



PORTLAND HARBOR RI/FS
**DRAFT MONITORED NATURAL RECOVERY (MNR)
TECHNICAL MEMORANDUM – STEP 2 DATA
EVALUATION METHODS**

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LIST OF ACRONYMS

CRS	Constant Rate of Supply
CIC	Constant Initial Concentration
FSP	Field Sampling Plan
FSR	Field Sampling Report
MNA	Monitored Natural Attenuation
MNR	Monitored Natural Recovery
Programmatic Work Plan	Portland Harbor RI/FS Programmatic Work Plan
RI/FS	Remedial Investigation/Feasibility Study
Site	Portland Harbor Superfund Site
SMA	Sediment Management Area
SMWG	Sediment Management Work Group
SOW	Statement of Work
USEPA	United States Environmental Protection Agency

1.0 INTRODUCTION

This technical memorandum presents the proposed approach for further evaluation of Monitored Natural Recovery (MNR) for the Portland Harbor (Site) Remedial Investigation/Feasibility Study (RI/FS). It has been prepared in general accordance with the Portland Harbor RI/FS Programmatic Work Plan (Programmatic Work Plan) specifically, Appendix A, Attachment A4 of that document. This technical memorandum uses the term “MNR” as equivalent to the definition previously used in this project related to the term “natural attenuation.” Reasons for this proposed change in terminology are discussed in Section 1.1.

1.1 DEFINITION OF MONITORED NATURAL RECOVERY (MNR)

At the time the project Statement of Work (SOW) was completed the term MNR was commonly applied to sediment sites, while the term “natural attenuation” was commonly applied to all types of hazardous waste sites and matrices. Since the SOW, EPA has drafted two rounds of draft guidance titled *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (USEPA 2005), which have consistently used the term MNR when discussing sediment remediation technologies. Further, consistent with this guidance, most of sediment Superfund sites in the nation are also now commonly using MNR to refer to this type of remedial technology. For these reasons, it is proposed that the term MNR be used for the remainder of this project and consistent with USEPA (2005) guidance is defined as follows:

“MNR is a remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediments...These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants...As used for the purposes of this guidance, MNR is similar in some ways to the Monitored Natural Attenuation (MNA) remedy used for groundwater and soils...The key difference between MNA for groundwater and MNR for sediment is the type of processes most often being relied upon to reduce risk.”

It should be noted that USEPA 2005 is a peer review draft document and should not be interpreted as final guidance. However, USEPA Region 10 has noted the relevance of this draft guidance in comments on a previous MNR technical memorandum (USEPA comment letter dated June 17, 2004), and the draft guidance provides general information on the current status of MNR approaches within USEPA that are relevant and useful for this project.

1.2 BACKGROUND ON MNR AND THE SITE RI/FS PROCESS

The Programmatic Work Plan describes a three step approach for evaluating MNR processes at the Site:

Step 1 - Identify areas that have basic processes that are potentially suitable for MNR based on general information about the river system.

Step 2 - Conduct select sampling (in Round 2) within a few areas that appear characteristic of the range of potential MNR processes at the Site and conduct simple data evaluations. Eliminate from future evaluations the types of areas that have a low probability of having processes that support MNR.

Step 3 - Conduct detailed sampling (in Round 3) and modeling in Sediment Management Areas (SMAs) that appear to have suitable processes for MNR (based on Step 2 results) to determine viability and rate of MNR as a remedial technology.

This work was initiated by submittal of the following technical memoranda:

- Draft Natural Attenuation Technical Memorandum – Step 1 Evaluation and Step 2 Field Sampling Plan and Data Evaluation Methods, March 2004
- Revised Draft Natural Attenuation Technical Memorandum – Step 2 Field Sampling Plan, July 2004
- Final Natural Attenuation Technical Memorandum – Sedimentation Field Sampling Plan, September 2004.

EPA provided comments in June 2004 on the first memorandum regarding the collection of field data and indicated that they would postpone commenting on data evaluation methods until a later date. This resulted in the subsequent memoranda focusing on the collection of field data relevant primarily to sedimentation processes in the river. The EPA-approved field sampling, described in the Final Field Sampling Plan (September 2004), was conducted in October 2004 and included collection of subsurface sediment cores at four locations for the sampling and analysis of radioisotopes and select bulk chemistry as detailed in the Final Field Sampling Plan (September 2004). The laboratory analysis results for these core samples were obtained in March of 2005.

EPA provided later comments (February 24, 2005) on those portions of the March 2004 memorandum above that discuss data evaluation methods. These February 2005 comments are addressed by the remainder of this document.

1.3 PURPOSE OF THIS MEMORANDUM

Due to the nature and timing of MNR discussions with EPA and comments on the above memoranda, it now appears that the three step process originally envisioned for the RI/FS and described in the Programmatic Work Plan requires modification. To this end, this memorandum was prepared with three primary objectives:

- Redefine the overall sequence of tasks for MNR evaluation for the RI/FS consistent with the current project conditions (discussed in Section 1.4)
- Describe the methods for MNR evaluation consistent with EPA's most recent comments and current project conditions (Sections 2 and 3)
- Present preliminary results of the subsurface core sampling conducted in October 2005 (Section 4).

1.4 OVERALL SEQUENCE OF MNR TASKS

Because data specifically designed to help understand some processes potentially relevant to MNR have been collected, data evaluation procedures can benefit from analysis of these data. Consequently, we propose to conduct the following sequence and timing of activities:

1. Submit a Step 2 MNR Data Evaluation Methods Memorandum that includes a preliminary analysis of recently collected data (this document)
2. Conduct a Step 2 MNR evaluation using historical and recently collected data consistent with the methods in Item 1 above and identify data that is needed in Round 3 of the RI/FS for final evaluations of MNR for the project FS (Summer/Fall 2005)
3. Conduct data collection for MNR evaluations in Round 3 field efforts for the RI/FS (2006)
4. Conduct Step 3 MNR evaluations (early 2007).

Although specific dates are not yet proposed for each of these activities, it is consistent with the overall expected progress of the RI/FS with the Step 2 MNR evaluation being completed prior to start of Round 3 data collection in 2006 and the Step 3 MNR evaluations being completed prior to FS completion in late 2007.

2.0 DESCRIPTION OF MNR AS A REMEDIAL TECHNOLOGY

This section discusses MNR as a remedial technology in the context of a sediment remediation project. This description is provided as an update to the information in the Programmatic Work Plan Appendix A, Attachment A4.

2.1 CONCEPT

Consistent with the definition provided in Section 1.1, MNR is a remedy for contaminated sediment that typically uses ongoing, naturally occurring processes to contain, destroy, or reduce the bioavailability or toxicity of contaminants in sediments. These processes may include physical, biological, and chemical mechanisms that act together to reduce the risk posed by the contaminants. Generally, MNR occurs in a specified time frame over which attainment of site-specific sediment remedial goals is expected to occur. MNR includes a monitoring component to confirm that decreases in sediment chemical concentrations or exposures occur as expected. It also includes contingency planning procedures in the event that the effectiveness of natural recovery processes is not confirmed. Such contingency planning might involve a range of activities from additional monitoring to implementing more active remedial technologies.

As summarized by USEPA (2005), MNR has been selected as a remedial technology for approximately a dozen Superfund contaminated sediment sites containing a variety of chemical contaminants. It has usually, although not always, been used in combination with other remedial technologies such as dredging and/or capping of higher-concentration sediment deposits. For example:

- MNR was selected as part of the final remedy for portions of the Eagle Harbor Superfund Site in Washington to address “moderate effect” sediment areas containing mercury and PAHs (USEPA 1994)
- In Lake Hartwell, South Carolina, MNR was used to remediate residual sediment PCB contamination following upstream source control efforts (Magar et al. 2003)
- MNR has been an integral part of the overall remedy for Bellingham Bay, Washington (Washington State 2002).

USEPA has noted that although partial natural recovery has been observed in many areas, there is not yet an extensive body of literature documenting complete recovery at contaminated sediment sites in general. However, as noted by USEPA (e.g., Swindoll et al. 2000; USEPA, 2001; USEPA, 2001b; Washington State, 2002), monitoring results from some areas are promising.

2.2 MECHANISMS OF NATURAL RECOVERY

MNR can include several mechanisms that affect the surface and near surface of the sediment bed. General mechanisms for MNR in sediments are illustrated in Figure 1. USEPA (2005) defines MNR mechanisms in the following hierarchy of preference:

- Conversion to a less toxic chemical form through transformation processes such as biodegradation
- Reduction of chemical mobility or bioavailability through processes binding contaminants to the sediment matrix
- Reduction of exposure levels by a decrease in chemical concentrations in the near-surface sediment through burial or mixing-in-place with cleaner sediment
- Reduction of exposure levels by a decrease in chemical concentrations in the near-surface sediment through dispersion of particle-bound chemicals and/or dissolved transport of chemicals to the water column.

As noted by USEPA (2005) mechanisms that reduce toxicity through destructive processes (e.g., biodegradation) or reduce bioavailability through increased sorption are usually preferable in Superfund projects to mechanisms that reduce exposure through burial or mixing because destructive/sorptive mechanisms generally have a higher degree of permanence. However, some chemicals are not easily transformed or destroyed in sediment. For such chemicals, risk reduction through sedimentation burial can be an acceptable sediment management option. The last of the four mechanisms (dispersion) typically is the least preferable mechanism for Superfund projects. If dispersion is estimated to be the primary mechanism of MNR at a site, USEPA indicates that project managers should carefully evaluate the effects of downstream loading before selecting MNR as a remedial alternative. However, at most sites, a variety of natural processes are occurring that may reduce risk. For this reason, USEPA (2005) indicates that all of the above mechanisms are valid as part of a potentially viable basis for selecting MNR.

The mechanisms of natural recovery are interrelated, but they do not always work in concert. For example, if sediments from the water column containing high chemical concentrations are settling onto bed sediments, these chemical inputs may overwhelm any decreases in sediment chemical concentrations caused by burial, diffusion/advection, and/or transformation. Similarly, groundwater advection can either decrease chemical concentrations in surface sediments (through dissolution and transport to overlying surface water) or increase chemical concentrations in sediments (where the groundwater itself is contaminated from up gradient sources). For this reason, effective source control is a necessary first step in any MNR scenario.

USEPA Region 10 has implied in recent comments on MNR for this project (February 24, 2005 comment letter) that, "...the loss of chemicals [in sediments] through the uptake of contaminants by biological organisms..." should be addressed by MNR models. Although USEPA (2005) notes that chemical bioaccumulation in organisms is a part of chemical cycling in aquatic ecosystems, it is generally not portrayed by USEPA or most other agencies or researchers as an acceptable mechanism of natural recovery in sediments. This concept should not be confused with the concept that the biological systems recovery is an important part of MNR for sediments, which is one of the primary lines of evidence currently recommended for evaluation by USEPA (2005) and Sediment Management Work Group (SMWG) as discussed further in Sections 2.3 and 2.4. Consequently, reduction in sediment concentrations that are primarily driven by

movement of chemicals to (for example) biological tissues in water column organisms would not be considered a viable MNR mechanism. It should also be noted that the risks associated with the uptake of chemicals from sediments under existing conditions is currently being assessed through the project risk assessments, which include a food web model designed to evaluate this mechanism. The integration of MNR evaluations with risk assessments and associated modeling efforts to understand potential future risks from uptake of chemicals in sediments to organisms is discussed further in Section 3.

Some important aspects of each of these natural attenuation mechanisms are discussed in the following subsections.

2.2.1 Chemical Transformation/Binding

Mechanisms of chemical transformation or binding to less toxic forms differ substantially between organic and inorganic chemicals.

For organic compounds, degradation or biodegradation of chemicals from one form to another is usually the key process examined for most MNR evaluations. Degradation refers to the breakdown of chemicals due to physical and/or chemical processes not mediated by microorganisms, and is often slow in comparison to biodegradation. During biodegradation, a chemical change is facilitated by microorganisms living in the sediment. Biodegradation has been observed for a variety of organic compounds and matrices (Aronson and Howard 1997) in both laboratory and field tests. Biodegradation rates of many organic compounds vary widely in anaerobic versus aerobic environments, often being slower in anaerobic environments (Aronson and Howard 1997) such as those occurring in subsurface sediments. For example, Aronson and Howard (1997) reported that benzene often does not degrade under anaerobic conditions but has aerobic half-lives (the time it takes for the chemical concentration to decrease by one-half) from 0.02 to 1.46 years. The depth in the sediments to which aerobic biodegradation can occur is determined by the diffusion of oxygen from water into the surface sediment porewater, the mixing of surface sediments by organisms and physical processes, and the oxygen demand of the sediments themselves (e.g., the amount and nature of sedimentary organic matter).

Chemical adsorption or binding to sediments for organic compounds is primarily determined by the molecular weight of the compound, the organic carbon content of the sediments, and the organic carbon partitioning coefficient (K_{oc}) of the organic compound. As the organic carbon content of the sediment and the K_{oc} (and usually the molecular weight) of the compound increases, so does the adsorption of the compound to the sediment matrix. Processes that increase the carbon content of surface sediment such as sedimentation of new materials may decrease the bioavailability of compounds already present in the sediments. Biodegradation of organic compounds to lower molecular weight compounds may increase availability, but in many cases, the toxicity of these smaller biodegradation products may be lower.

For inorganic chemicals, most notably metals, many environmental variables govern their chemical state, which in turn affects their mobility, toxicity, and bioavailability. This makes natural recovery difficult to predict for metals (USEPA 2005). Much of the current understanding of the metals toxicity in sediments focuses on changes caused by redox potential. Formation of relatively insoluble metals sulfides under reducing conditions can often reduce toxicity from metals in sediments if those reducing conditions are maintained. Thus, metals in surface sediments that are subsequently buried into anaerobic reducing conditions can be transformed to a less toxic sulfide-bound state. In addition, some metals, such as mercury, may form more toxic or mobile organometallic forms under certain conditions. For example, the production of methyl mercury (the bioaccumulative form of mercury) occurs more readily in reducing, anaerobic environments. As a result, the rate of conversion to methyl mercury can vary in the aerobic surface versus anaerobic subsurface sediment layers.

2.2.2 Surface Sediment Burial and Mixing

Burial, which isolates contaminated sediments under a layer of new, cleaner sediments, is often a key process for natural recovery. The most simplistic form of burial is when sediments settling out of the water column cover the existing sediment bed and remain in place permanently. While this can be the case in very quiescent areas, the process of burial is often dynamic. In many cases, the overall trend may be one of net sedimentation and burial of sediments over time, but this may include episodes of resuspension of some portion of the sediment bed due to physical disturbances such as increased river velocity, wind/wave-generated currents, and/or prop wash scour from vessels. This process causes both vertical and lateral mixing and can smooth chemical gradients that might otherwise exist in the sediment bed. Thus, it is important to distinguish between gross and net deposition rates when evaluating burial as a natural recovery mechanism and recognize that the bed sediments themselves (either from the same or other areas) may be a component of the material settling on and interacting with the sediment bed at any one time or location.

Even in quiescent areas, burial rarely results in discrete layers of sediment deposition. Biological activity in surface sediments can cause mixing and turnover of material within the upper sediment layer in a process referred to as bioturbation. Physical forces, as discussed above, can cause movement and mixing even when complete resuspension of sediment particles is not achieved. These processes also contribute to the dynamic nature of burial.

2.2.3 Dispersion

Dispersion includes both dissolved and particulate phase processes. Dissolved phase dispersion can occur through diffusion or advection of groundwater through sediments to overlying surface water. Particulate dispersion can include lateral and vertical mixing of surface sediments that results in a net dilution chemical concentrations over a wider area. Mechanisms for particulate dispersion include bioturbation and porewater/surface water exchange and pumping. As noted above, both dissolved and

particulate phase processes may be problematic from an MNR stand point if they increase risks to other areas or matrices. Once dispersed from the sediment matrix, these chemicals can be further dispersed through other processes such as dilution in the water column, bioturbation in sediments, further downstream transport, and/or volatilization to air.

2.3 EVALUATION OF MNR – STATE OF SCIENCE AND GUIDANCE

USEPA has recently formulated draft guidance for the evaluation of MNR at sediment remediation sites (USEPA 2005). USEPA is working with groups such as the SMWG to develop a weight-of-evidence approach for evaluating MNR at contaminated sediment sites (Evison 2003). The process being developed includes steps such as data assessment, modeling, and site monitoring to facilitate a thorough evaluation of MNR for contaminated sediment sites. USEPA's MNR guidance is intended to promote appropriate technical evaluation, increase certainty, and provide decision-makers with greater confidence in the selection and implementation of this remedial option as a permanent, effective means of risk reduction.

USEPA (2005) has indicated that the following types of information and conditions are generally needed to support MNR as a remedial technology at a site:

- A detailed understanding of natural processes affecting sediment and chemicals at the site
- A means to control any significant ongoing chemical sources
- Ability to evaluate ongoing risks during the recovery period and exposure control
- Ability to monitor the natural processes and/or concentrations of chemicals in sediment or biota to determine whether recovery is occurring at the expected rate
- A predictive tool (modeling or extrapolation of existing data) to predict effects of natural processes in the future.

The USEPA and SMWG have focused on five primary lines of evidence to evaluate MNR at contaminated sediment sites. As noted in USEPA (2005), not all lines of evidence or types of information are appropriate for every site, but generally, multiple lines of evidence are needed to support MNR as a remedial technology. This is particularly true where significant sources of chemical input to the aquatic system may not have been controlled. In such cases, historical lines of evidence may not be meaningful because ongoing chemical sources may have prevented natural recovery from occurring.

The five key lines of evidence include:

Characterize contamination sources and controls – This line of evidence includes characterizing historic and current contaminant loading to the sediments. Sediment trap data often provide a cost-effective method for characterizing ongoing sources. It can be

important to distinguish between and evaluate external upland/watershed sources versus internal sources associated with legacy sediments. For external sources, this may include assessing both point and non-point sources, including the potential for future control of those sources. For internal sources, this may include evaluation of resuspension from other areas that may or may not be undergoing more active remediation. Information such as source concentrations before and after source control may also support this line of evidence.

