

## *Appendix H*

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# **Evaluation of Monitored Natural Recovery**

# **Appendix H – Evaluation of Monitored Natural Recovery**

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This appendix presents an evaluation of the feasibility of monitored natural recovery (MNR) in selected portions of the Removal Action Area. MNR relies on natural recovery processes to achieve site-specific remediation objectives. A screening analysis of MNR was conducted and the results presented in Appendix B. As described in Appendix B, MNR is feasible in the following subareas of the Removal Action Area:

- A portion of Berth 401;
- A portion of Slip 1;
- A portion of Wheeler Bay; and
- North of Berth 414.

This section includes:

- MNR description (Section H.1),
- MNR evaluation (Section H.2), including qualitative (COPC fate and transport, source control, recontamination, exposure, and ability of sediment to recover) and quantitative (predictive modeling of COPC concentrations over time) evaluations of MNR at the Removal Action Area.

## **H.1 MNR Description**

MNR is defined by USEPA as “...sediment cleanup method that uses ongoing, naturally occurring processes to contain, destroy, or otherwise reduce the bioavailability or toxicity of contaminants in sediment.” (USEPA, 2002). MNR can be implemented as a stand-alone technology or in conjunction with other active measures, such as source control or source removal. MNR is a fundamental component of the USEPA’s Contaminated Sediment Management Strategy (USEPA, 1998) and is a USEPA-accepted technology that has been selected as a primary cleanup method for contaminated sediments at several Superfund sites (USEPA, 2002). MNR has also been applied successfully as a key component for several sediment remediation projects in the Pacific Northwest, including Whatcom Waterway in Bellingham, Washington; Manchester Annex in Manchester, Washington (Thornburg and Garbaciak, 1997); Sitcum Waterway in Tacoma, Washington (Hart Crowser, 2004); Thea Foss Waterway in Tacoma, Washington (Hart Crowser, 2003); Eagle Harbor in Bainbridge Island, Washington; Ketchikan Pulp Company in Ketchikan, Alaska; Puget Sound Naval Shipyard in Bremerton, Washington; Middle Waterway in Tacoma, Washington; and Hylebos Waterway in Tacoma, Washington (Keeley, 2004).

Natural recovery processes for contaminated sediment are well documented. The USEPA defines natural processes as the following physical, biological, or chemical mechanisms that reduce risks associated with constituents of potential concern (COPCs) in sediment (USEPA, 2002; Palermo, 2001):

- Physical processes: sedimentation, advection, diffusion, dilution, bioturbation, volatilization;
- Biological processes: biodegradation, biotransformation, phytoremediation, biological stabilization; and

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- Chemical processes: oxidation/reduction, stabilization, sorption.

Risks associated with COPCs in sediment may be reduced through MNR in one or more of the following ways (USEPA, 2002):

- Burial by or mixing in of cleaner sediments resulting in a reduction of COPC concentrations in surface sediment;
- Biodegradation or chemical transformation resulting in the conversion of the COPC to a less toxic form; and
- Sorption to sediment resulting in reduced COPC mobility and bioavailability.

COPC fate and transport are evaluated in Section H.2.1. Conceptual modeling of COPCs is presented in Appendix B of the EE/CA report. Predictive modeling of COPCs is presented in Section H.2.2. For the purposes of evaluating MNR, it was assumed that potential ongoing sources of contamination would be effectively controlled following Removal Action implementation. Appendix N presents an evaluation of recontamination potential. The Removal Action Area is an industrial site with controlled access, thereby limiting exposure to human receptors during recovery.

The streamlined risk evaluation for the Removal Action Area, including the proposed MNR areas, is presented in Appendix M. Appendix L presents potential MNR monitoring that may occur.

## **H.2 MNR Evaluation**

Based on USEPA guidance, there are five components involved in evaluating the feasibility of MNR for contaminated sediment (USEPA, 2002):

- COPC fate and transport;
- Conceptual and predictive modeling of COPC concentration changes over time;
- Source control;
- Limited COPC exposure during recovery, to extent possible; and
- Ability to monitor sediment recovery.

Each of these is discussed in the following sections.

### **H.2.1 COPC Fate and Transport**

COPC fate and transport within the proposed MNR areas were evaluated. The evaluation included:

- Surface sediment concentration of COPCs;
- COPC concentration profiles with depth;
- Sedimentation rates;
- Resuspension and advection;
- Diffusion, including bioturbation;
- Degradation of organic compounds; and
- Sediment/water partitioning.

