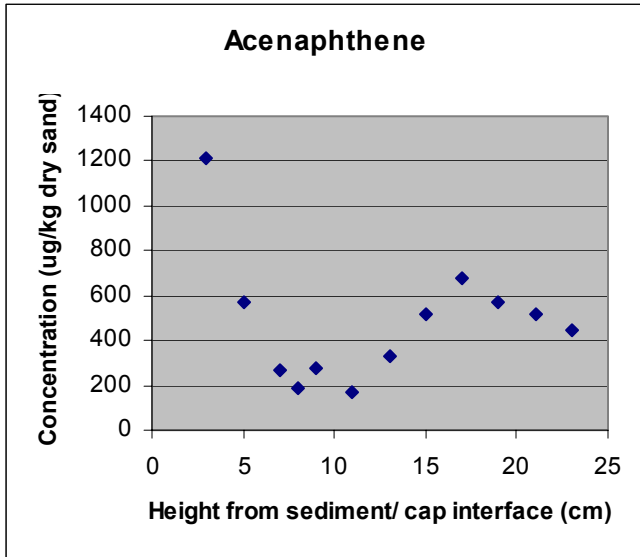
SP-2A (4")

<u>Height (cm)</u>	<u>Dry weight (kg)</u>	<u>Naphthalene(ppb)</u>	<u>Naphthalene (ug)</u>	Naphthalene <u>Con (ug/kg dry sand)</u>
3	0.057755378	2270.388389	90.81553557	1572.416942
5	0.051481474	688.9700077	27.55880031	535.3149048
7	0.035841034	211.8003738	8.472014951	236.3775276
8	0.009683669	92.4178265	3.69671306	381.7471337
9	0.010881751	90.75379113	3.630151645	333.599947
11	0.039714927	169.0710832	6.762843327	170.284674
13	0.042051681	426.5331961	17.06132784	405.7228478
15	0.03702395	397.377966	15.89511864	429.3199064
17	0.048449156	1130.628418	45.22513672	933.4556176
19	0.062230075	1264.898061	50.59592246	813.0461483
21	0.035383994	707.9698035	28.31879214	800.3277452
23	0.020547772	456.3231293	18.25292517	888.3164965



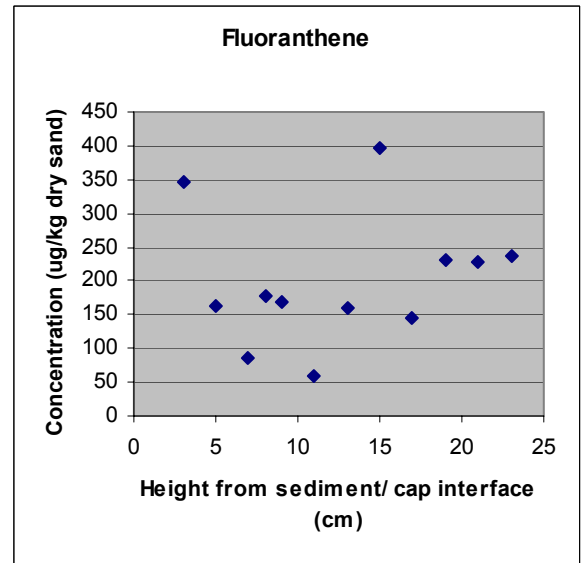
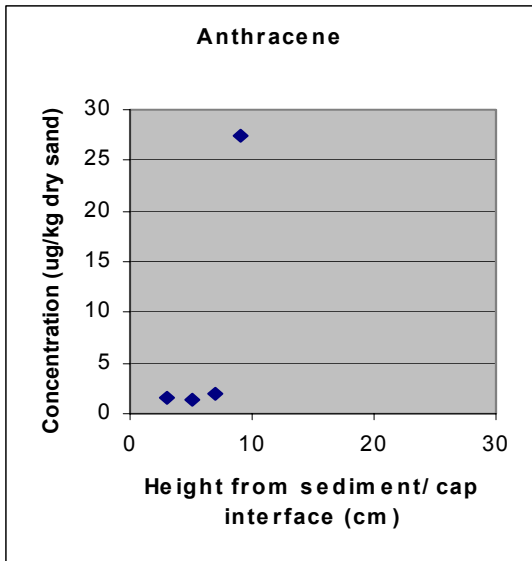
SP-2A (4'')

<u>Acenaphthene(ppb)</u>	<u>Acenaphthene (ug)</u>	<u>Acenaphthene Con (ug/kg dry sand)</u>	<u>Phenanthrene/ ppb)</u>	<u>Phenanthrene(ug)</u>	<u>Phenanthrene Con (ug/kg dry sand)</u>
1747.567156	69.90268623	1210.323404	168.9609253	6.758437014	117.0183141
736.8680739	29.47472296	572.5306739	53.3950104	2.135800416	41.48677676
241.8469971	9.673879885	269.9107381	16.48920412	0.659568165	18.40259878
45.29800896	1.811920358	187.1109258	-0.67093692	-0.026837477	-2.771416033
74.76792992	2.990717197	274.8378569			
169.8871952	6.795487808	171.1066441	5.3926455	0.21570582	5.431353864
350.1153101	14.0046124	333.0333534	27.93281896	1.117312758	26.56999023
476.2000845	19.04800338	514.4778855	43.93468624	1.75738745	47.46623366
818.6634675	32.7465387	675.8949276	88.26439726	3.53057589	72.87177304
882.7647306	35.31058922	567.4200047	116.554756	4.66219024	74.91860278
460.6273267	18.42509307	520.7182961	37.0243015	1.48097206	41.8542932
231.1634205	9.246536819	450.0019101	18.54298718	0.741719487	36.09731866