Characterize fate and transport processes – An understanding of environmental processes affecting sediment and contaminants is needed for most MNR investigations. Key processes that may affect sediments and chemicals are discussed above. Information that can support this characterization includes studies of sedimentation/erosion, groundwater, surface sediment mixing, chemical sorption or bioavailability, chemical transformations, and bioaccumulation pathways.

Establish historical record for contaminants in sediment – The purpose of this line of evidence is to evaluate the reduction in chemical exposure based on temporal trends in sediment chemical data. This usually entails compiling data from past sampling of surface sediments, waters, and/or sources to establish a record for contaminated sediments. Where sources have been controlled or partially controlled, this information can provide an indication of the potential for future natural recovery. It is important when evaluating historical data to consider its quality relative to the data evaluations being conducted (that is, the adequacy of the quality assurance and quality control [QA/QC] measures that were applied to all phases of data collection). In addition to time-series data, sediment chemistry and/or radioisotope dating of subsurface cores can be particularly useful. Such core data can provide a history of system reactions to past reductions in source loads and provide evidence regarding the timeframe of expected future responses of the system to similar additional reductions in sources.

Corroborate MNR based on biological endpoints – The primary purpose of this line of evidence is to determine whether any reduction found in the chemical record results in similar improvements in the biological data. The biological endpoints that may be of interest are site dependent, but often include fish or invertebrate tissue chemistry, histopathology/biomarkers, sediment bioassays, and fish or benthic community analysis. As with chemistry data, the quality (as demonstrated by QA/QC documentation) of historical biological data and variations in field and laboratory techniques between sampling events should be considered.

Develop acceptable and defensible predictive tools – This final line of evidence is to determine whether evidence of past reductions (where sources have been controlled) can be expected to continue or be augmented in the future with further source controls. In a few cases, extrapolation of historical trends may be sufficient, but in most cases well-constructed computer models of varying complexity (i.e., one-, two-, or three-dimensional) can be useful tools to predict the future behavior of the system. Accurate forecasting of future trends requires sufficient measurement of key process rates,

calibration to long-term trends, and reasonable confidence that future conditions will be similar to conditions during model calibration or methods to account for changed conditions in a quantitative manner.

2.4 MONITORING AND CONTINGENCY – KEY COMPONENTS OF MNR

MNR includes monitoring and contingency response components. The key difference between MNR and “no action” is the monitoring and contingency plans that are prepared and then implemented during the natural recovery period. Selection of MNR as a remedial technology involves a prediction of future conditions. Regardless of the amount of existing data and/or detail of predictive modeling, some amount of uncertainty will exist regarding future conditions at a site. The monitoring component of MNR is needed to track the progress of changes in the matrices of interest and determine whether the expected and/or acceptable changes are actually occurring.

The monitoring plan should focus on those measures that will be used to determine the acceptability of future conditions and answer questions of scientific, regulatory, or public concern about the future environment. Thus, the monitoring plan should have measures and specific performance criteria that are tailored to each site and situation. However, some general recommendations have been made by SMWG (Patmont 2003) for all MNR monitoring programs, including:

- Statistically based sediment chemistry monitoring, including both surface and subsurface sediment samples collected at regular intervals; and,
- Statistically based biological monitoring focused on key exposure and risk endpoints such as tissue chemistry.

If MNR becomes part of a site-wide remedy, a detailed monitoring plan following these general guidelines will need to be developed. The monitoring plan should include baseline monitoring of surface sediments and/or other agreed-upon measurement endpoints at the start of the remedial action period. These data will support the determination of the actual amount of natural recovery that has occurred following RI/FS sampling.

In addition to monitoring with clear performance criteria for determination of success, it is necessary to have contingency planning procedures in the event that the expected natural recovery does not occur. Contingency plans should contain a detailed set of procedures for triggering additional activities and a description of those activities in the event that performance criteria are not met. Contingency measures often include:

- Additional analysis of existing data to clarify monitoring results and underlying processes;
- Additional or different types of monitoring, observations, or measurements to clarify results;
- Additional institutional or other controls to limit human exposures during the MNR period;

- Pilot scale testing of alternate remedial actions (e.g., enhanced natural recovery or thin-layer capping) to determine their performance relative to MNR in light of data provided by the monitoring program; and,
- Guidelines for implementing full-scale remedial technologies if MNR is shown to be insufficiently effective.

The contingency plan should allow for decisions that lead to contingency activities without necessarily proceeding through the activities in any particular order. This flexibility might be particularly important where, for example, MNR performance criteria are not achieved by a wide margin. In cases where MNR performance criteria are nearly or mostly met, the above order of activities might represent a logical sequence from low-level to high-level intervention.

3.0 PROPOSED STEP 2 MNR EVALUATION METHODS

Step 2 of the MNR evaluations will utilize data already collected for MNR evaluation (as detailed in Section 4), historical data (e.g., summarized in the Programmatic Work Plan, groundwater data review, DEQ site summaries, etc.), and data recently collected for Round 2 RI efforts (to be presented in the Round 2 Comprehensive Data Report). The overall process for the Step 2 MNR evaluations is to assess these data via each of the lines of evidence described in Section 2.3 and recommended by USEPA (2005). This Step 2 evaluation will be presented in a Technical Memorandum to EPA to be submitted in Summer/Fall of 2005. This memorandum will also present the data needs for Step 3 MNR investigations.

For each line of evidence (except the development of predictive tools which is described in Section 3.5) the general approach will be to obtain and review historical information and sampling data relevant to each line of evidence. This historical information will be compared and collated with more recent sampling data, data analyses, and information gathering efforts conducted for the RI/FS (including the radioisotope information in Section 4 below). This combined information will be assessed to determine whether it supports each of the five lines of evidence indicating MNR is a potential remedial technology, and if so, the specific locations.

3.1 CHARACTERIZATION OF HISTORICAL CONTAMINANT SOURCES AND CONTROLS

This line of evidence includes characterizing historic and current contaminant loading to the sediments to determine whether it is likely that sources might impede the use of MNR as a remedial technology. The anticipated sources of information on historical sources and source controls include:

- DEQ site summaries, including source control measures implemented at upland sites
- Limited historical surface water data (as summarized in the Programmatic Work Plan)
- Historical surface and subsurface sediment data (as summarized in the Programmatic Work Plan)
- Surface water discharge and source sampling results from DEQ for individual sites and the City of Portland outfalls
- Information from the Groundwater Data Review Report
- River TMDL studies (applicable to only a few chemicals).

Round 1 and 2 data that will help support this line of evidence includes:

- Round 2, Phase 1 and 2 surface water data
- Rounds 1 and 2 surface and subsurface sediment data
- Round 2 groundwater data.

Information from site summaries and other descriptions of historical activities at upland sites will be assessed and compared to historical data and the timing of historical data to identify any patterns of decreased or lower chemical concentrations associated with cessation of historical activities or sources. Historical data will be compared to Round 1 and 2 data in the same area to determine whether any trends in decreasing concentrations in surface waters or sediments are present.

3.2 CHARACTERIZATION OF FATE AND TRANSPORT PROCESSES

An understanding of environmental processes affecting sediment and contaminants will be necessary for this MNR evaluation. As noted in USEPA (2005) the purpose is to understand those processes that are most critical to MNR at a site. As shown in Figure 1 there are a number of processes that are expected to be critical to MNR as a remedial technology. The following historical information will be used to characterize fate and transport at the Site:

- USGS water flow, level, and current data
- Historical Army Corps bathymetry
- Army Corps dredging records
- USGS and other suspended sediment data
- Storm water and combined sewer overflow (CSO) discharges data
- Historical sediment physical data (as summarized in the Programmatic Work Plan)
- Historical hydrogeological information (as summarized in the Programmatic Work Plan)
- Information from the Groundwater Data Review Report (in terms of gradients, flows, and velocities)

The following Round 1 and 2 data and data analysis will be used to characterize fate and transport at the Site:

- Round 1 Sediment Trends Analysis (Hill and McClaren 2001)
- Round 1 bathymetry change analysis and sediment stake data
- Step 2 MNR radioisotope cores (reported in Section 4 below)
- Revised Phase 1 hydrodynamic model
- Round 1 tissue data
- Round 2 groundwater studies (in terms of gradients, flows, and velocities)

This information will be used to assess the movement of chemicals and sediments into and out of the sediment bed as shown in Figure 1. Fate and transport processes will be quantified in terms of estimated ranges of potential mass loads of sediments and water into, out, and through the sediment portion of the system wherever possible. These mass loads will be ranked as a preliminary assessment of the potential for each process to conduct chemicals through the sediment system, thereby providing a preliminary assessment of those processes that are likely to be most important to changes in sediment chemical concentrations.

3.3 HISTORICAL RECORD OF CONTAMINANTS IN SEDIMENTS

The purpose of this line of evidence is to evaluate the reduction in chemical exposure based on temporal trends in sediment chemical data. Historical data most relevant to this evaluation will be:

- Limited historical surface water chemistry data (as summarized in the Programmatic Work Plan)
- Historical surface and subsurface sediment chemistry data (as summarized in the Programmatic Work Plan).

The following Round 1 and 2 data will be critical to evaluation of this line of evidence:

- Rounds 1 and 2 surface sediment data
- Round 2 subsurface sediment data
- Round 2, Phase 1 and 2 surface water data.

Historical sediment data will be compared to Round 1 and 2 surface sediment data by comparing the sediment concentrations identified during Round 1 and 2 data against historical sediment quality at close proximity sampling stations (comparison will be limited to historical data with sufficiently high quality). Changes in surface sediment chemistry over the duration between the two sampling events will be determined. Similarly, Round 2 subsurface cores (and to the extent possible, historical sediment cores) will be examined for vertical trends in sediment chemistry, either decreasing or increasing with depth. Finally, historical surface water data is relatively sporadic and often of questionable quality (particularly in terms of detection limits). However, to the extent practicable, comparable historical and Round 2 data will be evaluated to quantify any differences in water quality over the duration in question.

3.4 HISTORICAL RECORD OF BIOLOGICAL MEASURES

The primary purpose of this line of evidence is to determine whether any reduction found in the chemical record (as discussed in Section 3.3) results in similar improvements in the biological data over time. The most applicable biological endpoints for this evaluation will be developed in consultation with USEPA. However, two primary endpoints appear appropriate for this site, given the content of the Programmatic Work Plan and subsequent discussions and technical memoranda on risk issues. The first endpoint is changes in biota tissue concentrations. The second endpoint is changes in fish community structure. This is not to say that other potential endpoints are not important or potentially informative. However, for this Site it would appear that these endpoints are both relevant and some (although very limited) historical data exists for each of these biological measures.

Unfortunately, the amount of historical data for biota tissue concentrations for Portland Harbor is relatively sparse and is summarized in the Programmatic Work Plan. These data will be compiled with particular attention to data quality issues including detection

limits and the timing and location of the sampling. Similarly, the fish community review conducted by Ellis Ecological Services (2002) will be reviewed and summarized.

These historical data sets will be compared to fish tissue data and fish community information from Round 1 fish tissue sampling efforts. Any differences between tissue concentrations for the same species in the same general locations of the site will be compared while accounting for age, size, and other sampling differences and artifacts, where possible. Similarly, historical fish community information will be qualitatively compared to the locations and abundance of fish species indicated by the Round 1 fish sampling efforts. Given the limited amount of historical data, it is possible that meaningful trends or changes in biological endpoints may not be ascertainable.

3.5 DEVELOPMENT OF PREDICTIVE TOOLS

This final line of evidence is to determine whether past reductions in chemical concentrations (where sources have been controlled) can be expected to continue or be augmented in the future with the implementation of further source controls. As noted above, this can range from extrapolation of historical trends into the future where conditions are expected to be the same and/or determined through the use of computer models of varying complexity (i.e., one-, two-, or three-dimensional). Previously, two simple one-dimensional sediment models have been proposed (SEDCAM and Boudreau), which are discussed more below. USEPA has commented that these one-dimensional models may be insufficiently complex for the varied and dynamic processes likely to be present at this Site.

Consequently, it is proposed that the Step 2 evaluation proceed by first conducting the assessment of each of the four lines of evidence noted above to compile as detailed a picture as possible of the conditions and processes of the Site that might be most relevant to MNR as a remedial technology. Based on this information review (including new data from Round 2 investigations that have not yet been available for MNR discussions) it will be determined whether previously proposed sediment models could be relevant to at least some of the processes present in some portions of the Site. If so, trial model runs will be conducted using the one-dimensional models. Based on the information reviews and trial model runs, recommendations will be made for the type of predictive tool that would be most useful for further evaluating MNR in Step 3 of the MNR process.

The trial model runs are useful because they are relatively simple and quick to implement (as opposed to more complex two- and, particularly three-dimensional models), and they can provide a quantitative estimate of at least some processes likely to be relevant in some portions of the Site. The goal would not be to make any predictions about natural recovery using these more simplistic models but to understand in a quantitative manner the limitations, inherent uncertainties, disadvantages, and advantages of potentially using these models in the Step 3 MNR evaluations. Where the limitations, uncertainties, and disadvantages of these models appears substantial, the pros and cons of using more complex two- or three-dimensional models, including adapting and augmenting the

existing hydrodynamic model, would be evaluated and presented to USEPA. One possibility that we may evaluate is to revise the current two-dimensional hydrodynamic model to address chemical fate and transport.

The one-dimensional models discussed in previous documents are described again below for trial run use in the Step 2 MNR evaluation dependent on the outcome of the evaluation of the other four lines of evidence. The description of these models focuses on their use as simple tools to help further determine the types of models and modeling needed for Step 3 of the MNR evaluation.

3.5.1 SEDCAM Model

The SEDCAM model runs using an Excel platform and will be used in a probabilistic mode (using @RISK software) to determine the probabilities and rates changes of chemical concentrations in surface sediments due to some fate and transport processes relevant to sediments.

Model Inputs

The SEDCAM model (Jacobs et al. 1988) considers the following variables that can be important to MNR in some aquatic systems:

- Initial chemical concentrations in surface sediments (the mixed layer)
- Sediment physical characteristics (grain size, water content, specific gravity)
- Sedimentation rate
- Mixed layer depth
- Chemical concentration of the settling sediments
- Biodegradation rates.

Chemical concentration and physical characteristic inputs will come from Round 2 surface sediment sampling. Sedimentation rates and mixed layer depth inputs will come from the radioisotope subsurface cores described above. Chemical concentrations of settling sediments will be estimated from total chemical concentrations and total suspended solids data from surface water quality data. Biodegradation rates will come from literature searches for each chemical modeled. The ranges of biodegradation rates found in the literature for each chemical will be presented.

Model Equation and Boundary Conditions

The SEDCAM model uses the following equation:

$$C(t) = \left[\frac{S_a}{(S_a + kS)} * C_p * \left(1 - e^{\frac{-(kS + S_a)*t}{S}} \right) \right] + \left[C_o * \left(e^{\frac{-(kS + S_a)*t}{S}} \right) \right]$$

where:

C(t) = concentration of a contaminant in sediments at time t (mg/kg)

S_a = rate of deposition (g/cm²/yr)

S = total accumulation of sediments in the mixed layer during the period under consideration (g/cm²)

k = combined 1st order rate constant for chemical loss through decay and diffusion (yr⁻¹)

C_p = concentration of contaminant in settling sediments (mg/kg)

t = natural recovery time period (yr)

C_o = initial concentration in surface sediments (mg/kg)

The value for S is determined from the mixed layer depth and the density of sediments in that layer, which can be obtained from the total solids content and specific gravity of the dry sediment particles. The implied boundary conditions for this one-dimensional model are the top and bottom of the sediment mixed layer. There are no inputs from the bottom of the model and burial is the only output from the bottom of the model. The inputs and outputs from the top of the model (i.e., the water column) are diffusive loss and input via settling of new sediments. Diffusive loss within this model framework can be difficult to estimate and, for initial modeling efforts, this value will be set to zero.

Model Application

The SEDCAM model is simplistic in several respects, including that it deals only with the mixed sediment layer and it does not have separate variables for biodegradation and diffusion. Further, it does not expressly consider advection of porewater. However, SEDCAM approximates several processes that are important to chemical changes in surface sediments in some systems (e.g., sedimentation). Because the primary purpose of running the model is to understand modeling needs for Step 3 MNR evaluations, a few trial locations will be selected for model runs based on the proximity of recent data collection sites relevant to the model inputs described above.

To better understand the implications of the model's simplifying assumptions and the range of data values collected during sampling, it will be coupled with probabilistic

Monte Carlo simulation techniques to provide statistical estimates of the likelihood (cumulative probability) of ending sediment chemical concentrations. The commercially available @RISK software will be used to conduct Monte Carlo simulations. This information will be used to conduct a sensitivity analysis to identify those parameters that are the most important drivers changing chemical concentrations in sediments over time. The magnitude of changes in important variables that cause differing conclusions (i.e., increasing concentrations vs. decreasing concentrations) will be compared to the precision and accuracy of the site-specific data available.

At a minimum, the chemicals and conditions modeled will be specific to a particular area where sufficient data are available for each of the input parameters discussed above. Generally, chemicals with higher concentrations relative to available sediment benchmarks will be chosen for modeling. In addition, both metals (which do not degrade) and organic chemicals will be chosen for evaluation. Within the organic chemical group, the physical properties of these chemicals will be reviewed (e.g., solubility, partitioning coefficients, and biodegradation rates) so that chemicals with a range of adsorption and biodegradation rates are evaluated. We anticipate that the modeling will be limited to 5 or fewer chemicals to provide a manageable number of model runs; this limited number of runs should be sufficient to understand the limitations and potential uses of the model.