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Table H-1 summarizes this evaluation for each proposed MNR subarea.

### H.2.1.1 Surface Sediment Concentrations

The data presented in Appendix E were evaluated for surface sediment concentration of COPCs. These data were used in the streamlined risk evaluation for surface sediment concentrations in MNR areas (Appendix M). Areas selected for MNR contained relatively low surface sediment concentrations of COPCs [generally below the probable effects concentrations (PECs) (MacDonald et al., 2000a)]. Surface sediment concentrations of COPCs indicate MNR is a reasonable and feasible remedial action for the proposed MNR areas.

### H.2.1.2 COPC Concentration Profiles with Depth

In the areas of proposed MNR, COPC concentrations with depth, including lead, zinc, total PAHs,  $\Sigma$  DDTs, and total PCBs, were evaluated. The following locations in each subarea were evaluated:

- Berth 401: T4-VC02;
- Slip 1: T4-VC03, T4-VC04, and T4-VC05;
- Wheeler Bay: T4-VC17, T4-VC20, and T4-VC21; and
- North of Berth 414: T4-VC30 and T4-VC31.

At Berth 401, concentrations of the COPCs are generally low and a subsurface maximum concentrations is often present at approximately 2 feet below mudline, as shown on Figure H-1. The generally low concentrations support that MNR is feasible at Berth 401 and that monitoring of the sediment recovery will be important to confirm the low COPC concentrations over time.

In Slip 1, COPC trends generally fell into two categories: decreasing concentration with depth or subsurface maximum at about 2 feet below mudline, as shown on Figure H-2. Lead concentrations decreased with depth at all locations. Zinc, total PAH, and total PCB concentrations at T4-VC03 decreased with depth and at T4-VC04 and T4-VC05 contained subsurface maximum at approximately 2 feet below mudline.  $\Sigma$  DDTs concentrations typically decreased with depth except at T4-VC03 where there was a subsurface maximum at about 2 feet below mudline. This suggests that generally the surface sediment concentrations of COPCs are decreasing with time in the proposed Slip 1 MNR area. This evaluation suggests that MNR is feasible at the Slip 1 area proposed for MNR and monitoring will be important to confirm the COPC concentrations over time.

In Wheeler Bay, there tended to be a subsurface maximum of COPC concentrations below about 5 feet below mudline, as shown on Figure H-3. The only exception was  $\Sigma$  DDTs concentrations at location T4-VC21, which decreased with depth. This indicates that generally the surface sediment concentration of COPCs are decreasing with time in Wheeler Bay and that MNR is feasible in this area.

In the area north of Berth 414, there typically was a subsurface maximum of COPC concentrations at depths of approximately 5 feet or below, as shown on Figure H-4. The only exception was total PAH concentrations at

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location T4-VC31, which decreased with depth. This indicates that generally the surface sediment concentrations of COPCs are decreasing with time north of Berth 414 and that MNR is feasible in this area.

### **H.2.1.3 Sedimentation Rates**

Sedimentation rates were evaluated using the Port of Portland's 2002 Sedimentation at the Port of Portland Terminals report (Port of Portland, 2002). This report used bathymetric data to evaluate sedimentation rates in the Removal Action Area. A summary of the report findings is presented in Appendix G. The report generally showed deposition in the four areas proposed for MNR, indicating MNR is feasible in these areas. In addition, the sediment trend analysis performed for the Portland Harbor Superfund Site (Striplin, 2002) indicates the MNR areas are generally classified as total deposition or dynamic equilibrium (tending towards deposition).

### **H.2.1.4 Resuspension and Advection**

Resuspension and advection were evaluated with the sediment trap data presented in Appendix G. Distinct layering observed in the sediment traps corresponded to vessel traffic in the Removal Action Area. Sediment traps were deployed during a period of minimal rain fall and low river flows. It appears that the sediment collected in the traps is primarily related to resuspension of sediment associated with vessel traffic. The sediment trap data was used to estimate resuspension rates in the Removal Action Area. Sediment traps were not deployed in Berth 401 or in Wheeler Bay. Data from the north of Berth 414 sediment trap were used to evaluate resuspension and advection in Berth 401 and Wheeler Bay. Resuspension rates, based on sediment trap data, ranged from about 20 to 85 g/cm<sup>2</sup>/yr. These relatively high resuspension rates can aid in natural recovery by altering redox conditions (which can result in higher organic compound degradation rates) and by burying or mixing in cleaner sediment (which can result in a reduction of COPC concentrations of surface sediment). Resuspension rates combined with sediment profile data and sediment trap sampling results indicate MNR is feasible at the four areas proposed for MNR.