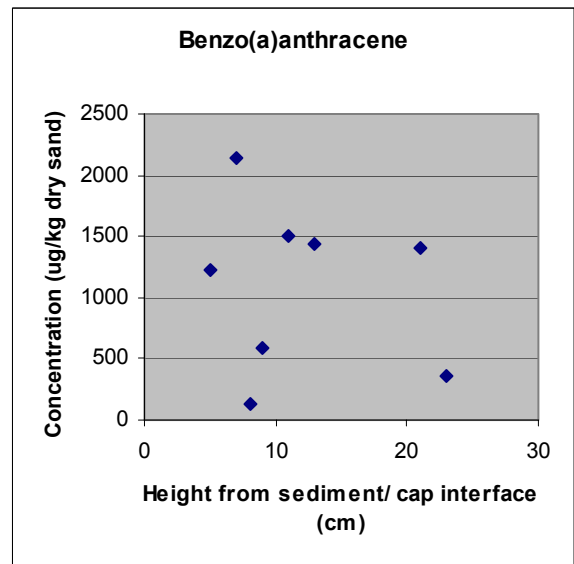
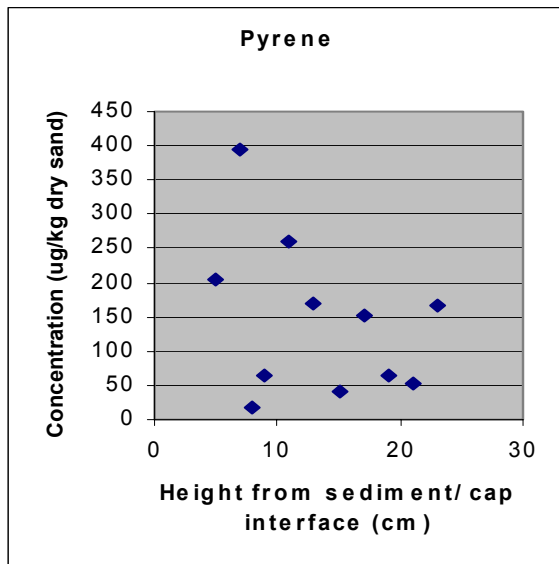
SP-2A (4'')

<u>Anthracene(ppb)</u>	<u>Anthracene(ug)</u>	<u>Anthracene Con (ug/kg dry sand)</u>	<u>Fluoranthene (ppb)</u>	<u>Fluoranthene (ug)</u>	<u>Fluoranthene Con (ug/kg dry sand)</u>
2.18013495	0.087205398	1.509909559	499.8064063	19.99225625	346.1540171
1.66666963	0.066666785	1.294966517	209.855899	8.394235958	163.0535282
1.75839805	0.070335922	1.962441218	77.56759167	3.102703667	86.56847583
			43.19652312	1.727860925	178.4303907
7.4741115	0.29896446	27.47392885	46.06296957	1.842518783	169.3218985
			57.35675681	2.294270272	57.76846312
			168.4002987	6.736011946	160.1841295
			366.6229668	14.66491867	396.0927663
			174.7217129	6.988868518	144.2516055
			360.5241628	14.42096651	231.7362884
			202.5946343	8.10378537	229.0240431
			121.9246055	4.876984219	237.3485617



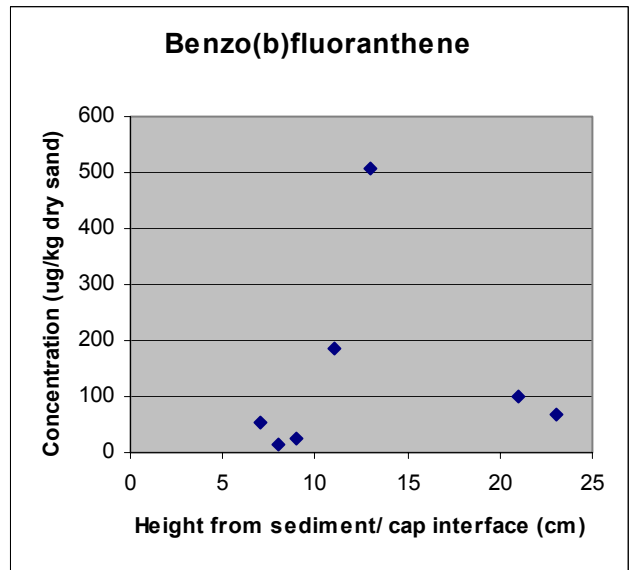
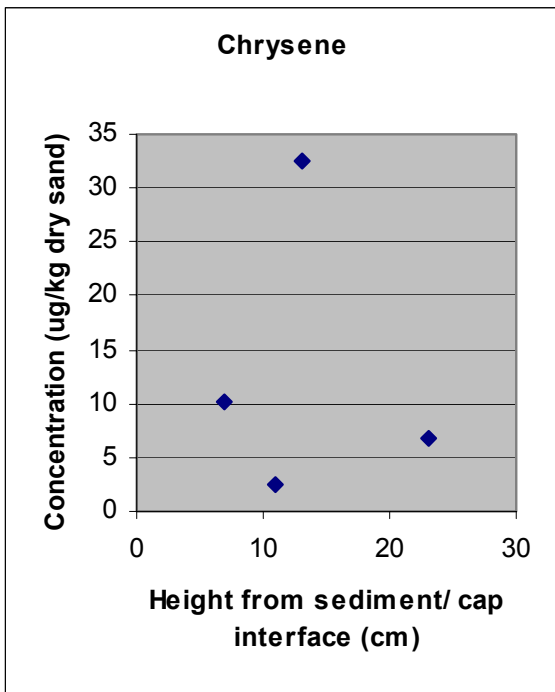
SP-2A (4")