For each chemical, the model will be initially run for a simulated period of 10 years. Although no specific guidance is available on this project for selecting an appropriate period of natural recovery, periods from 10 to 30 years have been used at other Superfund sites. A 10-year recovery period was used at the Commencement Bay (USEPA 1989) and Eagle Harbor (USEPA 1994) sites in Washington, while a 10 to 30-year period for recovery of sediment and fish tissue concentrations was used at the Fox River Superfund site (WDNR 2003). To be conservative, a 10-year natural recovery period was chosen.

Because this model will not be used for a full assessment of MNR (but rather an exercise in determining Step 3 modeling needs), formal calibration of the model will not be conducted. However, the accuracy of the model will be assessed by attempting to mimic historical core profiles of metals that do not biodegrade. The SEDCAM model inputs will include assigned surface sediment concentrations (the starting concentration), sedimentation rates, and incoming settling sediment concentrations. For comparison to historical core profiles, the model input for the starting sediment concentration will be set equal to the concentration at the depth of the core interval in question. Sedimentation rates will come from radioisotope core information discussed in Section 4. The incoming settling sediment metals concentrations will be set at current conditions indicated by surface water chemistry and at several arbitrary higher values (to be potentially more representative of higher historical sources) to see whether the model can approximate the metals concentrations over time represented in the core metals profile. The ability or difficulty in approximating the

observed core metals profile will provide a direct indication of the model's ability to mimic the actual combined processes at that location.

3.5.2 Boudreau Model

The Boudreau Model will be used in trial runs similar to those described above for SEDCAM to help assess Step 3 modeling needs. This numeric model is based on the extensive work done by Boudreau (1997) on diagenetic modeling for sediments.

Model Inputs

The primary limitation of using the Boudreau model at this time will be the relative paucity of dissolved phase chemical information (e.g., groundwater/porewater chemical concentrations) and, to some extent, groundwater advection rates. However, as noted above, these trial runs will be conducted to help assess Step 3 modeling needs. Consequently, for these trial runs, the use of regional groundwater information where data are available and/or use of partitioning literature values appears reasonable. Also, through trial runs of this model, we may be able to better understand the potential conditions under which contaminated groundwater advection or diffusion from buried contaminated sediments might be expected to significantly alter rates of change in surface sediment chemical concentrations. This is an important aspect of the Step 3 modeling needs.

The model will be used to assess the long-term solid and dissolved contaminant fate and transport associated with a number of natural recovery processes by simulating the diffusion, bioturbation, groundwater-mediated advection, settling, burial, and biodegradation mechanisms likely to be present at this site. The overall data inputs for the model will be the same as those for SEDCAM. The Boudreau model requires some additional inputs and data sources as described below in the model equation. Molecular diffusion coefficients for the model will be obtained from literature values. Porosity of sediments will be obtained from sediment core data on water contents and dry particle density. Tortuosity is a function of porosity. The depth of the mixed layer will be determined from visual observations of the surface sediments during core processing and radioisotope core information (Section 4). Biodiffusion values will be obtained from literature for similar river systems. Velocity of porewater will be obtained from upland information on groundwater gradients and hydraulic conductivities measured at various shoreline sites. For dissolved phase transport parameters (for which there is relatively little data), a range of potential values will be input to observe the sensitivity of the model to these input values.

Model Equation

The model is a one-dimensional simulator that assesses fate and transport along the vertical axis of the sediment bed. The governing equations for the model have been

extensively peer reviewed in the literature and through the publications of Boudreau (1997). The model is based on Boudreau's Equations 3.80 and 3.83 (1997), which determine the integral conservation balances of a species (e.g., a chemical of interest) for dissolved and solid phases in a thoroughly mixed layer of sediments. In this case, the "mixed layer" refers to the surface sediments at the site. The governing equation for the natural recovery model is:

$$\frac{\partial M}{\partial t} = D_o \left[\frac{\phi}{\theta^2} \frac{\partial C}{\partial x} \right]_L + \left[\phi D_B \frac{\partial C}{\partial x} \right]_L + [\phi u C]_L + [\phi_s w B]_0 - D_o \left[\frac{\phi}{\theta^2} \frac{\partial C}{\partial x} \right]_0 - \left[\phi D_B \frac{\partial C}{\partial x} \right]_0 - [\phi u C]_0 - [\phi_s w B]_L - \sum_0^L R dx$$

where:

- M = mass of chemical of interest (mg)
- t = time (yr)
- D₀ = molecular diffusion coefficient (cm²/yr)
- φ = porosity of sediments (unitless)
- θ = tortuosity of sediments (unitless)
- C = concentration of chemical in dissolved phase (mg/L)
- x = spatial variable (along the depth of sediments) (cm)
- L = where x = L; the bottom of the mixed layer
- D_B = biodiffusion or mixing coefficient for sediments (cm²/yr)
- u = velocity of pore water (cm/yr)
- φ_s = solid fraction volume (unitless)
- w = burial velocity of solids (or settling rate) (cm/yr)
- B = concentration of chemical in solid phase (mg/kg)
- 0 = where x = 0; top of the mixed layer (sediment water interface)
- R = reaction of chemical in depth interval (i.e., biodegradation loss) (/yr)

This equation provides the change in chemical mass over the specified time interval. By assuming a unit volume of mixed layer sediment, this equation can be used directly to calculate concentrations of the chemical of interest in the mixed layer over the same time. The net change in mixed layer mass is determined by the sum of

changes produced by diffusion, biodiffusion, groundwater advection, sediment settling, burial, and biodegradation (for organic chemicals). (Biodiffusion is mixing of sediments caused by organisms in the mixed layer, which results in movement of chemical species through and out of the mixed layer. This is not a term for bioaccumulation of chemicals in biota.) It should be noted that the model is applicable to any chemical species, and review of Boudreau (1997) indicates that there are very few limitations in terms of chemicals that might be modeled. The most important factor is that mass conservation is observed by ensuring that all production and destruction reactions that are thought to be important are accounted for in the R term. This model has been applied at a variety of sites, as noted above, with application to numerous types of chemical species including metals, PAHs, and PCBs.

Following numerous examples in Boudreau (1997), the partial differential equation noted above is converted to a series of ordinary differential equations by substituting spatial finite differences for spatial derivatives. The resulting ordinary differential equations are solved numerically using Euler's method. The model is executed with STELLA Research® software.

The variable R represents the total mass change due to all chemical production/destruction reactions that occur in the mixed layer, such as biodegradation. The only such reaction typically considered is biodegradation for organic chemicals, which was assumed to follow a first-order decay relationship of:

$$C_{t1} = C_{t0}^{(1-e(-kt))}$$

where:

C_{t1} = concentration of chemical at time one

C_{t0} = concentration of chemical at time zero

k = first order decay constant (yr^{-1})

The model assumes that mixing of sediments within the surface layer is essentially instantaneous within each time step. Generally, mixing of surface sediments due to physical and biological (bioturbation) activity takes place on a sufficiently short time scale that this assumption is reasonable for the purpose of predicting sediment chemistry changes over a period of years (Boudreau 1997). The depth of the mixed layer itself can be varied within the model and will be based on observations of mixed layer depths in the sediments including: visual observations, SPI photos, and radioisotope core results (particularly ^{210}Pb and ^7Be results for the top intervals of cores, see Section 4).

The equation includes both dissolved phase and solid phase chemicals. Consequently, equilibrium-partitioning assumptions are used to obtain the mass of

chemical present in each phase at any given time in the model. Distribution coefficients will be obtained from literature values and any available porewater/sediment data pairs available from Portland Harbor. These coefficients are used to describe the equilibrium partitioning of the chemicals across solid/aqueous phases in the mixed layer and the buried layer.

Recent information (Section 4) indicates that the process of sedimentation at even quiescent locations within the river may be very dynamic and includes large amounts of resuspension and redeposition of sediments overtime. These rates of particulate flux into an out of the mixed layer appear to be relatively high as compared to the net sedimentation rates over time. USEPA has also expressed an interest in models that explicitly consider resuspension mechanisms. Depending on the results of trial runs of the Boudreau model as described above, an additional resuspension term could be added to the model equation. This would essentially be a mass loss term that is the reverse of the sedimentation term shown in the above equation. Further, the model could be applied in one-dimensional “paired” runs. A second location would represent an area of relatively clean “downstream” sediments that receives the particulate associated chemical inputs from the “upstream” location. This would also provide additional information on the potential impacts on downstream areas due to the dispersion of chemicals created by more dynamic sedimentation processes. Further, such an analysis might help determine whether more detailed two- or three-dimensional models are needed to fully understand the issues associated with this potential downstream impact.

In addition, USEPA has commented that bioaccumulation of chemicals in biota may be one mechanism that affects the concentrations of chemicals in sediments. The input of chemicals from biota to the sediment layer is typically accounted for in settling sediment chemical concentrations. That is, these concentrations include organic matter (and any associated chemicals) that may be present in settling sediments due to the life cycles of water column biota (e.g., excretions, detritus, and/or dead organisms). However, the model does not include an explicit loss term for movement of chemicals out of the surface sediments and into biota through bioaccumulation. In this respect, the model is conservative (would estimate higher chemical concentrations in the mixed layer over time), because it includes an input from biota but no output to biota. The importance of this assumption on the accuracy of the model could be tested by adding one additional bioaccumulation loss term to the equation. The parameters for this biota loss term would be obtained from the food web model inputs being used for the risk assessment. These terms would be used to determine a partitioning factor between surface sediments and water column biota. The final requirement to obtain this loss term would be an understanding of the bioaccumulative biomass present per unit area of the riverbed, which should be attainable from various risk assessment data collection efforts including fish studies, multiplates, and benthic studies. These data would allow calculation of mass loss to biota per unit area of surface sediment, which is the unit system used in the model.

Boundary Conditions

The one-dimensional mixed layer mass or concentration, which is the primary focus of the model, is bounded by surface water at the top ($x=0$) and buried layer at the bottom ($x=L$).

The concentration of the chemical in the surface water is assumed to be zero. Generally, surface water concentrations are well below pore water chemical concentrations (particularly for contaminated sediments), so the use of a zero value for surface water does not greatly effect changes in sediment chemical concentrations. That is, the model is very insensitive to small changes in surface water concentration. The primary input from the surface water is suspended sediment (and associated chemicals) settling on the mixed layer bed.

The buried layer is assumed to be infinitely thick and to have an infinite source of chemicals at the specified concentration. Because chemical contamination is found relatively deep in most site sediments, this assumption appears valid over the time periods of interest (i.e., several years). Further, this assumption is conservative (i.e., would tend to under predict the likelihood of natural recovery) because it assumes no reduction in chemical flux from the buried layer over time. Where the buried layer has higher concentrations than the mixed layer, the primary inputs from the buried layer are groundwater advective flux and diffusive flux of dissolved chemicals. The dissolved chemical concentrations for the buried layer are obtained from equilibrium partitioning assumptions and data as noted above for the mixed layer. Because the buried layer is defined at the point at which mixing ceases, physical movement of solids from the buried layer to the mixed layer is assumed to be zero.

Model Application

The model will be applied to similar trial locations and for the same chemicals used for the SEDCAM modeling. A baseline point of comparison between the two models will be obtained by setting advective and diffusive chemical transport from the buried layer and to the water column to zero in the Boudreau model. This will allow a straight forward comparison of the models on a consistent basis. In addition, the Boudreau model dissolved phase transport parameters will be varied over large but reasonable ranges (based on site data wherever possible) to determine the relative impact of potential groundwater advection of dissolved chemicals and/or diffusion of chemicals from buried sediments. An assessment of potential model accuracy (rather than formal calibration) of the Boudreau model to the metals profile observed in sediment cores will also be conducted similar to the procedure described above for the SEDCAM model. Because there may be a lack of site-specific data for some potentially important parameters, a full calibration of the Boudreau model will not be attempted for these trial runs.

4.0 PRELIMINARY MNR SUBSURFACE CORE METHODS AND RESULTS EVALUATION

This section presents sediment core data collected in support of the evaluation of MNR for the Portland Harbor RI/FS. The specific sampling and analysis procedures for the coring activities are described in detail in the Site RI/FS Natural Attenuation Technical Memorandum – Sedimentation Field Sampling Plan (herein referred to as FSP) (Anchor 2004a) and the Site Natural Attenuation Field Sampling Report (herein referred to as the FSR) (Anchor 2004b).

4.1 SUMMARY OF FIELD SAMPLING AND ANALYSIS ACTIVITIES

As described in the FSR, subsurface cores were collected in October 2004 in accordance with the procedures described in the FSP. Based on a review of dredging records, bathymetry, site use, and hydrodynamic conditions within the Site, sediment cores were collected in areas that showed the potential for net sedimentation and a varying degree of natural attenuation processes. A single core was collected adjacent to the Linnton Plywood facility (core NA-1), within Willamette Cove (core NA-2), at Willbridge Terminal (core NA-3), and in the Swan Island Lagoon (core NA-4), as shown in Figure 2. Samples were collected from the mudline elevation to a depth of 94 cm below the mudline elevation in the intervals described in the FSP. In the appropriate depth intervals ^7Be , ^{137}Cs , and ^{210}Pb radioisotope analyses as well as bulk metals analyses were conducted. Co-located ancillary cores were also collected at each location to provide sufficient volume for additional and chemical analyses. It should be noted that while the radioisotope cores were sectioned in fine increments (as small as 1 cm), 3 samples were taken from each ancillary core, with each sample representing a composite of material across many centimeters.

4.2 MNR CORE EVALUATION METHODOLOGY

Evaluation of radioisotope activity with depth in a sediment column provides estimates of the depth and rate of any bioturbation activities in the surface sediment layers as well as the long term sedimentation rates indicated by subsurface layers in that area. The vertical profile of radioisotopes can also provide valuable information on the stability and/or periodic erosion of the sediment bed. The following sections describe background information on radionuclide evaluation and the methodology for evaluating the measured ^7Be , ^{137}Cs , and ^{210}Pb activities at the Site.

4.2.1 Background

Since the 1960's, atmospheric fallout radioisotopes, particularly ^7Be , ^{137}Cs , and ^{210}Pb , have been used increasingly in sedimentation studies. Each of these isotopes is deposited on the earth's surface as atmospheric fallout at rates that are thought to be spatially uniform within a limited geographic range (i.e., similar latitude and annual precipitation) (Hewitt 2000). Following deposition into a water body, the radionuclides

adsorb to water column particulates and settle to the sediment surface following some residence time in the water column. Once deposited, each isotope decays exponentially with a specific half life decay period. The half life period for ^7Be , ^{137}Cs , and ^{210}Pb is 53 days, 30 years, and 22 years, respectively. Because this decay is rapid, with respect to geographic time scales, deeper soils are essentially devoid of fallout isotope activities. Consequently, measured subsurface radioisotope concentrations with depth can be used to approximate the net sedimentation rate and to date the approximate age of sediments as a function of depth. Due to the continuous decay, sediments exposed to direct atmospheric fallout (i.e., water column sediments with high residence periods and soils introduced from direct overland runoff) have higher radioisotope activities relative to soils/sediments that are eroded from within the watershed. Therefore, the introduction of eroded soils/sediments into the Portland Harbor simultaneously increases the net sedimentation rate but functions to decrease the observed radioisotope activity with depth.

In order to successfully use radioisotope data to approximate the net sedimentation rate and/or sediment age with depth, the following conditions were assumed during the initial evaluation process: 1) the sedimentation rate is constant at all times (i.e., Constant Rate of Supply [CRS] Model), 2) the initial ^{210}Pb concentration in the deposited sediment is always the same regardless of potential changes in the sediment accumulation rate (i.e., Constant Initial Concentration [CIC] Model), 3) there is no post-depositional migration of the radionuclide, and 4) the activity of the ^{210}Pb supported by the ^{226}Ra in the sediments is independent of depth (Robbins and Edgington 1975; Brigham et al. 2001; Hewitt 2000; Ciavola et al. 2002). In riverine environments, conditions 1 and 2 can be variable, and thus additional weight of evidence information is incorporated into the data evaluation process so the radioisotope evaluation considers potential variations in the deposition rate, sediment physical characteristics, and/or erosional processes (i.e., prop wash scour, dredging, high velocity events). In addition, sampling artifacts (e.g., mixing in the upper layers of the core during core processing) and sample holding times must also be considered when analyzing the radioisotope trends.

4.2.2 Radioisotope CRS and CIS Methods

Each of the four cores was analyzed for ^7Be , ^{137}Cs , and ^{210}Pb at the sampling depths shown in Table 1. Using the methodology described in the FSP appendix, the total ^{210}Pb activities measured at each station were corrected to account for the proportion of ^{210}Pb resulting from atmospheric fallout only, excluding any contribution of ^{210}Pb in secular equilibrium with ^{210}Po at deeper depths. The corrected ^{210}Pb was designated Excess ^{210}Pb . No corrections were necessary for the ^7Be and ^{137}Cs isotopes. Following this correction, each of the measured isotope activities was plotted versus depth for each sampling station to determine whether any trends existed using the assumptions of the CRS and CIC Models noted above.

The mixing layer at each station was evaluated using the ^7Be data. This isotope is a naturally occurring isotope continually produced by cosmic ray bombardment of

oxygen and nitrogen in the atmosphere (Brigham et. al. 2001). Given the half life of this isotope is relatively short (53 days), detected activities indicate recent mixing has occurred. Therefore, where this isotope was detected, the approximate mixing layer depth could be obtained directly from the activity profiles.

The activity plots for the ^{210}Pb and ^{137}Cs were evaluated in tandem to calculate the net sedimentation rate and to date the sediments with depth. ^{210}Pb is a naturally occurring isotope which is formed as part of the ^{238}U decay of the earth's crust soils (Brigham et. al. 2001). Given radioactive decay is an exponential process, the logarithm of the ^{210}Pb activity should decrease linearly with depth (assuming conditions implied by the CRS and CIC Models) and the slope of the line can be used to calculate the sedimentation rate. As described in Hewitt (2000), when base 10 logarithms are used and the sediment depths are expressed in cm, the sedimentation rate in cm per year equals - 0.01352 divided by the slope. Following this method, the ^{210}Pb activity data at each data was logarithmically transformed, the logarithmic ^{210}Pb activity versus depth was plotted, and the linear-regression best fit from the curve was calculated using Excel. The slope of the best fit line was then used to calculate the net sedimentation rate.