### **H.2.1.5 Diffusion**

The diffusion aspect of MNR is primarily an evaluation of bioturbation rates. There are no site specific data on bioturbation rates within the Removal Action Area. However, bioturbation in freshwater sediments is well documented (Matisoff et al., 1999; Bosworth and Thibodeaux, 1990).

The life activities of benthic organisms are capable of altering the biological, physical, and chemical properties of sediments (Rhoads, 1974; Guinasso and Schink, 1975; Pryor, 1975; Rice, 1986; Aller, 1988). These activities, such as burrowing and irrigation, tend to increase the exchange of solutes within the bioturbated zone and between sediment and overlying water (Rhoads, 1974; Schink and Guinasso, 1977; Aller and Yingst, 1985; Kristensen et al., 1991). Bioturbation can also physically rework the sediment and increase the resuspension of sediment into the water column (Aller, 1978; Nowell et al., 1981; McCall et al., 1986; Bosworth and Thibodeaux, 1990; and Davis, 1993). The transport of solutes and solids within the sediment and across the sediment-water interface influences many natural biogeochemical cycles, as well as the movement of pollutants in sediments. The intensity of bioturbation depends on the benthic community, in which many characteristics

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may vary spatially, such as the concentration of organisms, the size of the animals, and the life activities of the species present (Rhoads, 1974; Myers, 1977; Aller, 1982 and 1988; Matisoff et al., 1985; Aller and Aller, 1992; Marinelli, 1994).

Organic compounds are decomposed in the sediment through a variety of chemical pathways, depending on the availability of a number of oxidizing agents, such as oxygen. In the absence of burrowing organisms in the sediment or the absence of frequent resuspension of sediment, the supply of oxygen is limited to molecular diffusion through the sediment-water interface. Oxygen will usually penetrate ~2-3 mm into the sediment by molecular diffusion (Aller, 1994). Thus, within a few millimeters of the sediment-water interface, the sediment will be anoxic. Bioturbation in the sediment dramatically increases the supply of oxygen and other solutes to the sediment and, as a result, greatly affects reduction-oxidation (redox) pathways within the sediment.

The standard profile of sediment respiration consists of a series of oxidants that are consumed in order of free energy release, that order being: oxygen, nitrate, manganese, iron, sulfate, and carbon dioxide (Berner, 1980; Froelich et al., 1979; Stumm and Morgan, 1979). The explanation given for this succession is the metabolic free energy yield of the oxidants (Berner, 1980; Froelich et al., 1979; Stumm and Morgan, 1970). Generally, the lower free energy oxidants will not be utilized until the higher-energy oxidants have been consumed. If molecular diffusion from the overlying water column were the only source of these oxidants to the sediment, the major oxidant profile would be one dimensional (Aller, 1982; Aller, 1988; Berner, 1980). The presence of invertebrate infauna, however, introduces burrows into the sediment. Typically, burrows are tube-shaped voids in the sediment and are usually irrigated by the inhabitant with overlying water. Depending on the permeability of the burrow walls, the burrows may introduce oxygen and other oxidants into the sediment. Ventilated burrows extend the sediment-water interface and greatly increase the surface area-to-volume ratio of this interface (Aller, 1988).

Burrowing animals, by altering redox in the sediment, play a key role in the degradation of organic compounds. Burrows increase the depth to which oxygen is supplied. These tubes also assist in the transport of solutes into and out of the sediment. Burrows often transport organic compounds from the sediment-water interface to depth in the sediment. All of these factors affect redox reactions in the sediment, which are often bacterially mediated. There often appears to be a close relationship between burrows and bacteria and sometimes between the infaunal invertebrates themselves and the bacteria (Matisoff et al., 1985; Kristensen et al., 1991). The effects of individual species vary, but generally burrowing animals markedly affect degradation of organic compounds in the sediment by increasing the depth at which it occurs (Matisoff et al., 1985).

When the burrows are ventilated, oxygen radially diffuses into the anoxic sediment (Aller, 1988). This diffusion will locally alter the redox profile around the burrow. Burrows change the rate of oxygen supply from a one-dimensional system of molecular diffusion to a two-dimensional system of radial diffusion (Aller, 1988). Thus, radial diffusion enhances the supply of oxygen to the sediment. Radial diffusion from burrows dramatically alters redox pathways in the sediment in comparison to non-bioturbated sediment.