<u>Pyrene(ppb)</u>	<u>Pyrene(ug)</u>	<u>Pyrene Con (ug/kg dry sand)</u>	<u>Benzo(a)anthracene(ppb)</u>	<u>Benzo(a)anthracene (ug)</u>	<u>Benzo(a)anthracene Con (ug/kg dry sand)</u>
296.5356951	11.8614278	205.373562	1767.019941	70.68079763	1223.79594
508.6351024	20.3454041	395.198555	2761.860918	110.4744367	2145.90664
14.74956146	0.58998246	16.4610893	123.4341088	4.937364354	137.7573086
15.89464661	0.63578586	65.6554694	143.1376369	5.725505475	591.2537079
71.13377578	2.84535103	261.479146	410.7600052	16.43040021	1509.904041
169.1915151	6.7676606	170.40597	1422.797246	56.91188983	1433.010072
43.837872	1.75351488	41.6990434			
139.6768979	5.58707592	150.904373			
78.91453825	3.15658153	65.1524567			
83.52361427	3.34094457	53.6869768	2175.770167	87.03080667	1398.5329
148.4225627	5.93690251	167.784974	313.151189	12.52604756	354.0032128



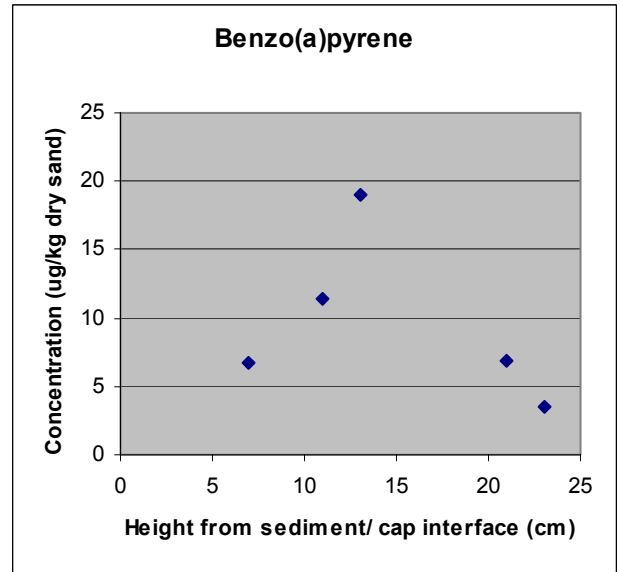
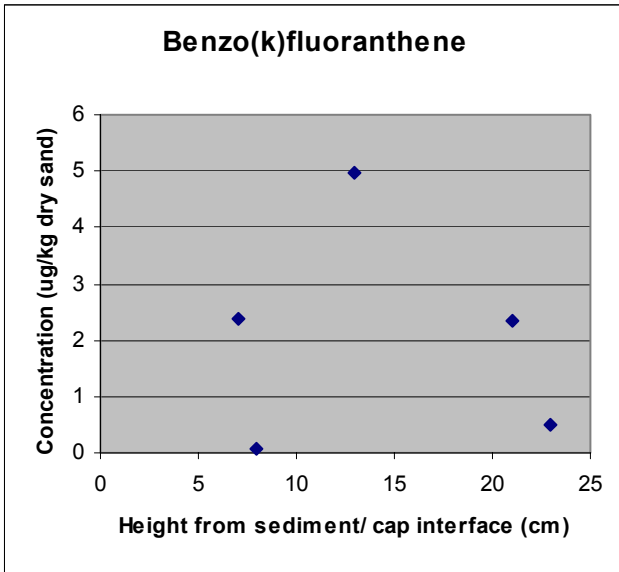
SP-2A (4'')

<u>Chrysene</u> (ppb)	<u>Chrysene</u> (ug)	<u>Chrysene</u> Con (ug/kg dry sand)	<u>Benzo(b)fluoranthene</u> (ppb)	<u>Benzo(b)fluoranthene</u> (ug)	<u>Benzo(b)fluoranthene</u> Con (ug/kg dry sand)
14.57692	0.5830768	10.09562736	78.38080835	3.135232334	54.28468169
-1.81075	-0.07243	-1.406910875	16.21291106	0.648516442	12.59708382
-0.81185	-0.032474	-0.906058595	21.47324282	0.858929713	23.96498153
0.615713	0.0246285	2.543305223	44.75406668	1.790162667	184.8640822
8.82202	0.3528808	32.42867563	137.6981017	5.507924068	506.1615483
-2.00227	-0.080091	-1.653085807	123.1259285	4.925037141	101.6537245
10.62403	0.4249612	6.828871576	103.0384548	4.121538192	66.23064842