The ^{137}Cs profiles were evaluated to assign calendar dates to the sediment column. This isotope is a result of thermonuclear reactions and was introduced into the atmosphere during the early days of nuclear testing (Brigham et. al. 2001). In the United States, the first appearance of the isotope was in 1954 and the activity peaked in 1963 (Hewitt 2000). Thus if ^{137}Cs is detected at a given depth, the date is interpreted to be 1954 or afterward and the peak in the profile can be assigned to 1963.

4.2.3 Core Bulk Chemistry Methods

Bulk concentrations of metals typically introduced into riverine environments from anthropogenic activities in the surrounding watershed (i.e., copper, lead, and zinc), were plotted with depth for the ancillary co-located cores to determine whether the input of these anthropogenic compounds showed similar trends to the radioisotope profiles. These bulk metals samples were collected from the same depths shown in Table 1. In addition, the bulk chemistry results obtained from the ancillary cores were examined for chemicals that were detected over most samples. Three chemical groups, total polychlorinated biphenyls (PCBs), total polycyclic aromatic hydrocarbons (PAHs), and total dichloro-diphenyl-trichloroethane and related breakdown products (total DDTs), were plotted and examined for additional information on vertical trends in contamination.

4.2.4 Additional Weight of Evidence Methods

Given that the Willamette River exhibits seasonally variable flow rates and deposition rates and is not a quiescent environment (i.e., such as a deep lake), additional site specific information was examined to determine how the potential variability may have affected the applicability of the CRS and CIC Models. Both ^{210}Pb and ^{137}Cs strongly adsorb to clay minerals and organics in the water column and therefore deposition of

these isotopes increase with increases in clay and organics content (Robbins and Edgington 1975; Robbins et al. 1979). The presence of sandy substrates, gravel, and woody debris which are commonly encountered in riverine environments therefore effectively reduce the measured radioisotope activity which can lead to an underestimation of the sedimentation rate (i.e., decrease the slope of the logarithmic ^{210}Pb profile). To determine if changes in activity were linked to substrate composition, the grain size information obtained from the ancillary co-located sediment cores was evaluated throughout the depths analyzed for radioisotopes. In addition, the physical characteristics noted in the field sampling boring logs were evaluated to determine if field identified sediment characteristics (i.e., sand lenses, woody debris, etc.) potentially affected the activity profiles.

4.3 MNR CORE RESULTS AND EVALUATION

The radioisotope profiles with depth are depicted in Figures 3 through 6. The activities, measured in picocuries per gram dry weight sediment (pCi/g), ranged from approximately non-detectable levels to peak concentrations of 0.23, 0.37, and 0.25 pCi/g for ^7Be , ^{137}Cs , and ^{210}Pb , respectively. It should be noted that the radioisotope analyses were only conducted to a depth of 90 cm below the mudline elevation so the evaluation was limited to depths less than 90 cm. These ^7Be and ^{210}Pb activities are approximately an order of magnitude less than activities documented in other riverine systems (Hewett 2000; Brigham 2001). These low level activities do not necessarily indicate that net sedimentation is low in the sampling areas. Rather, as discussed above, the low observed radioisotope activities may be due to the introduction of eroded soils/sediments into the Portland Harbor.

4.3.1 ^7Be Results and Evaluation

The ^7Be activities were undetectable at every station except NA-1, as shown in Figures 3 through 6. At this station detectable concentrations (ranging from 0.05 to 0.26 pCi/g) were detected in the upper 5 cm of the core. Although this range of activities is low, detectable concentrations indicate that the upper five cm of the sediment column is well mixed with recently (e.g., 6 months to a year) incorporated sediments. The lack of detectable ^7Be concentrations at the remaining stations indicates that either net deposition has not occurred in the past six months to a year and/or net deposition has occurred in these areas but the mixed layer contains undetectable levels of ^7Be . The latter scenario is indicative of sedimentation sources with relatively low levels of atmospheric radioisotope sources. Evaluation of the ancillary core grain size characteristics and physical characteristics identified in the field boring logs (Figures 7 through 10) did not indicate that physical conditions were affected by or clearly related to the results of the radioisotope analysis for NA-2, 3, and 4. However, a clear substrate change occurs (coarse sand lens) in core NA-1 at approximately 7 cm below the surface, which is consistent with the loss of ^7Be activity at about this same depth (approximately 5 cm). This may indicate that this site transitioned recently (within the

last 6 months) from a more erosional condition to a depositional one consistent with the presence of ^7Be in the upper newly deposited layer.

Although all samples were analyzed within one half life (53 days) following collection, the samples showing detectable concentrations at station NA-1 were analyzed earliest (within two weeks of collection). Given the detected activities were very low, the additional analysis duration for the remaining samples (analyzed from 3 to 6 weeks following collection) may have contributed to the observed undetectable concentrations.

4.3.2 ^{210}Pb Results and Evaluation

As shown in Figure 3 through 6, the ^{210}Pb profiles at the sampled stations did not show the exponential decay profile normally exhibited in a quiescent depositional environment. Evaluation of the data indicates that although no apparent decay trends exist for stations NA-3 and NA-4, stations NA-1 and NA-2 showed a general decay trend with depth. This trend, although potentially biased by the low level activity range observed, provides some information on the potential net sedimentation rates at these stations. Based on the methods discussed above, following logarithmic transformation of the data, the approximated sedimentation rates at these stations was calculated to be approximately 1 cm/yr (similar for both stations) (see Figures 11 through 14). Although the least squares fit (i.e., r^2 value) for both logarithmically transformed profiles was low, this rate of deposition is within the range of similar riverine environments (Hewitt 2000) and provides an estimate of the potential net sedimentation rates. This long-term (i.e., decades) 1 cm/yr net sedimentation rate is substantially less than the short-term gross sedimentation rates determined for the Portland Harbor based on evaluation of river wide bathymetry changes over a 6-month to 1-year period.

The downward trends in ^{210}Pb concentrations in two cores and the generally low ^{210}Pb concentrations in all cores suggest a much more dynamic sedimentation environment than assumed by simple application of the CRC or CIC models. Such profiles are indicative of sediment systems that have large amounts of gross sedimentation and gross resuspension. The resulting large particulate flux dilutes and disperses all deposited chemicals both vertically and horizontally, including the ^{210}Pb examined here. In such cases, chemical trends and/or peaks become “smeared” out over the vertical profile and the overall concentrations are diluted by the constant particulate flux. In the case of stations NA-1 and 2 the general decreasing ^{210}Pb activity indicates that this may result low net sedimentation rate over time relative to the overall rate of particulate flux in and out of the surface sediment layer. The results for NA-3 (to some extent) and NA-4 (particularly) are somewhat unexpected in that these are relatively quiescent areas of the river and would be expected to have some measurable net deposition of material overtime similar that shown in NA-1 and 2. One possible explanation for the profiles observed in at NA-3 and 4 is that sediments have been disturbed through prop wash scour to such an extent that no net deposition is observable in these particular locations.

Evaluation of the co-located ancillary core grain size characteristics and physical characteristics identified in the field boring logs did not indicate that physical characteristics at the sampling stations generally affected the radioisotope activities (Figures 7 through 10). However, the coarse sand lens at 7 cm in core NA-1 coincides with a drop in ^{210}Pb activity at this same depth, which may have been related to a high flow event that removed sediments containing higher levels of excess ^{210}Pb .

The comparative plots of the ^{210}Pb and the bulk metals concentrations (see Figures 3 through 6) indicate dissimilar trends for stations NA-1 and NA-2 and similar trends for stations NA-3 and NA-4. The similarity in trends for stations NA-3 and NA-4 indicate that the net sedimentation in these locations is likely due to a sediment source equally affected by both atmospheric and anthropogenic sources. For all stations, the observed metals concentrations are not particularly high compared to concentrations observed near some types of historical anthropogenic inputs.

4.3.3 ^{137}Cs Results and Evaluation

Stations NA-2, 3, and 4 showed peak ^{137}Cs activities (0.13 to 0.37 pCi/g) within the top 5 cm of the cores (Figures 4 through 6) and attained an approximate baseline activity at 0.05 pCi/g at deeper depths. Station NA-1 showed a consistent activity matching the baseline activity (0.05 pCi/g). In environments where the assumptions of the CRM and CIC Models are accurate, these peaks are highly correlated with the peak in nuclear arms testing in 1963. Therefore, under these assumptions, the exposed surface sediment layer is indicative of the 1963 surface. Although possible, this scenario is likely implausible given each of the sampling stations was chosen purposely to avoid recently dredged areas and each area was estimated to be a net depositional environment by the STA analysis (Hill and McClaren 2001).

However, the ^{210}Pb evaluation indicated that sedimentation rates at stations NA-1 and NA-2 were approximately 1 cm/yr. If accurate, this sedimentation rate indicates the peak ^{137}Cs concentrations should occur at approximately 40 cm below the mudline elevation at these locations. Given the initial sampling tier only included analysis of ^{137}Cs in the upper 30 cm of each core, it is possible that peaks might occur at greater than this depth consistent with the extrapolated sedimentation rates in cores NA-1 and NA-2. It is recommended that additional deeper samples from all four cores be pulled from archive and analyzed to determine whether ^{137}Cs levels increase at deeper depths consistent with the calculated 1 cm/yr deposition rates. If started immediately, the results of such archive sample analyses should be available in time for the Step 2 MNR Evaluation proposed in Section 3.

4.3.4. Bulk Chemistry Evaluation

The results of the bulk metals analysis are shown in Figures 3 through 6. As discussed in Section 4.3.2, at cores NA-1, 2, and 3 these bulk metals concentrations generally increase with depth, but at relatively low concentrations throughout their profiles. This could be indicative of general changes in background metals concentrations in the river

over time or the result of dynamic sediment exchange resulting in diluted metals concentrations showing a general trend of decreased metals concentrations over time.

Although only sampled at three composite depths, the organic chemistry in the ancillary cores provides a second method of determining whether these sites show historically elevated levels of pollutants. As noted above, total PCBs, PAHs, and DDT (including related breakdown products) were chosen as representative organic chemicals for initial data analysis. Unlike metals, these organic chemicals are almost exclusively associated with human activity. Thus, detectable levels of organic chemicals at a sediment depth indicate that, at some time in the recent past, the sediments at this depth were present at the surface of the sediment column. (This assumes that groundwater sources of these chemicals are not significant at these locations. Because each of these chemical groups is generally poorly transported by groundwater, this appears to be a reasonable assumption for the purpose of this initial data analysis.) Figures 15 and 16 present plots by depth for each core of these organic chemicals as well as the bulk metals data from the finely sectioned cores. For summation of each organic chemical group, where an individual organic compound was undetected, a value of zero was assumed. Thus, all the concentrations presented in Figures 15 and 16 represent detected values of organic chemicals. Anthropogenic organic chemicals are evident up to 90 cm deep in each of the cores. Further, many of the organic chemicals concentrations increase with depth indicating that historical sources may have been higher compared to more recent sources. This trend is most notable at station NA-1, which has the clearest depositional history of any of the cores, and to a lesser extent at NA-2. Station NA-3 shows a decrease and then increase with depth of most organic chemical concentrations. Alternatively, station NA-4 shows potentially decreasing organic chemical concentrations with depth.

Overall, these cores are consistent with a conceptual model of dynamic exchange within the surface sediments over time with the gross deposition and resuspension being orders of magnitude higher than any observable constant net deposition over time, at least within the sampled upper 90 cm. The consequences of this process is general dilution of chemical concentrations in the sediment column, dispersion of chemicals to greater depths within the sediment column during scour events followed by subsequent deposition, and a resulting sediment profile that records anthropogenic inputs at relatively great sediment depths as compared to a more quiescent system. Deeper samples indicating non-detects of organic chemicals would help gauge to what depth this vertical dispersion extends. Consequently, it is recommended that archive samples from deeper portions of these cores be analyzed to determine at what depths organic chemicals are no longer detectable.

4.4 USE OF PRELIMINARY RESULTS IN OVERALL IN OVERALL EVALUATION METHODS

The above analysis represents a preliminary evaluation of sampling results collected specifically to assess MNR processes. Additional analyses of archived core samples for ¹³⁷Cs and organic chemicals are proposed to help further illuminate some of the hypotheses presented above. These combined results will be used in the five lines of evidence approach described in Section 3 for the Step 2 MNR Evaluation. In particular, these results will help support characterization of historical sources (as evidenced by chemical concentrations in deeper sediments), characterization of fate and transport processes (particularly issues related to sedimentation and resuspension), establishment of the historical record of contamination in sediments, and will be used as inputs to modeling trial runs (i.e., possible predictive tools).

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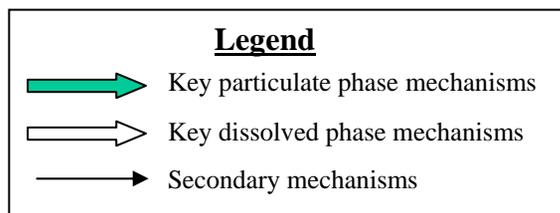
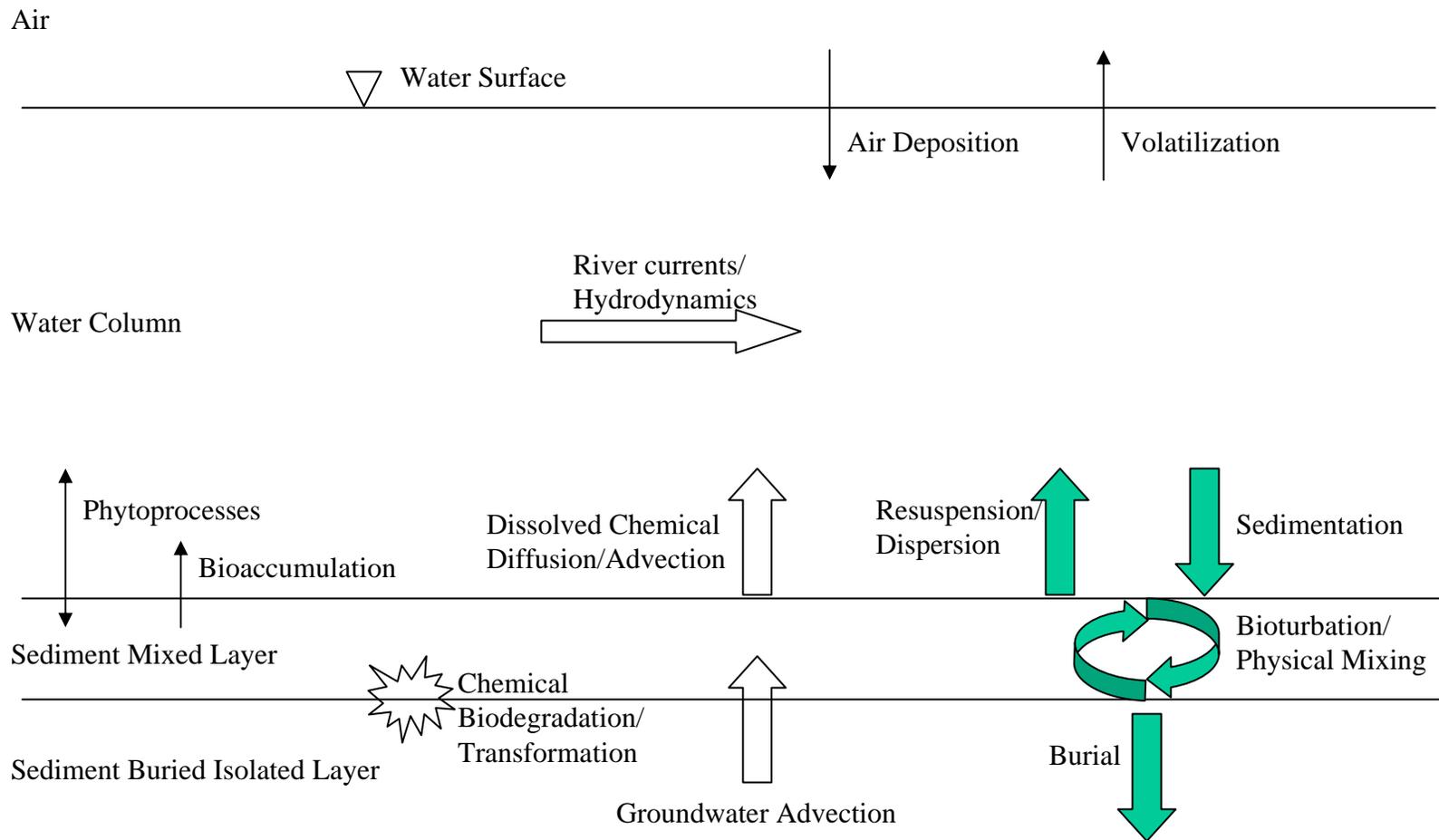
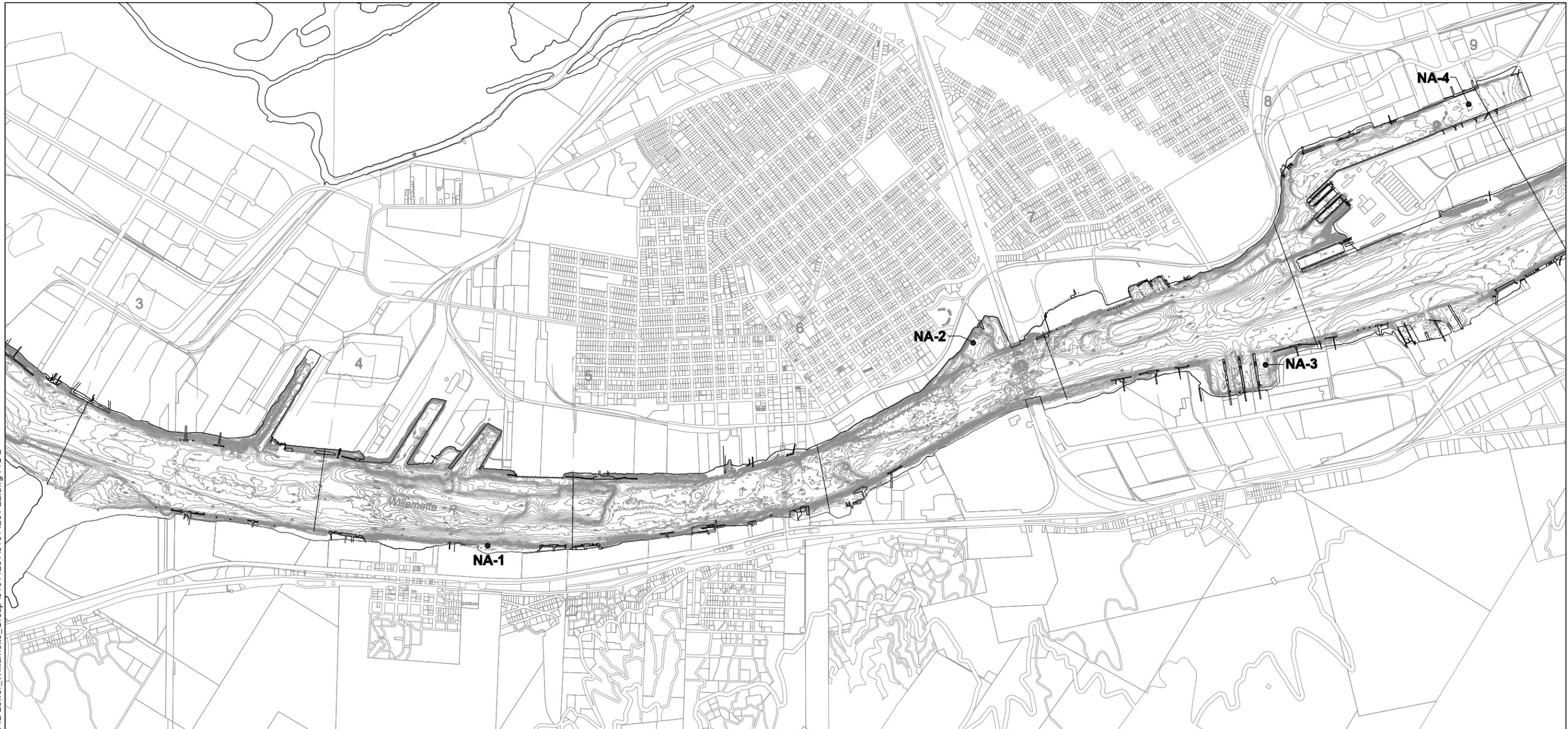