Oxygen penetrates approximately 70-80% farther into sediments around burrows than at surficial sediment-water interfaces, assuming same sediment reactivity (Aller, 1988). Burrows increase the depth over which organic compound decomposition can occur (Matisoff et al., 1985).

Burrowing organisms also alter the surrounding sediment chemistry by affecting bacteria populations. Bacteria play a major role in both aerobic and anaerobic decomposition of organic compounds. Many of the redox

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pathways are microbially mediated. Anaerobic bacteria use the major oxidants as sources of energy and, in the process of releasing this energy, metabolize organic compounds. Aerobic bacteria frequently reoxidize reduced oxidants, thereby creating a loop in which solutes fluctuate between oxic and anoxic conditions and are oxidized and reduced, respectively. Mucus secretions and metabolite excretions from burrowers can create favorable environments for bacterial growth (Matisoff et al., 1985). Polychaetes often create local “hot spots” of microbial activity by virtue of the solute distributions set up by their burrows. These bacteria play an integral role in degradation of organic compounds.

The oscillating oxygen conditions created by burrow ventilation enhance organic compound decomposition. Aller (1994) found that oscillating redox conditions can promote the degradation of organic compounds. Brief exposure to oxygen may promote anaerobic decomposition of refractory compounds, that is, compounds that are otherwise anaerobically stable (Aller, 1994). Meiofauna and bacteria may be adapted to these oscillating oxygen conditions created by burrow ventilation from polychaetes. Not only can these changing oxygen conditions alter decomposition pathways of organic compounds, they can also engender specific microbial communities that also alter sediment chemistry. The changing oxygen conditions can produce favorable conditions for microbial communities that degrade PAHs, DDT, and PCBs.

#### **H.2.1.6 Degradation of Organic Compounds**

There are no site specific data on degradation rates of organic compounds. However, literature data indicate that PAHs degrade in sediment (Seech et al. 1993; USEPA, 1996; Shuttleworth and Cerniglia, 1995; Cerniglia, 1992; Poeton et al, 1999; and Montgomery and Matisoff, 2004). Literature data also indicate PCBs and  $\Sigma$  DDTs degrade in sediment, although at slower rates than PAHs (Montgomery and Matisoff, 2004; Fish, 1997; Brown et al, 1987; Abramowicz and Olsen, 1995; Bedard and May, 1996; Strand, 2004; Flanagan and May, 1993; Harkness et al., 1993; Johnsen, 1976; Quensen et al., 1998; and Kale et al., 1999). Based on the potential for organic compounds to degrade, MNR is feasible in the four areas proposed for MNR.

PAHs, DDT, and PCBs can be degraded by bacteria and fungi (Cerniglia, 1992; Shuttleworth and Cerniglia, 1995; Johnsen, 1976; Rochkind-Dublinsky et al., 1987). Studies of microbial communities from freshwater sediment indicated freshwater sediment microbial communities can degrade PAHs, DDT, and PCBs (Cerniglia, 1992; Rochkind-Dublinsky et al., 1987; Bedard and May, 1996; Brown et al., 1987; Heitkamp and Cerniglia, 1987; Herbes and Shwall, 1978).

PAH degradation appears to be more rapid and efficient under aerobic conditions (Cerniglia, 1992; Shuttleworth and Cerniglia, 1995). PAH biodegradation mechanisms require the presence of molecular oxygen to initiate enzymatic attack on the PAH rings. Degradation rates for PAHs decrease in anaerobic environments compared to aerobic (Shuttleworth and Cerniglia, 1995). The potential biodegradation rates for PAHs are higher in PAH-contaminated sediments than in pristine sediments (Cerniglia, 1992). Low-molecular-weight PAHs are more easily degraded than high-molecular-weight PAHs (Cerniglia, 1992; Shuttleworth and Cerniglia, 1995; Heitkamp and Cerniglia, 1987).

DDT degrades best under anaerobic conditions (Johnsen, 1976; Huang et al., 2001; Quensen et al., 1998). Under anaerobic conditions, DDT degrades by reductive dechlorination (Johnsen, 1976; Rochkind-Dublinsky, 1987). DDT can degrade aerobically, at a slower rate and less efficiently than anaerobically, by dehydrochlorination (Johnsen, 1976; Rochkind-Dublinsky, 1987).