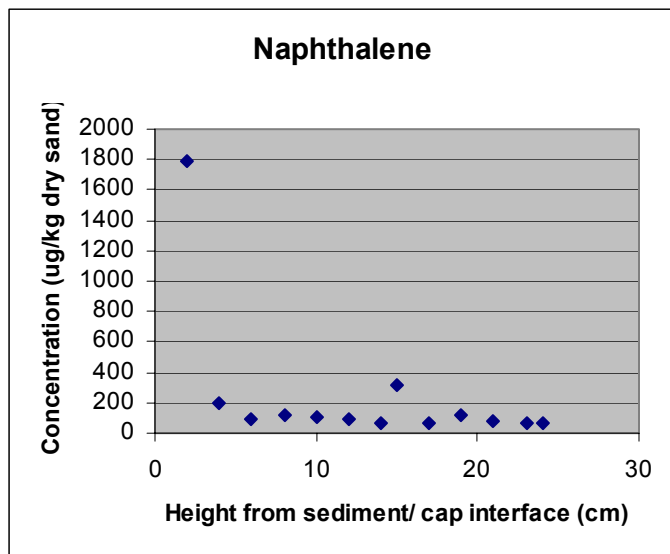
SP-2A (4'')

<u>Benzo(k)fluoranthene</u> (ppb)	<u>Benzo(k)fluoranthene</u> (ug)	<u>Benzo(k)fluoranthene</u> Con (ug/kg dry sand)	<u>Benzo(a)pyrene</u> (ppb)	<u>Benzo(a)pyrene</u> (ug)	<u>Benzo(a)pyrene</u> Con (ug/kg dry sand)
3.438363712	0.137534548	2.381328843	9.811916973	0.392476679	6.795500083
0.080356332	0.003214253	0.062435145		0	
-0.237258324	-0.009490333	-0.264789599	-0.383642226	-0.015345689	-0.428159777
-0.082056564	-0.003282263	-0.338948223	2.772976373	0.110919055	11.45423802
1.34913962	0.053965585	4.959273878	5.182469188	0.207298768	19.0501292
				0	
				0	
				0	
2.848219664	0.113928787	2.351512313	8.356453999	0.33425816	6.899153431
0.76035122	0.030414049	0.488735535	5.493414351	0.219736574	3.531035042



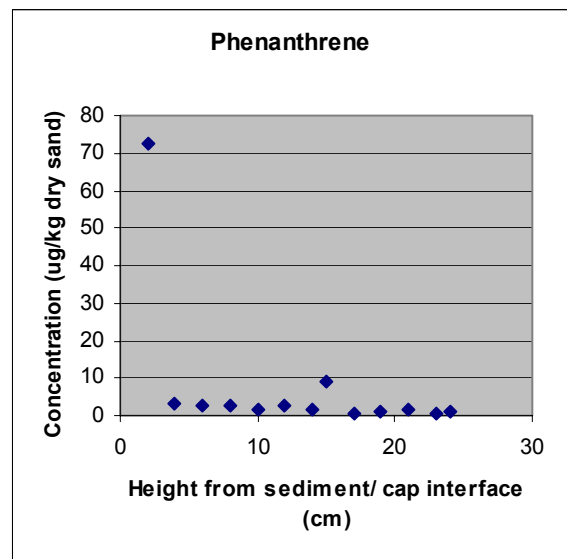
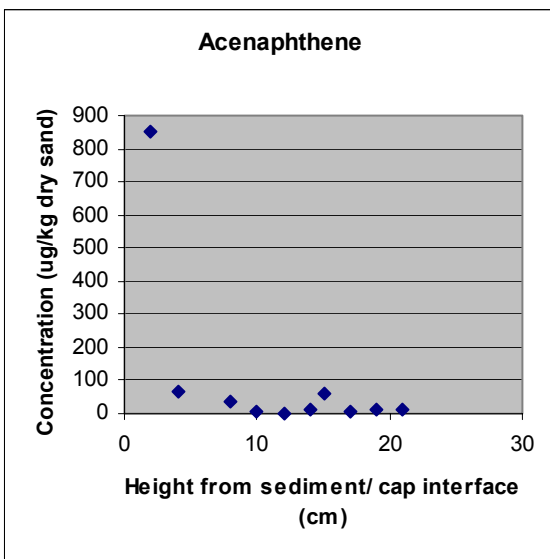
SP-1 (8")

<u>Naphthalene(ppb)</u>	<u>Naphthalene (ug)</u>	<u>Naphthalene</u> <u>Con (ug/kg dry sand)</u>
1898.854798	75.95419191	1789.039599
148.8621404	5.954485617	194.1965943
106.4835532	4.259342127	91.82321185
74.20806693	2.968322677	118.6026739
69.64807149	2.78592286	105.1305347
95.53986042	3.821594417	96.37996835
105.4407394	4.217629576	68.41867096
94.09963963	3.763985585	311.1133406
57.76875004	2.310750002	68.3677876
99.0027088	3.960108352	118.174254
60.94796908	2.437918763	78.79940068
56.78223251	2.2712893	63.5849474
46.65094634	1.866037854	63.69031599