Figure 1. Natural Attenuation Mechanisms

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K:\Jobs\010142-Lower_Willamette_Group\01014201\01014201-22.dwg FIG 2
Apr 25, 2005 1:43pm cdavidson



● **NA-1** Radioisotope Subsurface Coring Station

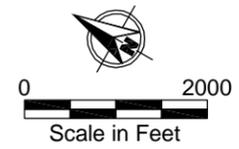
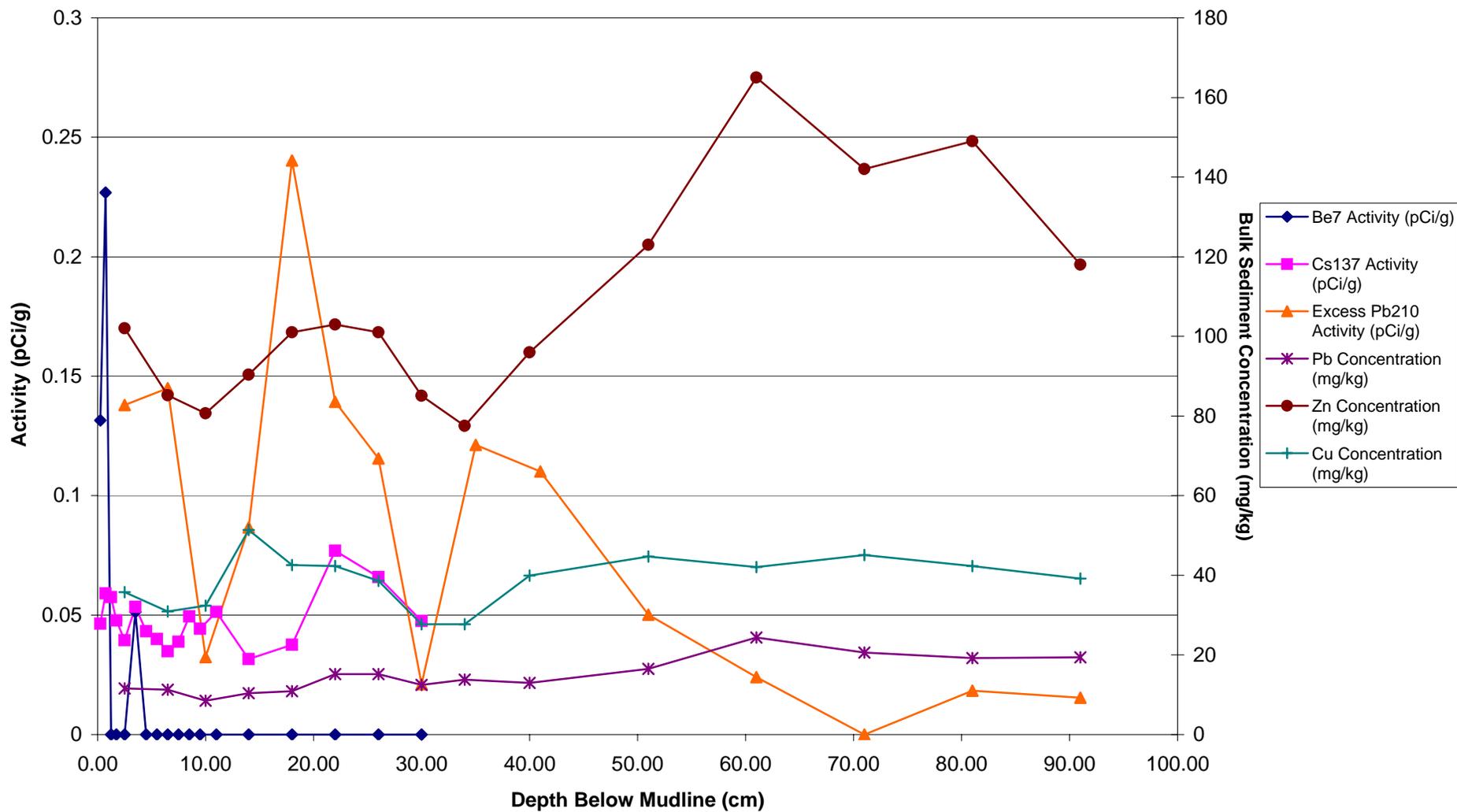
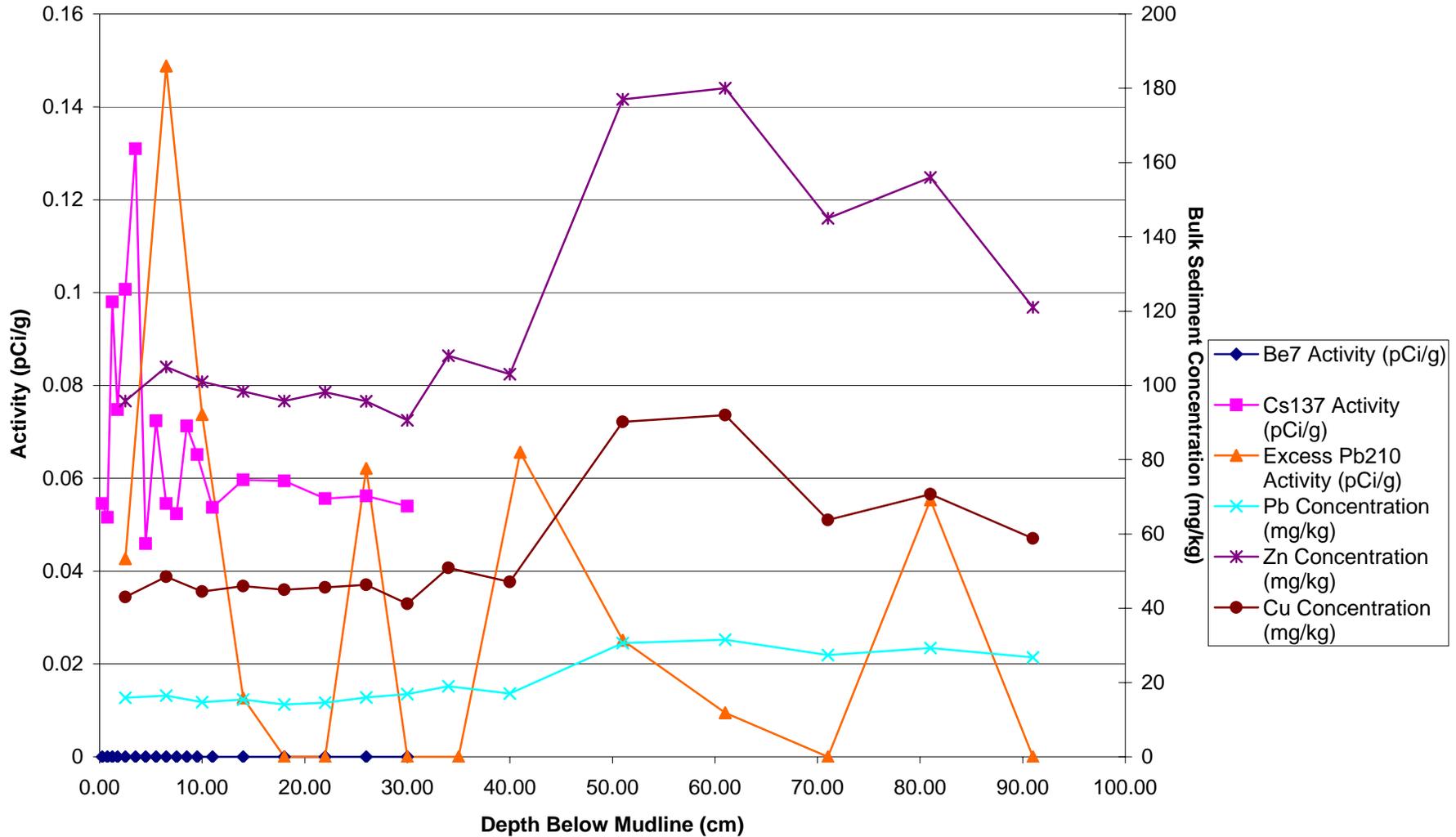


Figure 3 - Station NA-1 - Radioisotope Activity and Metals Concentrations with Depth



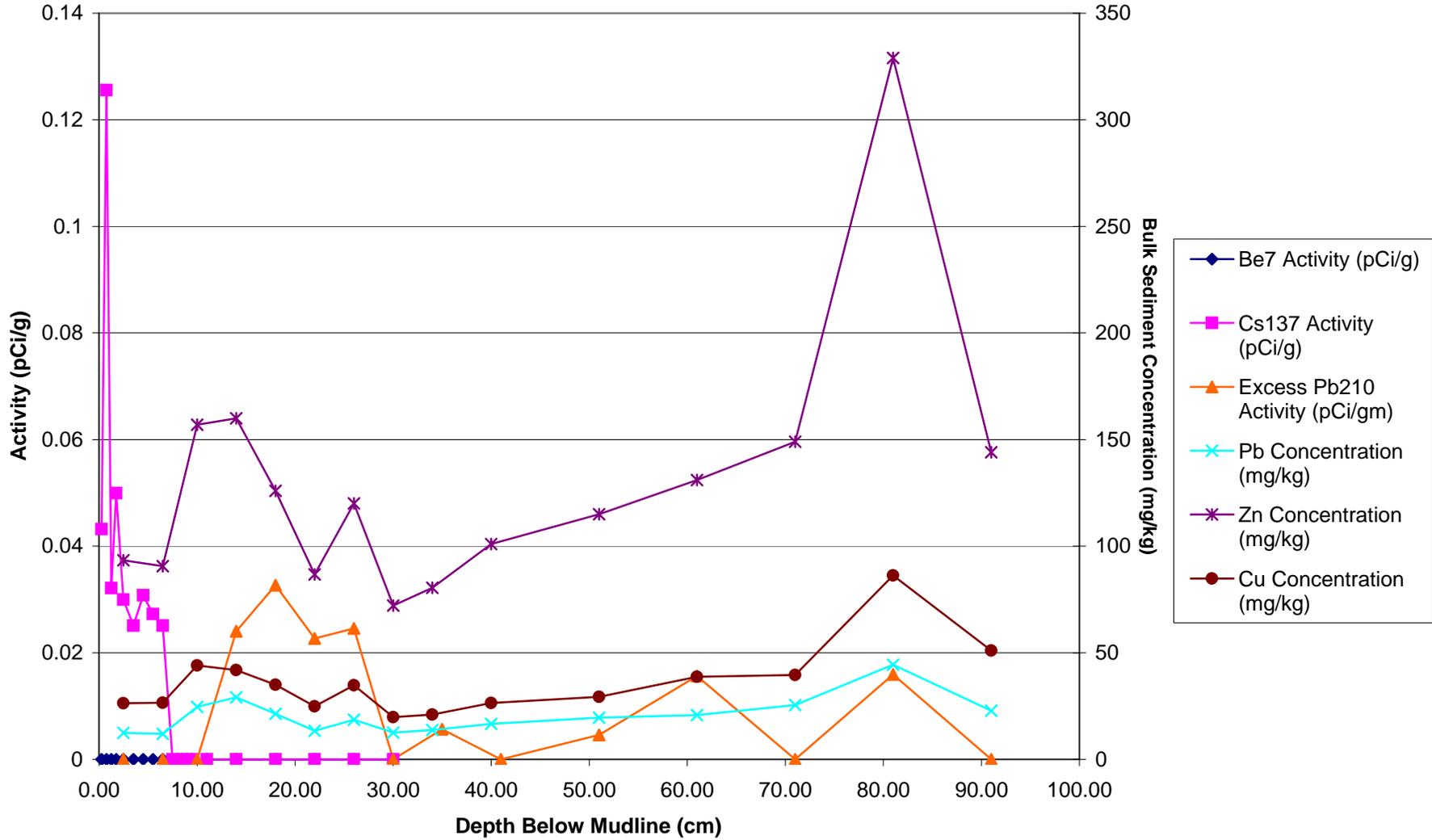
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Figure 4 - Station NA-2 - Radioisotope Activity and Metals Concentrations with Depth



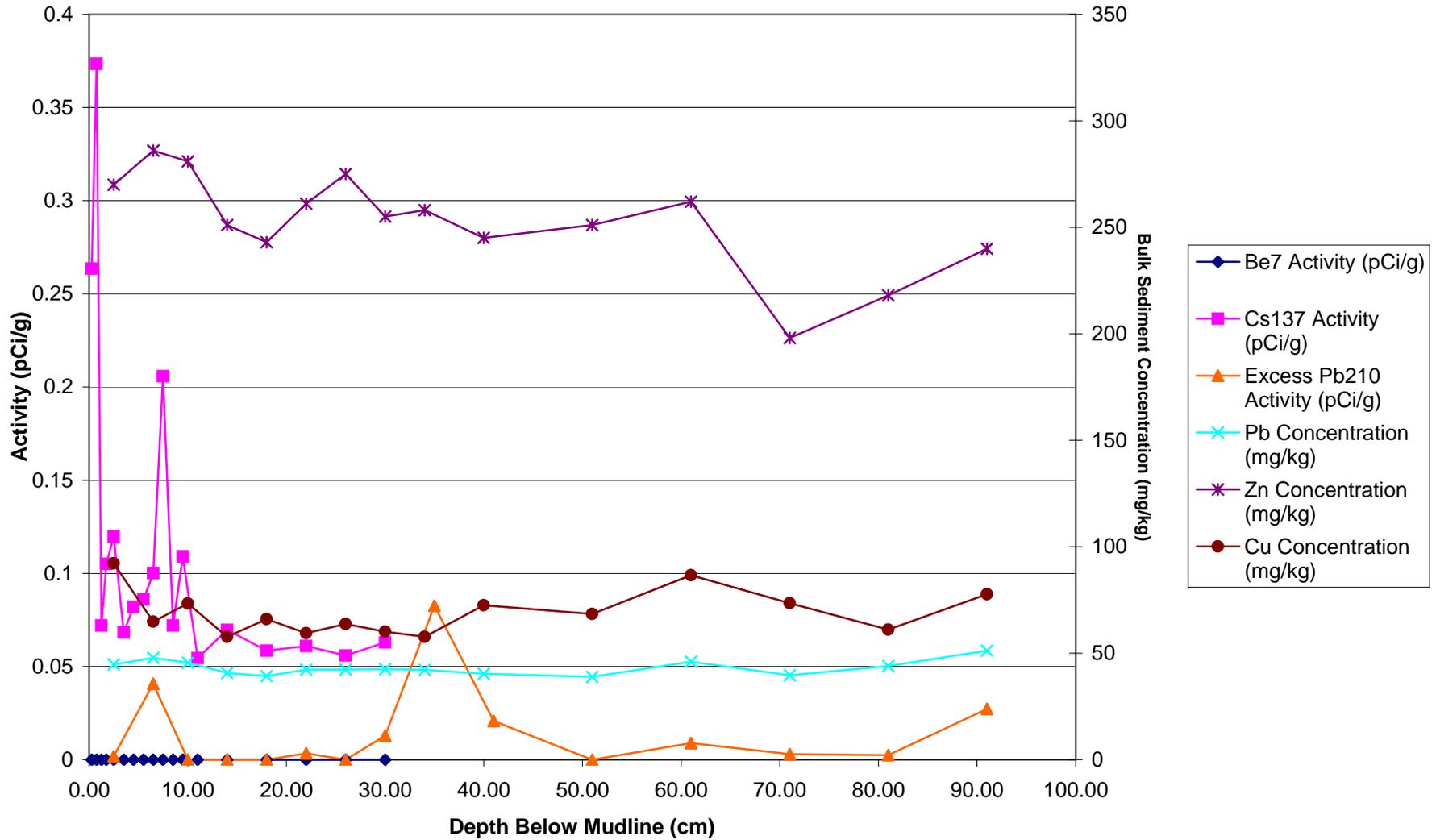
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Figure 5 - Station NA-3 - Radioisotope Activity and Metals Concentrations with Depth