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PCBs degrade best anaerobically (Rochkind-Dublinsky, 1987; Brown et al., 1987). There is also evidence of aerobic degradation of PCBs in frequently mixed freshwater sediments (Harkness et al., 1993). PCBs with fewer than five chlorines per molecule are extensively degraded, whereas heavier PCB molecules tend not to be degraded (Rochkind-Dublinsky, 1987). Degradation tends to involve hydroxylation, ring cleavage, and degradation of the nonchlorinated ring (Rochkind-Dublinsky, 1987). There was no apparent difference in degradation rates for bacteria cultures that were acclimated and nonacclimated to PCBs (Rochkind-Dublinsky, 1987).

### **H.2.1.7 Sediment/Water Partitioning**

Site-specific partition coefficients were calculated from the thin column leaching test (TCLT) and are presented in Appendix K. Sediment from the north of Berth 414, Slip 3, and Wheeler Bay was used in the TCLT. The TCLT partition coefficients are considered applicable to Berth 401 and Slip 1, given the similarity of contaminants found through out the Removal Action Area. Data from the dredging elutriate test and modified elutriate test are also available for estimating partition coefficients. Site-specific partition coefficients are relatively high, indicating that COPCs are bound to the solid phase. This indicates that COPCs will likely stay sorbed to the solid phase rather than partition into the porewater phase and potentially diffuse into the surface water. This would likely limit the migration of COPCs in the dissolved phase and reduce exposure during MNR. Sediment/water partition coefficients indicate MNR is feasible in the proposed MNR areas.

## **H.2.2 Conceptual and Predictive Modeling of COPC Concentrations Over Time**

Two models, Officer and Lynch (1989) and SEDCAM (Jacobs et al., 1988), were run to estimate changes in COPC concentrations in sediment over time.

### **H.2.2.1 Officer and Lynch Model**

#### **H.2.2.1.1 Model Description and Parameters**

The predictive model Officer and Lynch (Officer and Lynch, 1989) was run to estimate changes in COPC concentrations in sediment over time following implementation of the Removal Action. The Officer and Lynch model is a theoretical solution of sediment contaminant distribution over time in the mixed layer. The mixed layer is represented as a system undergoing physical and chemical processes to some depth below the sediment-water interface. Beneath the mixed layer, sediment concentrations are considered fixed. Sediment below the mixed layer is not considered in this model. The model addresses the mixed layer.

The following physical processes are considered in the model: mixing rates in the mixed layer (bioturbation), accumulation rates, and non-advective exchange rates (resuspension). Contaminants associated with particulate matter are deposited to the sediment surface by sedimentation processes. The non-advective concentrate exchange rate at the sediment-water interface is dependent on the fraction of particles which have been lifted and then returned back to the sediment column and the horizontal water column exchange rate out of the computational region. High rates of resuspension and the removal of contaminated particles out of the region

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are important processes. Because the model does not address spatial variability, the amount of resuspended particulate that is advected out of the waterway is determined as the ratio of the water column residence time and water column particulate residence time.

The Officer and Lynch model has been applied to a number of northwest sediment sites to predict changes in sediment concentrations over time (Officer and Lynch, 1989; Port of Tacoma, 1993; Templeton et al., 1993; and Thornburg and Garbaciak, 1997). The model is an appropriate tool for describing bioturbation, sedimentation, and non-advective sediment water exchanges within the sediment column.

### H.2.2.1.2 Officer and Lynch Model Results

The bioturbation, sedimentation, and sediment-water exchange factors (i.e., terms) were incorporated into a computer model and applied to the Removal Action Area sediments to predict changes in sediment concentrations with time. The physical processes presented in Figure H-5 and used in the model are represented by the following terms (Officer and Lynch, 1989):

- v = the mass accumulation rate in gm/cm<sup>2</sup>-yr
- V = interface concentrate exchange coefficient in gm/cm<sup>2</sup>-yr
- D = diffusion parameter in gm<sup>2</sup>/cm<sup>4</sup>-yr
- d = mixed layer sediment particle accumulation in gm/cm<sup>2</sup>

The following terms were also used in the model (Officer and Lynch, 1989):

- c<sub>1</sub> = concentration in mixed layer
- z = total sediment particle accumulation in gm/cm<sup>2</sup>
- t = time in yr
- k = inherent decay constant for the constituent in yr<sup>-1</sup>