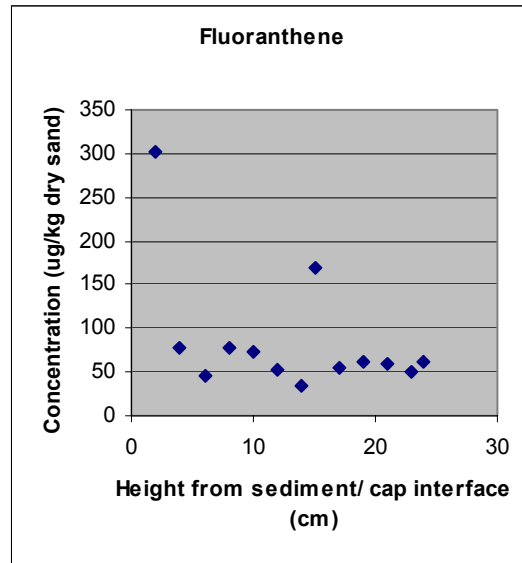
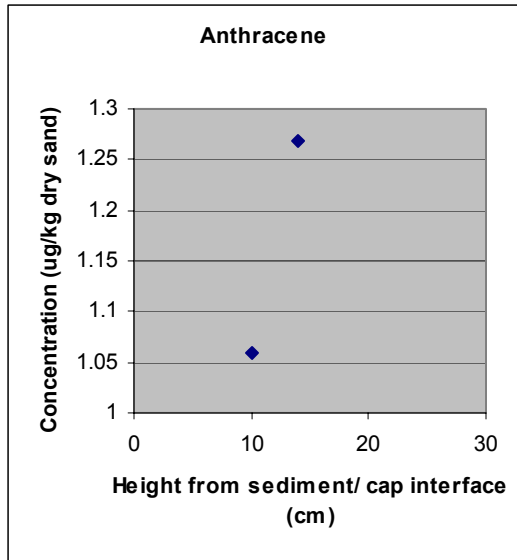
SP-1 (8")

<u>Acenaphthene</u> <u>ppb</u>	<u>Acenaphthene</u> <u>(ug)</u>	<u>Acenaphthene</u> <u>Con (ug/kg dry sand)</u>	<u>Phenanthrene</u> <u>(ppb)</u>	<u>Phenanthrene</u> <u>(ug)</u>	<u>Phenanthrene</u> <u>Con (ug/kg dry sand)</u>
902.831823	36.11327292	850.6189543	77.15382352	3.086152941	72.69183808
50.77457248	2.030982899	66.23745315	2.532954014	0.101318161	3.304339448
			2.8579076	0.114316304	2.464439317
24.26478592	0.970591437	38.78107341	1.660203668	0.066408147	2.653412255
2.34169888	0.093667955	3.534685889	0.901009701	0.036040388	1.360032369
1.56780256	0.062712102	1.581588674	2.845083151	0.113803326	2.87010074
22.8142912	0.912571648	14.80379872	2.455908857	0.098236354	1.593596754
18.26846048	0.730738419	60.39939994	2.767856765	0.110714271	9.151120747
6.29803488	0.251921395	7.453557688	0.494680013	0.019787201	0.58544071
8.62935392	0.345174157	10.3003996	1.048819788	0.041952792	1.251920251
7.1352352	0.285409408	9.225118834	1.427395753	0.05709583	1.845474616
-8.26655584	-0.330662234	-9.256918847	0.469559105	0.018782364	0.525813968
			0.634954113	0.025398165	0.86687262



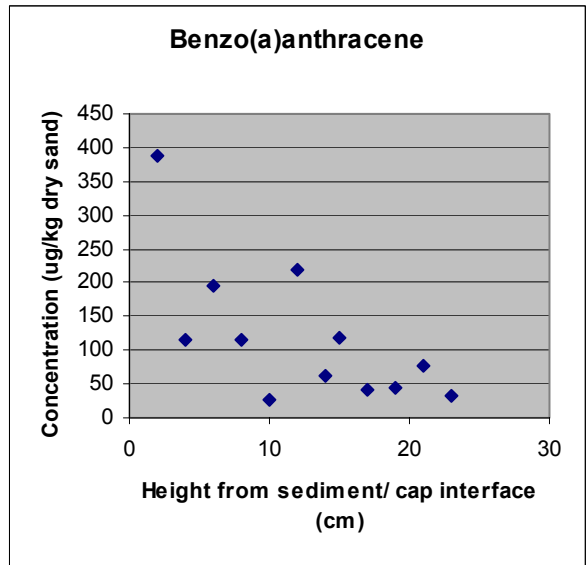
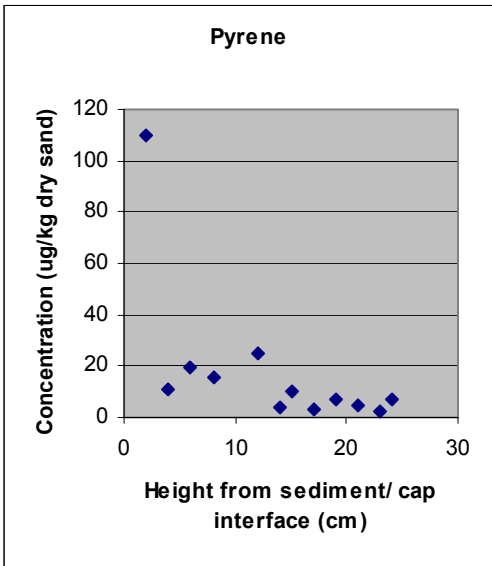
SP-1 (8")