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Figure 6 - Station NA-4 - Radioisotope Activity and Metals Concentrations with Depth



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Figure 7 - Station NA-1 –Radioisotope Activity and Physical Characteristics with Depth

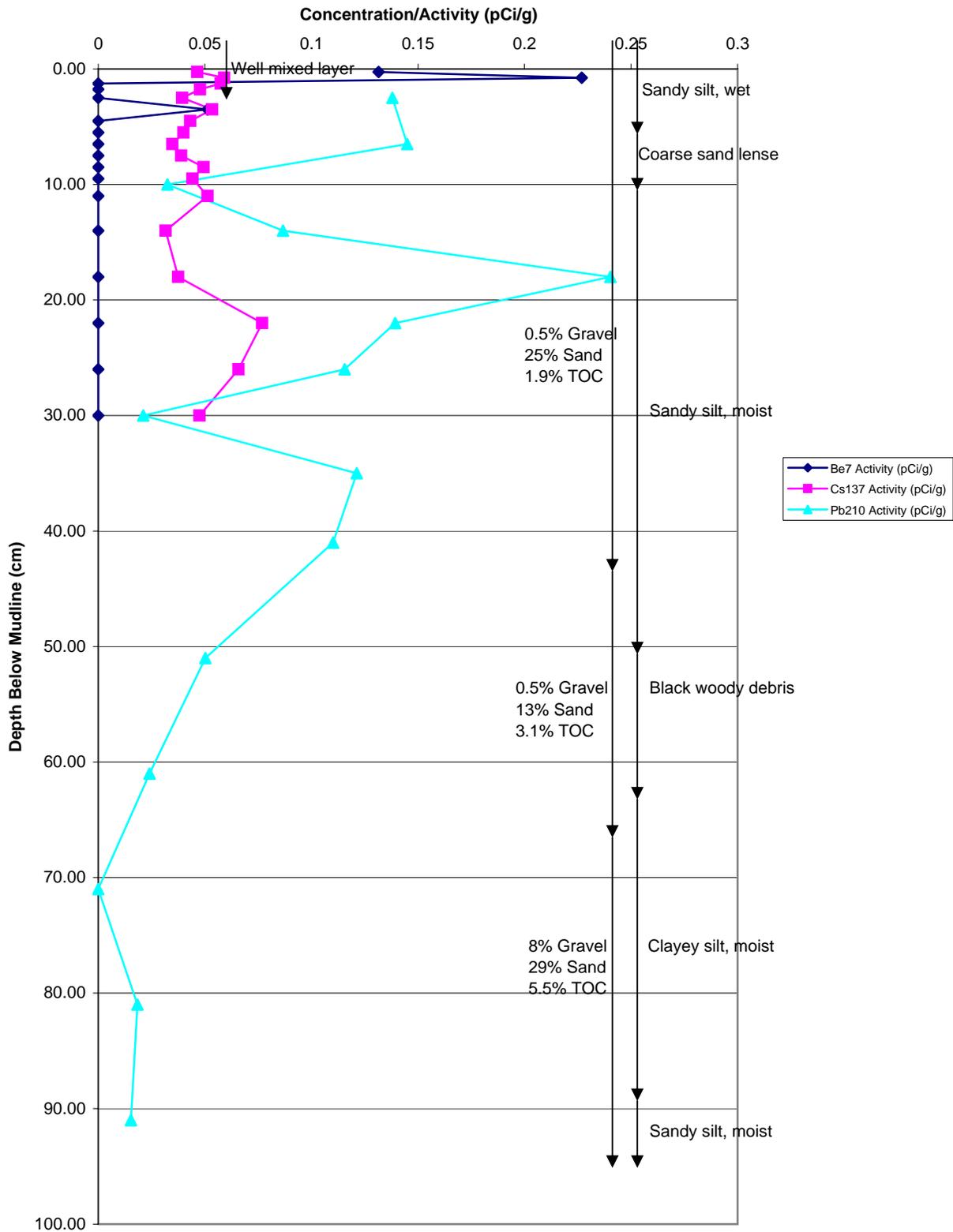


Figure 8 - Station NA-2 –Radioisotope Activity and Physical Characteristics with Depth

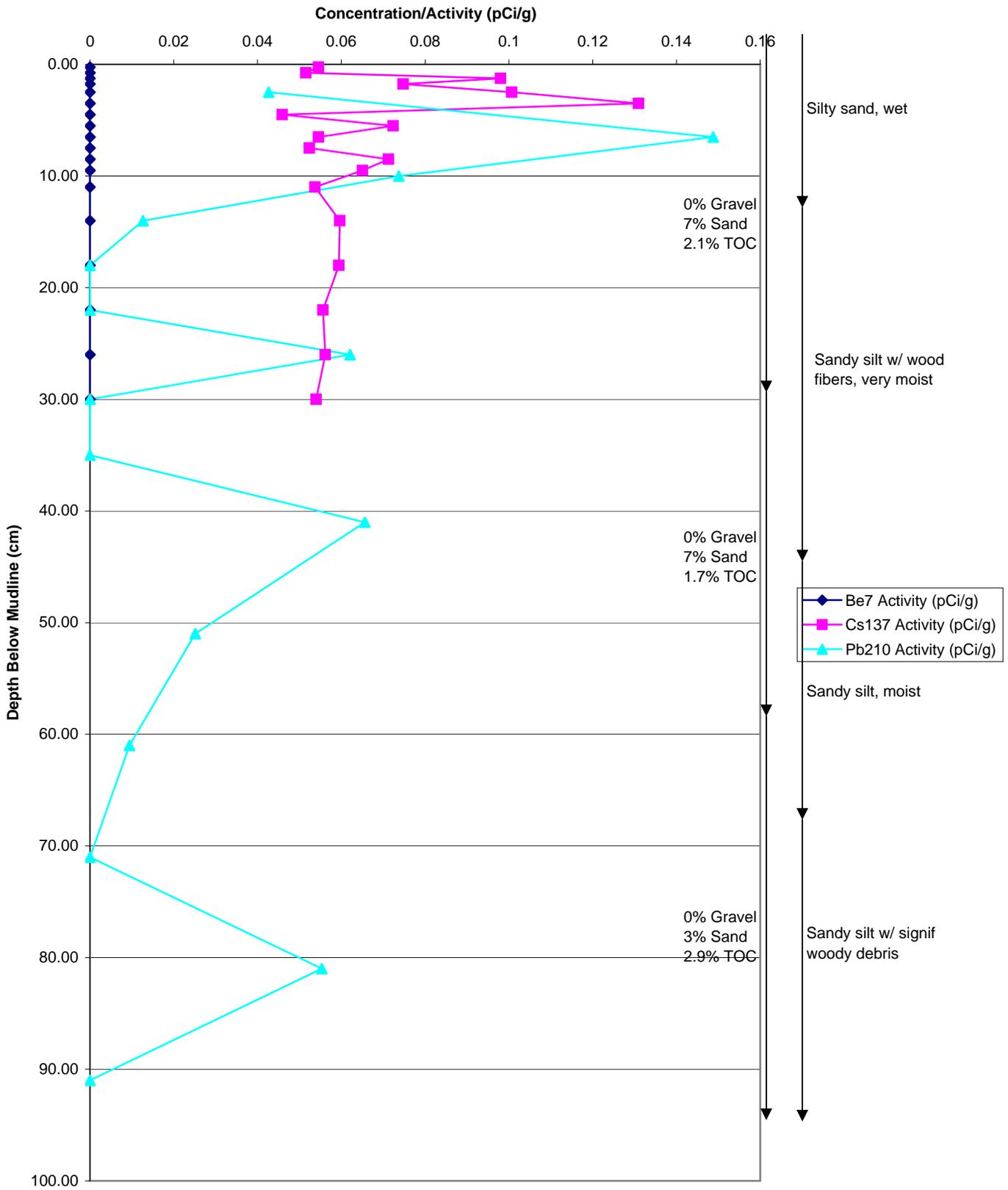


Figure 9 - Station NA-3 –Radioisotope Activity and Physical Characteristics with Depth

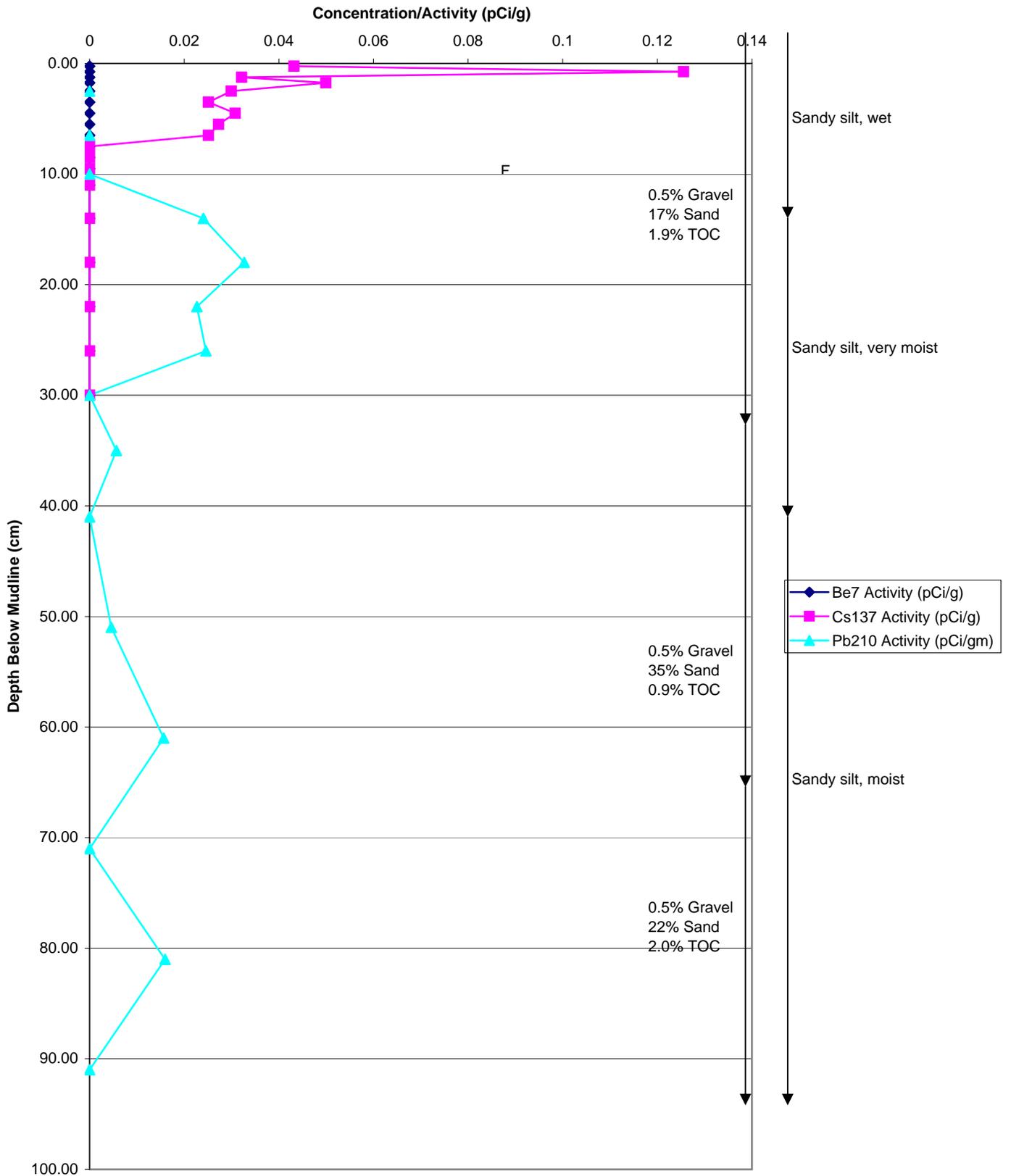


Figure 10 - Station NA-4 –Radioisotope Activity and Physical Characteristics with Depth