<u>Anthracene(ppb)</u>	<u>Anthracene(ug)</u>	<u>Anthracene</u> <u>Con (ug/kg dry</u> <u>sand)</u>	<u>Fluoranthene</u> <u>(ppb)</u>	<u>Fluoranthene</u> <u>(ug)</u>	<u>Fluoranthene</u> <u>Con (ug/kg dry</u> <u>sand)</u>
			319.668823	12.78675292	301.1816298
			59.6199141	2.384796563	77.77655373
			53.322456	2.13289824	45.98117764
			48.5263187	1.94105275	77.55694758
1.125192475	0.045007699	1.060119972	47.8487034	1.913948137	72.22539936
			51.6962233	2.06784893	52.15080219
1.47104	0.0588416	1.268511554	53.1674939	2.126699755	34.49946662
			51.4822064	2.059288258	170.2110794
			46.0834363	1.84333745	54.53852783
			52.2108025	2.088432101	62.32125076
			46.5558682	1.862234728	60.19190742
			45.9368398	1.83747359	51.44023773
			44.4313306	1.777253225	60.65998033



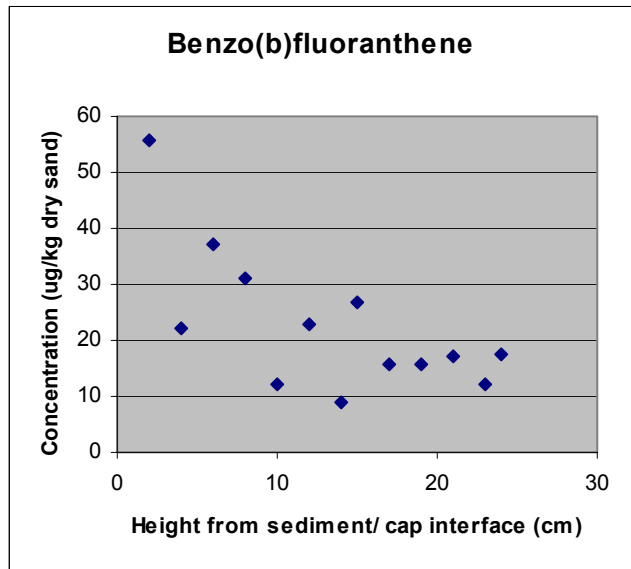
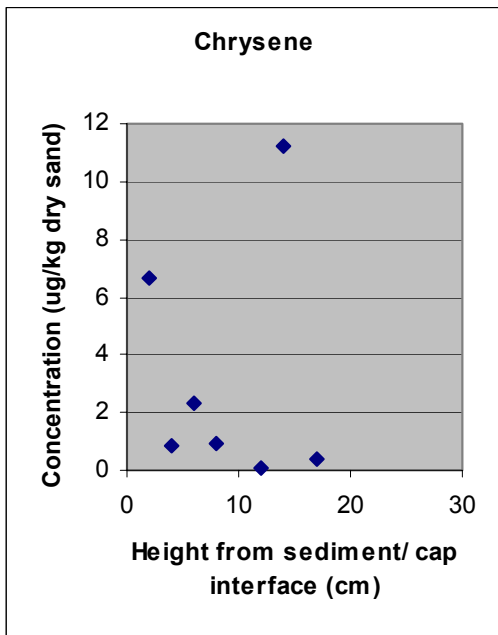
SP-1 (8")

		<u>Pyrene</u>	<u>Benzo(a)anthracene</u>	<u>Benzo(a)anthracene(</u>	<u>Benzo(a)anthracene</u>
<u>Pyrene(ppb)</u>	<u>Pyrene(ug)</u>	<u>Con (ug/kg dry sand)</u>	<u>(ppb)</u>	<u>ug)</u>	<u>Con (ug/kg dry sand)</u>
116.4514085	4.65805634	109.7167521	410.3991335	16.41596534	386.664795
8.087869856	0.32351479	10.55094853	88.13645764	3.525458306	114.9775212
22.99249978	0.91969999	19.82696027	227.7233787	9.108935148	196.371096
9.52840408	0.38113616	15.22872443	71.54861474	2.861944589	114.3522176
			17.63688884	0.705475554	26.62206598
24.99748166	0.99989927	25.21729131	217.3117238	8.69246895	219.2226047
5.569857704	0.22279431	3.614184268	97.16018638	3.886407455	63.04556342
3.015824208	0.12063297	9.970953638	35.69174352	1.427669741	118.0044642
2.454457784	0.09817831	2.904785863	35.5969991	1.423879964	42.12810684
5.613038176	0.22452153	6.699984347	36.04409987	1.441763995	43.02391992
3.818138528	0.15272554	4.936456985	59.69868099	2.38794724	77.18420079
1.969511184	0.07878045	2.20546568	29.48987608	1.179595043	33.02286889
5.184968984	0.20739876	7.078791298			