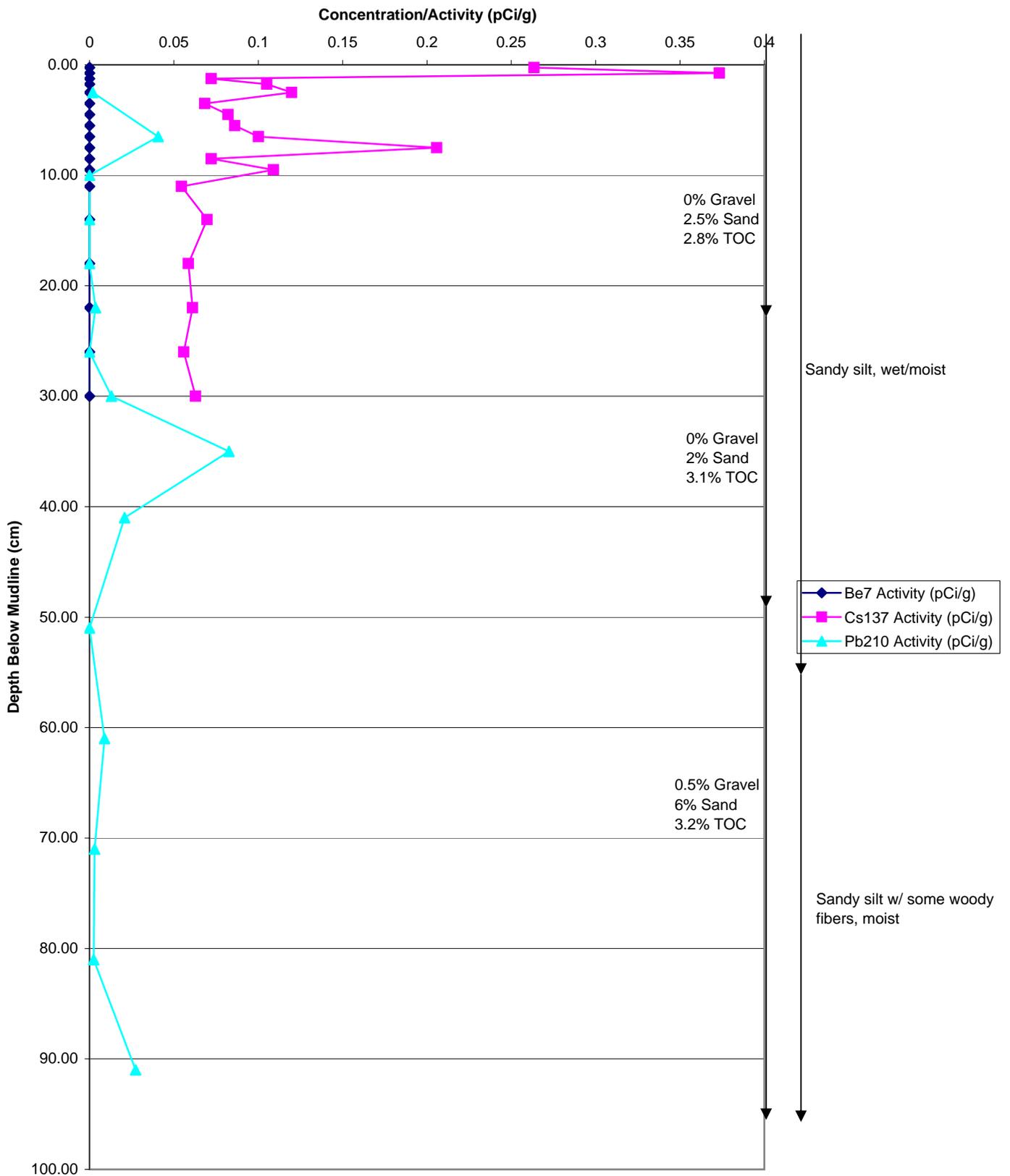


Figure 11 - Station NA-1 - Lead²¹⁰ Radioisotope Activity with Depth

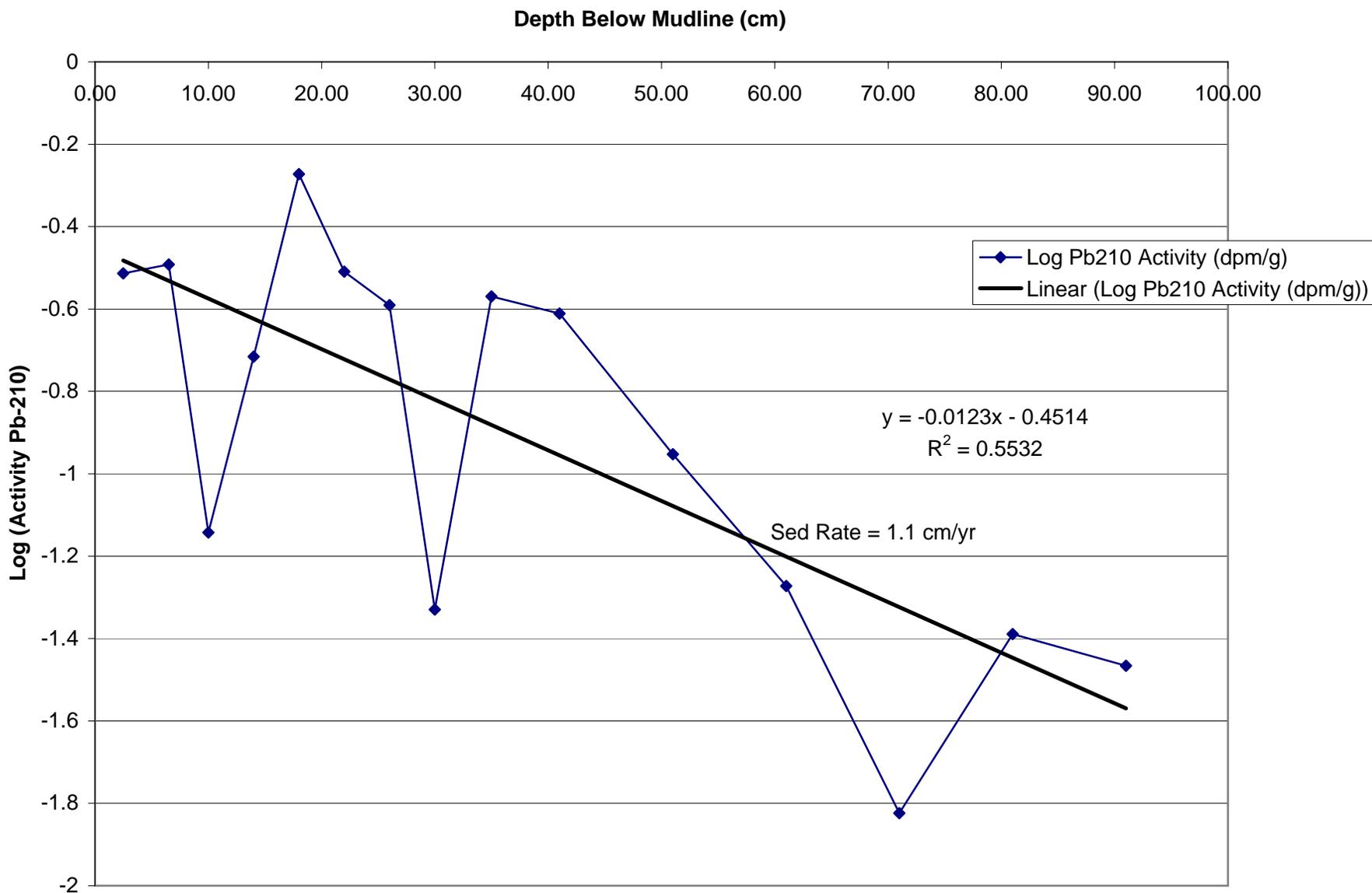


Figure 12 - Station NA-2 - Pb²¹⁰ Radioisotope Activity with Depth

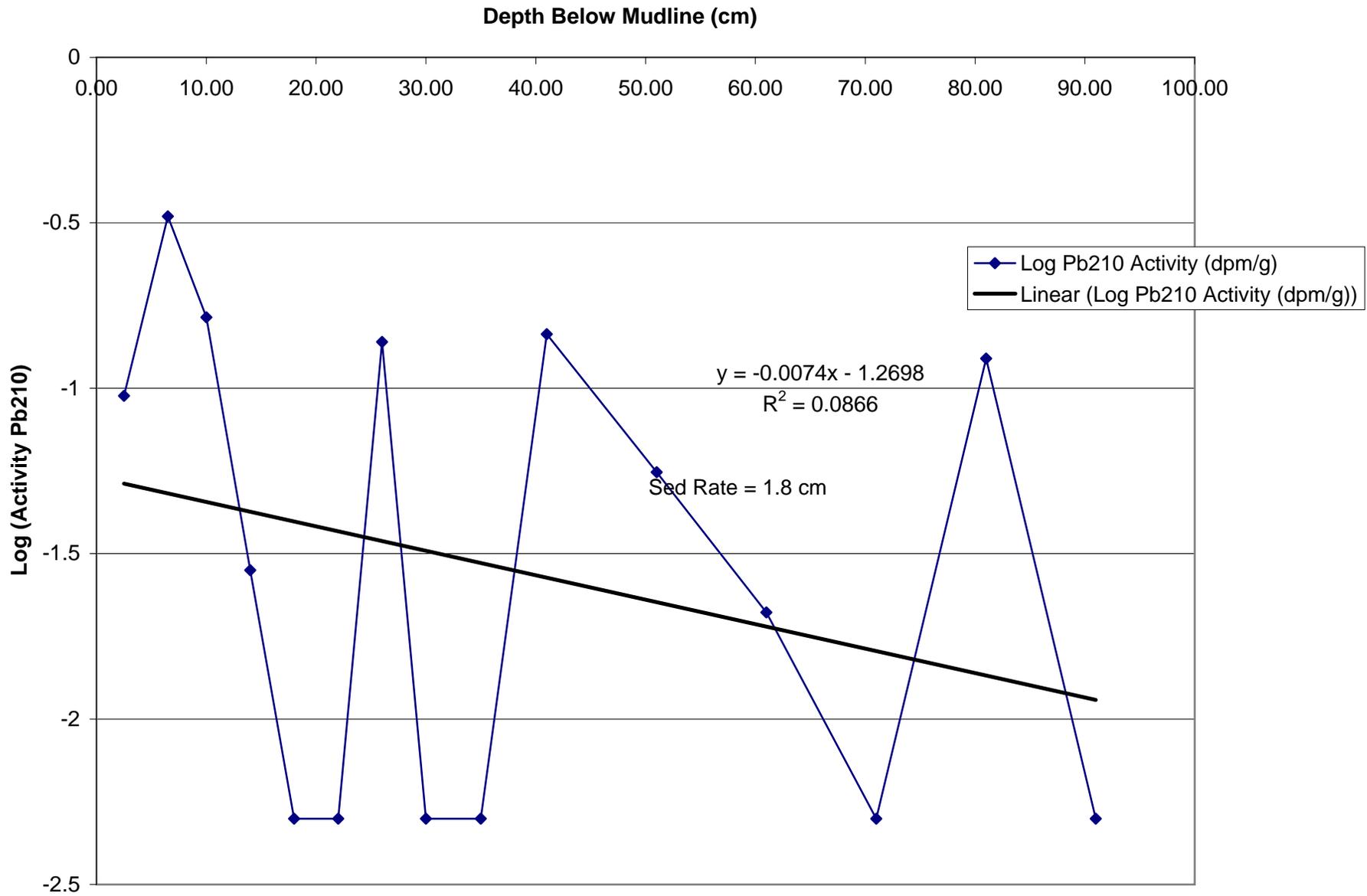
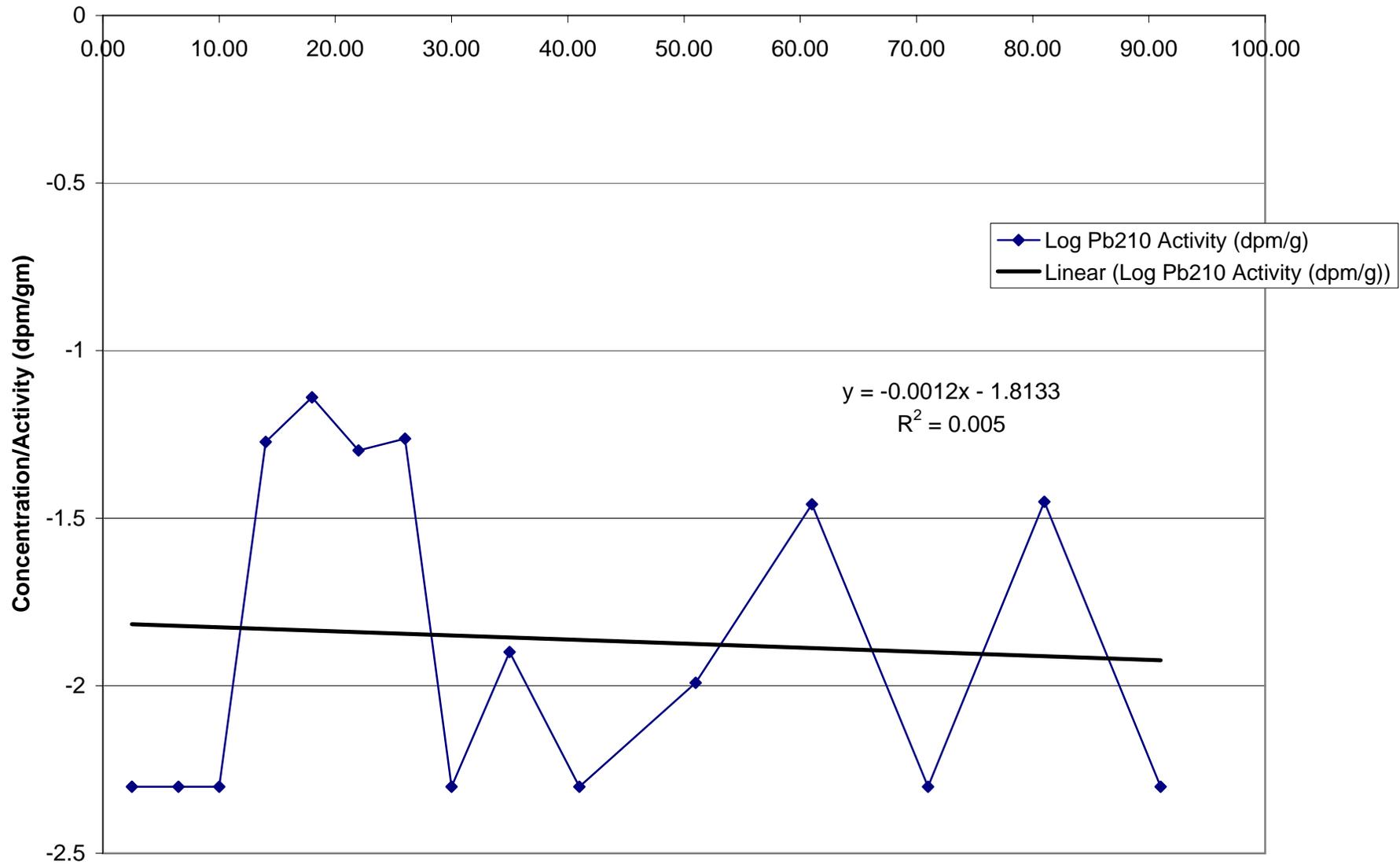
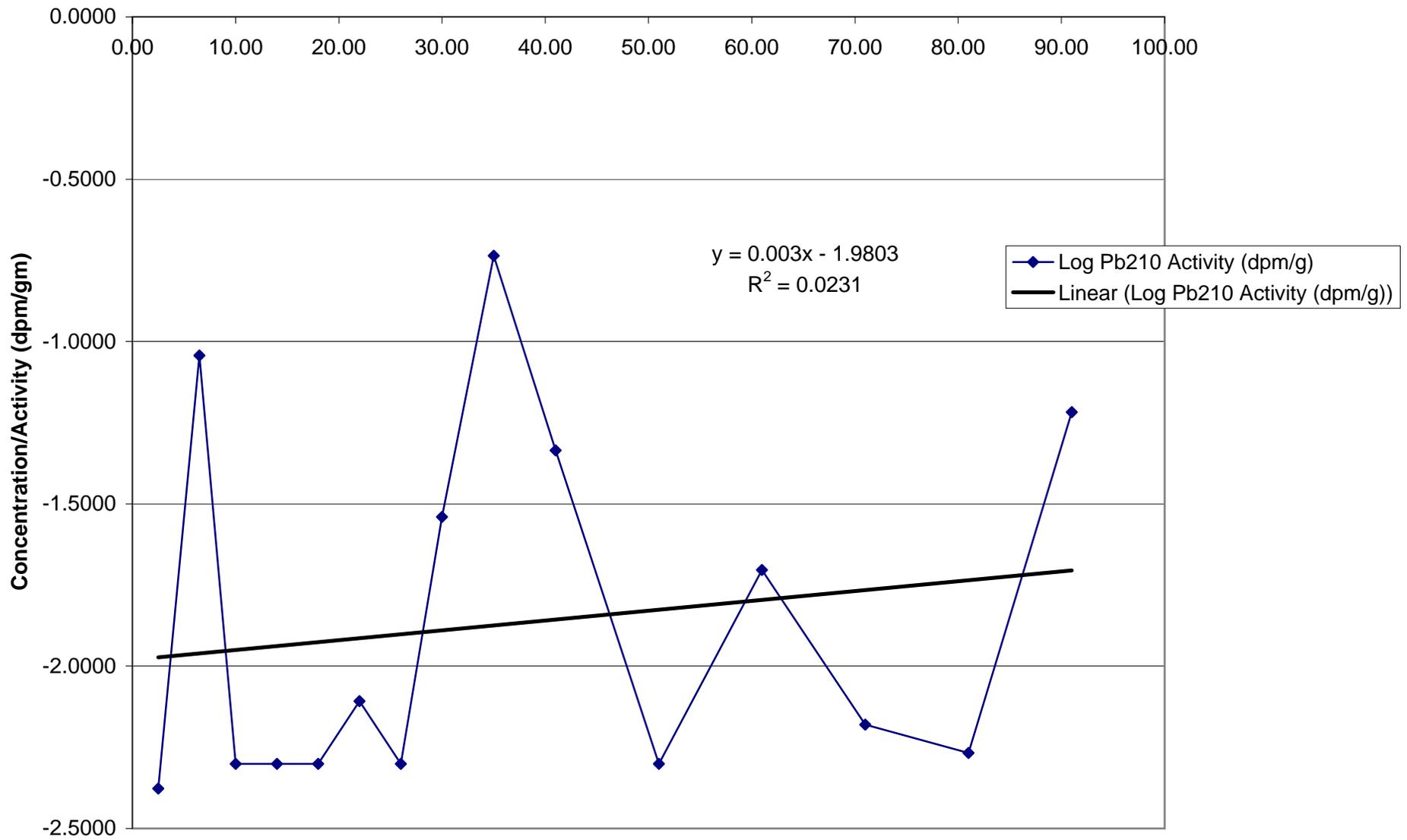


Figure 13 - Station NA-3 - Lead²¹⁰ Radioisotope Activity with Depth
Depth Below Mudline (cm)



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Figure 14 - Station NA-4 - Lead²¹⁰ Radioisotope Activity with Depth
Depth Below Mudline (cm)



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Figure 15. Stations NA-1 and NA-2 - Bulk Metals and Organic Chemical Concentrations with Depth

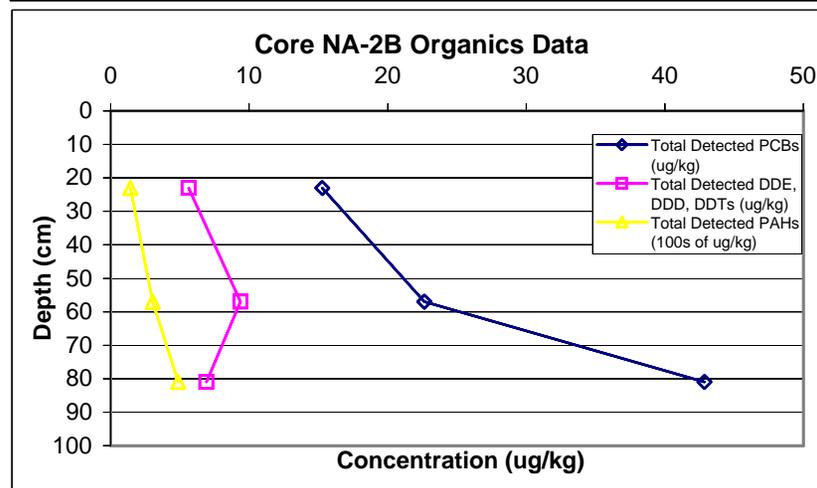
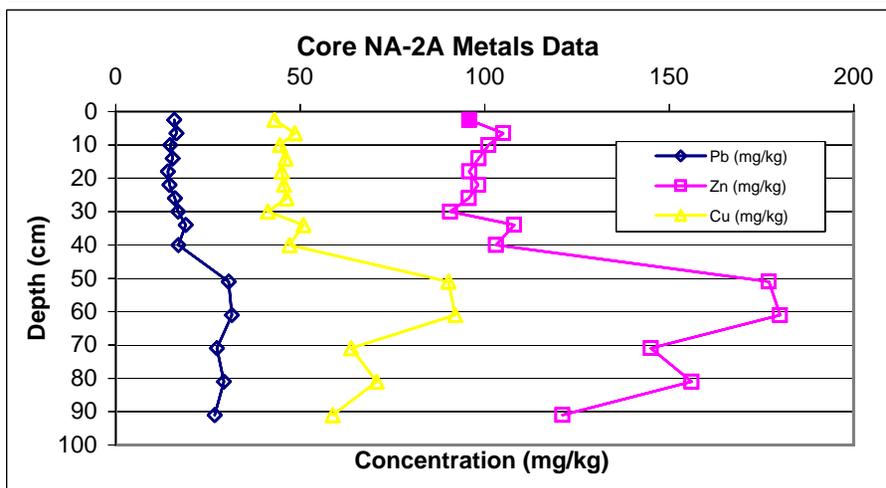
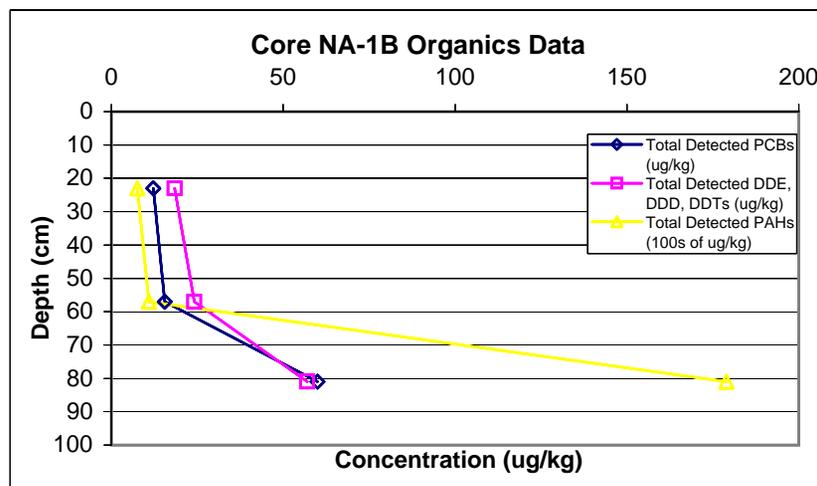
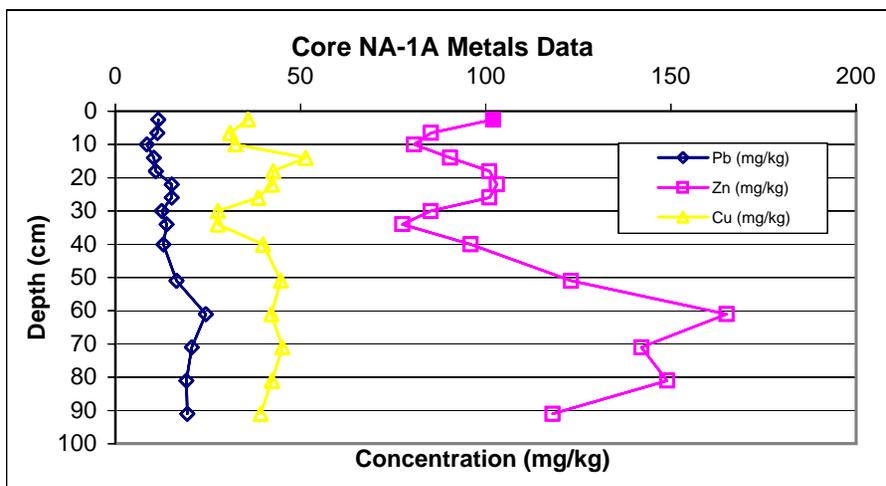