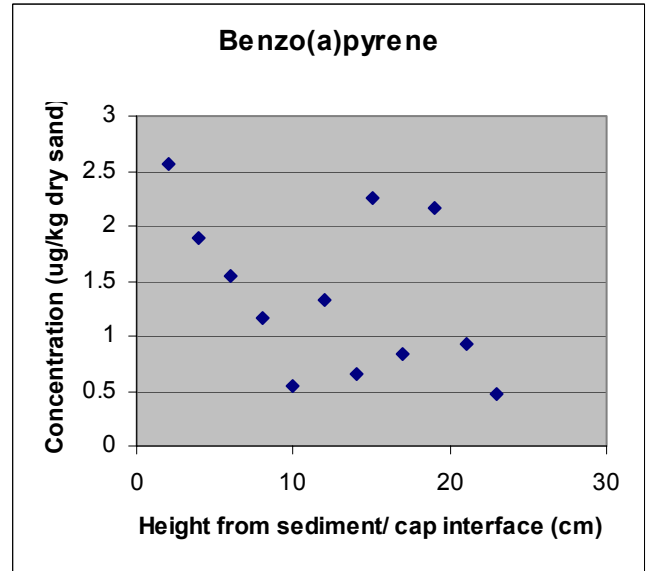
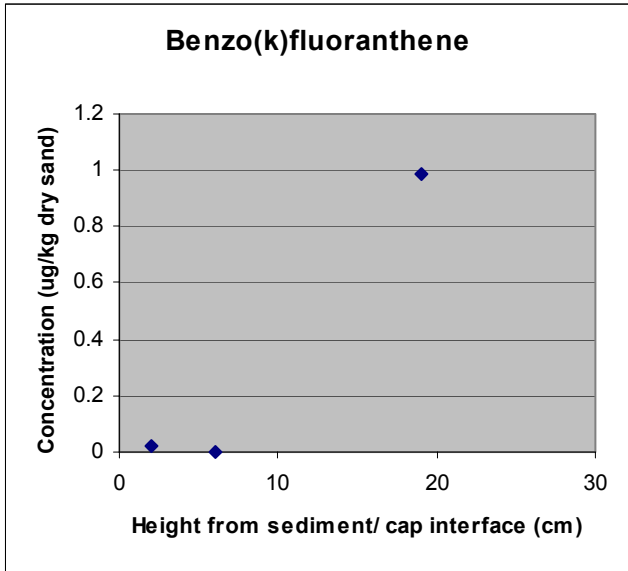
SP-1 (8")

		<u>Chrysene</u>		<u>Benzo(b)fluoranthene</u>		<u>Benzo(b)fluoranthene</u>
<u>Chrysene</u>	<u>Chrysene</u>	<u>Con (ug/kg dry</u>		<u>Benzo(b)fluoranthene</u>	<u>Benzo(b)fluoranthene</u>	<u>Con (ug/kg dry sand)</u>
<u>(ppb)</u>	<u>(ug)</u>	<u>sand)</u>		<u>(ppb)</u>	<u>(ug)</u>	
7.068341	0.282734	6.659562581		59.25138524	2.37005541	55.82473953
0.634063	0.025363	0.827160777		17.0774627	0.683098508	22.27823062
2.705664	0.108227	2.333156347		42.93312278	1.717324911	37.02221715
0.59505	0.023802	0.951035895		19.3543466	0.774173864	30.93298819
-0.82813	-0.03313	-1.250027492		8.11492049	0.32459682	12.24909624
0.080138	0.003206	0.080842473		22.72094945	0.908837978	22.92074093
17.3037	0.692148	11.22807424		14.00962571	0.560385028	9.090603662
-0.02581	-0.00103	-0.085317391		8.07079265	0.322831706	26.68375004
0.347482	0.013899	0.411235164		13.32583193	0.533033277	15.7707696
-1.10925	-0.04437	-1.324051188		13.18794584	0.527517834	15.74174768
-0.45768	-0.01831	-0.591728554		13.21214195	0.528485678	17.08192878
				10.69101278	0.427640511	11.97183441
				12.84256682	0.513702673	17.53334505



SP-1 (8")

<u>Benzo(k)fluoranthene</u>		<u>Benzo(k)fluoranthene</u>	<u>Benzo(k)fluoranthene</u>	<u>Benzo(a)pyrene</u>		<u>Benzo(a)pyrene</u>	<u>Benzo(a)pyrene</u>
(ppb)		(μg)	Con ($\mu\text{g}/\text{kg}$ dry sand)	(ppb)		(μg)	Con ($\mu\text{g}/\text{kg}$ dry sand)
0.019811768		0.000792471	0.018666007	2.713361746		0.10853447	2.556441712
				1.45464873		0.058185949	1.897647235
-0.000597712		-2.39085E-05	-0.000515421	1.787388896		0.071495556	1.541306468
-0.26961908		-0.010784763	-0.430917354	0.732495375		0.029299815	1.17070709
-0.179841932		-0.007193677	-0.271463058	0.364216112		0.014568644	0.549767335
				1.321057998		0.05284232	1.33267442
				1.015035875		0.040601435	0.658639212
				0.683053114		0.027322125	2.258318278
				0.707581662		0.028303266	0.83740418
0.829299164		0.033171967	0.989890189	1.809429123		0.072377165	2.159819054
-0.07725982		-0.003090393	-0.099888932	0.710919931		0.028436797	0.919145713
				0.429583007		0.01718332	0.48104859
-0.229793716		-0.009191749	-0.31372642				