Figure 16. Stations NA-3 and NA-4 - Bulk Metals and Organic Chemical Concentrations with Depth

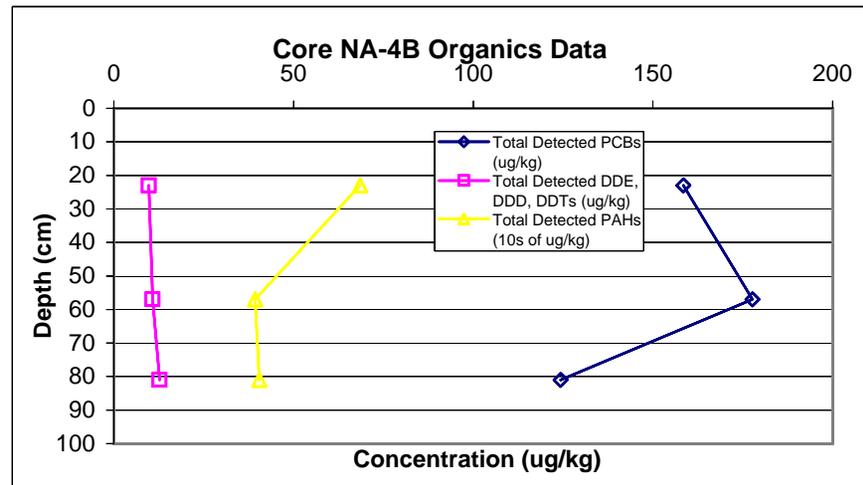
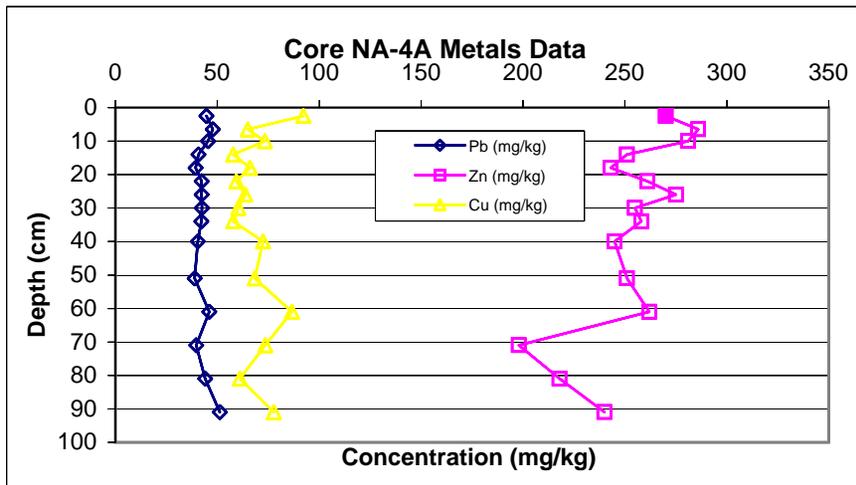
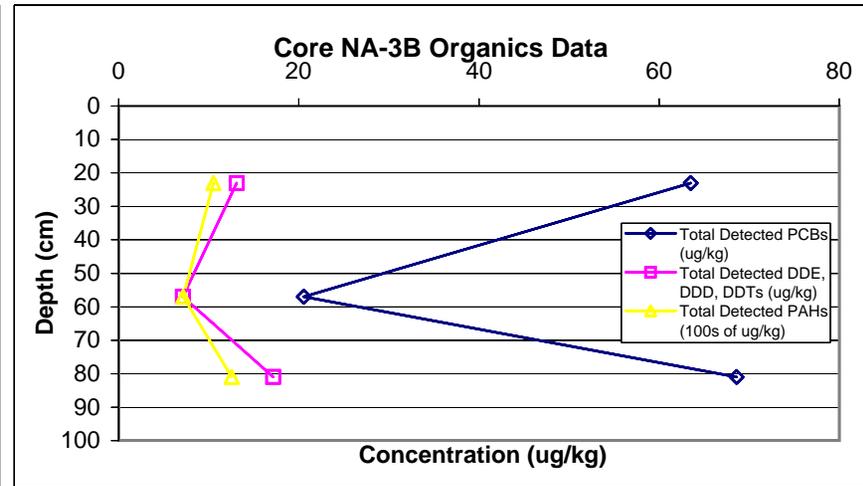
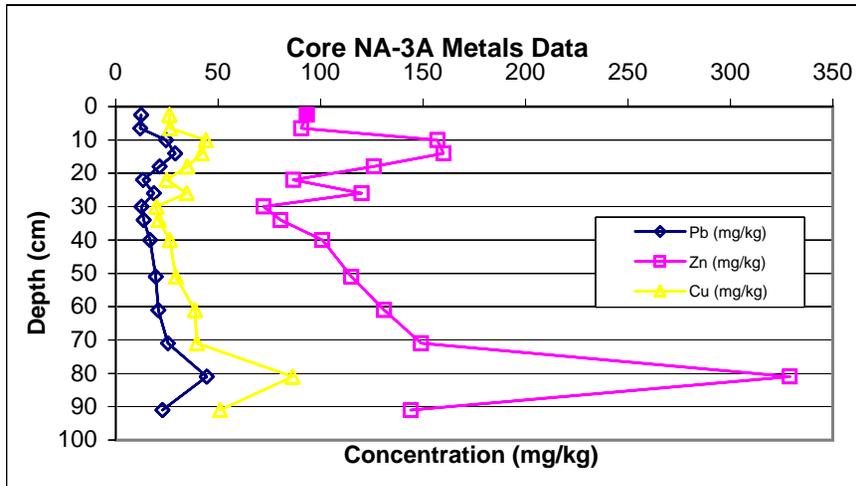


Table 1. Radioisotope Analyses for Natural Attenuation Cores

Date Sampled	Sample ID^a	⁷Be	¹³⁷Cs	²¹⁰Pb	Metals	Archive
10/20/04	NA-1A-0005			X	X	
10/20/04	NA-1A-0508			X	X	
10/20/04	NA-1A-0812			X	X	
10/20/04	NA-1A-1216			X	X	
10/20/04	NA-1A-1620			X	X	
10/20/04	NA-1A-2024			X	X	
10/20/04	NA-1A-2428			X	X	
10/20/04	NA-1A-2832			X	X	
10/20/04	NA-1A-3238			X	X	
10/20/04	NA-1A-3844			X	X	
10/20/04	NA-1A-4448					X
10/20/04	NA-1A-4854			X	X	
10/20/04	NA-1A-5458					X
10/20/04	NA-1A-5864			X	X	
10/20/04	NA-1A-6468					X
10/20/04	NA-1A-6874			X	X	
10/20/04	NA-1A-7478					X
10/20/04	NA-1A-7884			X	X	
10/20/04	NA-1A-8488					X
10/20/04	NA-1A-8894			X	X	
10/20/04	NA-1A-0000.5	X	X			
10/20/04	NA-1A-00.501	X	X			
10/20/04	NA-1A-0101.5	X	X			
10/20/04	NA-1A-01.502	X	X			
10/20/04	NA-1A-0203	X	X			
10/20/04	NA-1A-0304	X	X			
10/20/04	NA-1A-0405	X	X			
10/20/04	NA-1A-0506	X	X			
10/20/04	NA-1A-0607	X	X			
10/20/04	NA-1A-0708	X	X			
10/20/04	NA-1A-0809	X	X			
10/20/04	NA-1A-0910	X	X			
10/20/04	NA-1A-1012	X	X			
10/20/04	NA-1A-1216	X	X			
10/20/04	NA-1A-1620	X	X			
10/20/04	NA-1A-2024	X	X			
10/20/04	NA-1A-2428	X	X			
10/20/04	NA-1A-2832	X	X			
10/20/04	NA-1A-3238					X
10/20/04	NA-1A-3844					X
10/20/04	NA-1A-4448					X
10/20/04	NA-1A-4854					X
10/20/04	NA-1A-5458					X

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Table 1. Radioisotope Analyses for Natural Attenuation Cores

Date Sampled	Sample ID^a	⁷Be	¹³⁷Cs	²¹⁰Pb	Metals	Archive
10/20/04	NA-1A-5864					X
10/20/04	NA-1A-6470					X
10/20/04	NA-1A-7076					X
10/20/04	NA-1A-7682					X
10/20/04	NA-1A-8288					X
10/20/04	NA-1A-8894					X
10/21/04	NA-2A-0005			X	X	
10/21/04	NA-2A-0508			X	X	
10/21/04	NA-2A-0812			X	X	
10/21/04	NA-2A-1216			X	X	
10/21/04	NA-2A-1620			X	X	
10/21/04	NA-2A-2024			X	X	
10/21/04	NA-2A-2428			X	X	
10/21/04	NA-2A-2832			X	X	
10/21/04	NA-2A-3238			X	X	
10/21/04	NA-2A-3844			X	X	
10/21/04	NA-2A-4448					X
10/21/04	NA-2A-4854			X	X	
10/21/04	NA-2A-5458					X
10/21/04	NA-2A-5864			X	X	
10/21/04	NA-2A-6468					X
10/21/04	NA-2A-6874			X	X	
10/21/04	NA-2A-7478					X
10/21/04	NA-2A-7884			X	X	
10/21/04	NA-2A-8488					X
10/21/04	NA-2A-8894			X	X	
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10/21/04	NA-2A-0101.5	X	X			
10/21/04	NA-2A-01.502	X	X			
10/21/04	NA-2A-0203	X	X			
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10/21/04	NA-2A-0405	X	X			
10/21/04	NA-2A-0506	X	X			
10/21/04	NA-2A-0607	X	X			
10/21/04	NA-2A-0708	X	X			
10/21/04	NA-2A-0809	X	X			
10/21/04	NA-2A-0910	X	X			
10/21/04	NA-2A-1012	X	X			
10/21/04	NA-2A-1216	X	X			
10/21/04	NA-2A-1620	X	X			
10/21/04	NA-2A-2024	X	X			
10/21/04	NA-2A-2428	X	X			

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Date Sampled	Sample ID^a	⁷Be	¹³⁷Cs	²¹⁰Pb	Metals	Archive
10/21/04	NA-2A-2832	X	X			
10/21/04	NA-2A-3238					X
10/21/04	NA-2A-3844					X
10/21/04	NA-2A-4448					X
10/21/04	NA-2A-4854					X
10/21/04	NA-2A-5458					X
10/21/04	NA-2A-5864					X
10/21/04	NA-2A-6470					X
10/21/04	NA-2A-7076					X
10/21/04	NA-2A-7682					X
10/21/04	NA-2A-8288					X
10/21/04	NA-2A-8894					X
10/21/04	NA-2A-94112					X
10/22/04	NA-3A-0005			X	X	
10/22/04	NA-3A-0508			X	X	
10/22/04	NA-3A-0812			X	X	
10/22/04	NA-3A-1216			X	X	
10/22/04	NA-3A-1620			X	X	
10/22/04	NA-3A-2024			X	X	
10/22/04	NA-3A-2428			X	X	
10/22/04	NA-3A-2832			X	X	
10/22/04	NA-3A-3238			X	X	
10/22/04	NA-3A-3844			X	X	
10/22/04	NA-3A-4448					X
10/22/04	NA-3A-4854			X	X	
10/22/04	NA-3A-5458					X
10/22/04	NA-3A-5864			X	X	
10/22/04	NA-3A-6468					X
10/22/04	NA-3A-6874			X	X	
10/22/04	NA-3A-7478					X
10/22/04	NA-3A-7884			X	X	
10/22/04	NA-3A-8488					X
10/22/04	NA-3A-8894			X	X	
10/22/04	NA-3A-0000.5	X	X			
10/22/04	NA-3A-00.501	X	X			
10/22/04	NA-3A-0101.5	X	X			
10/22/04	NA-3A-01.502	X	X			
10/22/04	NA-3A-0203	X	X			
10/22/04	NA-3A-0304	X	X			
10/22/04	NA-3A-0405	X	X			
10/22/04	NA-3A-0506	X	X			
10/22/04	NA-3A-0607	X	X			
10/22/04	NA-3A-0708	X	X			

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April 2005

Table 1. Radioisotope Analyses for Natural Attenuation Cores

Date Sampled	Sample ID^a	⁷Be	¹³⁷Cs	²¹⁰Pb	Metals	Archive
10/22/04	NA-3A-0809	X	X			
10/22/04	NA-3A-0910	X	X			
10/22/04	NA-3A-1012	X	X			
10/22/04	NA-3A-1216	X	X			
10/22/04	NA-3A-1620	X	X			
10/22/04	NA-3A-2024	X	X			
10/22/04	NA-3A-2428	X	X			
10/22/04	NA-3A-2832	X	X			
10/22/04	NA-3A-3238					X
10/22/04	NA-3A-3844					X
10/22/04	NA-3A-4448					X
10/22/04	NA-3A-4854					X
10/22/04	NA-3A-5458					X
10/22/04	NA-3A-5864					X
10/22/04	NA-3A-6470					X
10/22/04	NA-3A-7076					X
10/22/04	NA-3A-7682					X
10/22/04	NA-3A-8288					X
10/22/04	NA-3A-8894					X
10/22/04	NA-3A-9498					X
10/21/04	NA-4A-0005			X	X	
10/21/04	NA-4A-0508			X	X	
10/21/04	NA-4A-0812			X	X	
10/21/04	NA-4A-1216			X	X	
10/21/04	NA-4A-1620			X	X	
10/21/04	NA-4A-2024			X	X	
10/21/04	NA-4A-2428			X	X	
10/21/04	NA-4A-2832			X	X	
10/21/04	NA-4A-3238			X	X	
10/21/04	NA-4A-3844			X	X	
10/21/04	NA-4A-4448					X
10/21/04	NA-4A-4854			X	X	
10/21/04	NA-4A-5458					X
10/21/04	NA-4A-5864			X	X	
10/21/04	NA-4A-6468					X
10/21/04	NA-4A-6874			X	X	
10/21/04	NA-4A-7478					X
10/21/04	NA-4A-7884			X	X	
10/21/04	NA-4A-8488					X
10/21/04	NA-4A-8894			X	X	
10/21/04	NA-4A-0000.5	X	X			
10/21/04	NA-4A-00.501	X	X			
10/21/04	NA-4A-0101.5	X	X			

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Table 1. Radioisotope Analyses for Natural Attenuation Cores

Date Sampled	Sample ID^a	⁷Be	¹³⁷Cs	²¹⁰Pb	Metals	Archive
10/21/04	NA-4A-01.502	X	X			
10/21/04	NA-4A-0203	X	X			
10/21/04	NA-4A-0304	X	X			
10/21/04	NA-4A-0405	X	X			
10/21/04	NA-4A-0506	X	X			
10/21/04	NA-4A-0607	X	X			
10/21/04	NA-4A-0708	X	X			
10/21/04	NA-4A-0809	X	X			
10/21/04	NA-4A-0910	X	X			
10/21/04	NA-4A-1012	X	X			
10/21/04	NA-4A-1216	X	X			
10/21/04	NA-4A-1620	X	X			
10/21/04	NA-4A-2024	X	X			
10/21/04	NA-4A-2428	X	X			
10/21/04	NA-4A-2832	X	X			
10/21/04	NA-4A-3238					X
10/21/04	NA-4A-3844					X
10/21/04	NA-4A-4448					X
10/21/04	NA-4A-4854					X
10/21/04	NA-4A-5458					X
10/21/04	NA-4A-5864					X
10/21/04	NA-4A-6470					X
10/21/04	NA-4A-7076					X
10/21/04	NA-4A-7682					X
10/21/04	NA-4A-8288					X
10/21/04	NA-4A-8894					X
10/21/04	NA-4A-94101					X

Notes:

^a - Sample nomenclature includes the sampling interval depth. For example, NA-4A-1216 indicates a sample collected from the 12 to 16 cm interval

Stations NA-1, 2, 3, and 4 were collected in approximately 13, 38, 30, and 27 ft of water, respectively.