Appendix F
Depth of Pore Water migration and Retardation Factors

<u>Column Name</u>	<u>Collection method</u>	<u>Num. of Days</u>	<u>Porosity</u>	<u>ΔL_{sed} (cm)</u>	<u>ΔL_{sedpw} calc (cm)</u>	<u>ΔL_{sedpw} exp (cm)</u>	<u>Rf exp</u>	<u>log Koc</u>	<u>Koc</u>	<u>Rf calc</u>
L-29-1 (4")	intact core	30	0.42	4.29	10.22					
Naphthalene					10.22	6	1.70	3.10	1258	4.76
Acenaphthylene						UD		3.17	1470	
Phenanthrene								4.40	25118	
Anthracene								4.37	23493	
Fluoranthene								4.69	49096	
Pyrene						UD		4.80	63095	
Benzo(a)anthracene								5.55	357537	
Chrysene								4.66	45800	
Benzo(b)fluoranthene								6.16	1450000	
Benzo(k)fluoranthene								6.18	1530000	
Benzo(a)pyrene								6.00	968774	
L-29-2 (4")	intact core	32	0.42	2.22	5.29					
Naphthalene					5.29	3	1.76	3.10	1258	4.76
Acenaphthylene								3.17	1470	
Phenanthrene						UD		4.40	25118	
Anthracene						UD		4.37	23493	
Fluoranthene					5.29	4	1.32	4.69	49096	169.80
Pyrene						UD		4.80	63095	
Benzo(a)anthracene					5.29	2	2.65	5.55	357537	1233.92
Chrysene								4.66	45800	
Benzo(b)fluoranthene					5.29	2	2.65	6.16	1450000	5002.92
Benzo(k)fluoranthene						UD		6.18	1530000	
Benzo(a)pyrene								6.00	968774	
L-29-4 (6")	intact core	30	0.42	5.4	12.85					
Naphthalene					12.85	4	3.21	3.10	1258	4.76
Acenaphthylene					12.85	3	4.28	3.17	1470	5.49
Phenanthrene					12.85	3	4.28	4.40	25118	87.08
Anthracene								4.37	23493	

Fluoranthene			12.85	2	6.43	4.69	49096	169.80
Pyrene						4.80	63095	
Benzo(a)anthracene						5.55	357537	
Chrysene						4.66	45800	
Benzo(b)fluoranthene			12.85	3	4.28	6.16	1450000	5002.92
Benzo(k)fluoranthene						6.18	1530000	
Benzo(a)pyrene						6.00	968774	
L-29-6 (8")	reconstituted	33	0.42	4.29	10.21			
Naphthalene			10.21	10	1.02	3.10	1258	4.76
Acenaphthylene			10.21	10	1.02	3.17	1470	5.49
Phenanthrene					UD	4.40	25118	
Anthracene						4.37	23493	
Fluoranthene			10.21	15	0.68	4.69	49096	169.80
Pyrene					UD	4.80	63095	
Benzo(a)anthracene						5.55	357537	
Chrysene					UD	4.66	45800	
Benzo(b)fluoranthene			10.21	2	5.11	6.16	1450000	5002.92
Benzo(k)fluoranthene					UD	6.18	1530000	
Benzo(a)pyrene					UD	6.00	968774	
SP-3B (4")	intact core	38	0.42	7	16.6			
Naphthalene			16.6	13	1.28	3.10	1258	4.76
Acenaphthylene			16.6	12	1.38	3.17	1470	5.49
Phenanthrene			16.6	18	0.92	4.40	25118	87.08
Anthracene			16.6	8	2.08	4.37	23493	81.47
Fluoranthene			16.6	18	0.92	4.69	49096	169.80
Pyrene			16.6	21	0.79	4.80	63095	218.10
Benzo(a)anthracene			16.6	22	0.75	5.55	357537	1233.92
Chrysene			16.6	14	1.19	4.66	45800	158.43
Benzo(b)fluor			16.6	14	1.19	6.16	1450000	5002.92

anthene										92
Benzo(k)fluoranthene					16.6	UD	6.18	1530000	5278.	92
Benzo(a)pyrene					16.6	UD	6.00	968774		
SP-2A (4")	intact core	106	0.42	10.8	25.702					
Naphthalene					25.702	23	1.12	3.10	1258	4.76
Acenaphthylene					25.702	23	1.12	3.17	1470	5.49
Phenanthrene					25.702	23	1.12	4.40	25118	87.08
Anthracene						UD		4.37	23493	
Fluoranthene						UD		4.69	49096	
Pyrene						UD		4.80	63095	
Benzo(a)anthracene						UD		5.55	357537	
Chrysene						UD		4.66	45800	
Benzo(b)fluoranthene						UD		6.16	1450000	
Benzo(k)fluoranthene						UD		6.18	1530000	
Benzo(a)pyrene						UD		6.00	968774	
SP-1 (1")	reconstituted	65	0.42	10.8	25.702					
Naphthalene					25.702	15	1.71	3.10	1258	4.76
Acenaphthylene					25.702	14	1.84	3.17	1470	5.49
Phenanthrene					25.702	2	12.8	4.40	25118	87.08
Anthracene						UD		4.37	23493	81.47
Fluoranthene					25.702	14	1.84	4.69	49096	169.80
Pyrene					25.702	12	2.14	4.80	63095	218.10
Benzo(a)anthracene						UD		5.55	357537	
Chrysene						UD		4.66	45800	
Benzo(b)fluoranthene						UD		6.16	1450000	
Benzo(k)fluoranthene						UD		6.18	1530000	
Benzo(a)pyrene						UD		6.00	968774	

Vita

Melanie Harris was born and raised in New Orleans, Louisiana. She pursued chemical engineering by first getting an undergraduate degree from Carnegie Mellon University located in Pittsburgh, Pennsylvania, on May 24, 2003. She continued her chemical engineering studies at Louisiana State University to obtain a master's degree. She finished her studies at Louisiana State University on August 11, 2005, and began working in industry.