Based on constant sedimentation and bioturbation mixing, for an instantaneous source of unit strength, the concentration in the mixed layer can be calculated as (Officer and Lynch, 1989):

$$c_1(z, t) = e^{\left(\frac{vz}{2D} - \frac{v^2 t}{4D} - kt\right)} \sum_{n=1}^{\infty} Z_n(z) e^{-Da_n^2 t} \quad (1)$$

where a<sub>n</sub> is given by solution to the transcendental equation:

$$\tan a_n d = \frac{4Da_n(v+V)}{4D^2 a_n^2 - v(v+2V)} \quad (2)$$

and where Z<sub>n</sub> is given by:

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$$Z_n(z) = \frac{2D^2 a_n^2 \left( D^2 a_n^2 + \frac{v^2}{4} \right) \left( \cos a_n z + \frac{v + 2V}{2Da_n} \sin a_n z \right)}{d \left( D^2 a_n^2 + \frac{v^2}{4} \right) \left( D^2 a_n^2 + \frac{(v + 2V)^2}{4} \right) + D(v + V) \left( D^2 a_n^2 + \frac{v(v + 2V)}{4} \right)} \quad (3)$$

Input variables for the Officer and Lynch model were based on site specific data and literature values and are presented in Tables H-2 and H-3. The mass accumulation rate ( $v$ ) was based on the Port's bathymetry report (Port, 2002). The interface concentrate exchange coefficient ( $V$ ) and the mixed layer sediment particle accumulation ( $d$ ) were taken from sediment trap data from the Removal Action Area. The diffusion parameters ( $D$ ) were from literature values (Officer and Lynch, 1989). The inherent decay constants for a constituent ( $k$ ) were from literature values (Herbes and Schwall, 1978; Heitkamp and Cerniglia, 1987; Shiaris, 1989; Lun et al., 1998; Krieger-Brockett et al., 1999; Geiselbrecht, 2000; Mackay and Hickie, 2000; Connor et al., 2004; and Huang et al., 2001).

The input variables were used to calibrate the Officer and Lynch model for lead, zinc, total PAHs,  $\Sigma$  DDTs, and total PCBs. The variables were adjusted until the existing surface sediment concentrations for these compounds were approximated. The existing surface sediment concentrations were based on average values from the proposed MNR areas. Depositing sediment concentrations were based on average values from the sediment traps that were deployed within proposed MNR areas. Table H-4 presents the calibration results. The Officer and Lynch model calibrated well for lead, zinc, and total PAHs. The model predicted lower than observed average values for  $\Sigma$  DDTs and total PCBs. The low prediction for  $\Sigma$  DDTs may be a result of the low detection limits used for these compounds. The low prediction for total PCBs is likely because most total PCB summations include one or two Aroclors that were detected near (less than two times) or below the method reporting limit. The total PCB results, in the proposed MNR areas, are dominated by near method reporting limit results, which cannot be approximated by the model using reasonable input variables.

Once the Officer and Lynch model was calibrated, it was run to estimate future surface sediment concentrations for lead, zinc, total PAHs,  $\Sigma$  DDTs, and total PCBs. Depositing sediment concentrations were based on average concentrations of modeled post Removal Action sediment. Modeled concentrations contain total calculations that use one half the detection limit for not detected values rather than treating not detected values as zero, as described in Appendix E. The use of one half the detection limit rather than treating non-detects as zero results in higher total concentrations. Because the Removal Action Area has high resuspension rates, it was assumed that depositing sediment concentrations would consist of post Removal Action surface sediment concentrations. Results of the Officer and Lynch model are presented in Table H-5. Modeled results are presented along with adjusted modeled results, which are adjusted to account for low or high predictions of the calibrated model, presented in Table H-4.

The Officer and Lynch model predicts that surface sediment concentrations quickly move to equilibrium as a result of the high sedimentation rates at the proposed MNR areas. Although it is not shown in Table H-5 because of the number of significant figures that were used, the Officer and Lynch model predicts that surface sediment concentrations for lead, zinc, total PAHs,  $\Sigma$  DDTs, and total PCBs would stabilize by three years after completion of the Removal Action.

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The results of the Officer and Lynch model were compared to the threshold effects concentrations (TECs) (MacDonald et al., 2000a). The use of these guidelines does not imply that they should or would be used as cleanup levels for the Removal Action Area. Existing lead and zinc surface sediment concentrations in the proposed MNR areas are below the TEC. Modeled lead and zinc concentrations remained below the TEC. The existing maximum total PAH concentrations are above the TEC. Modeled total PAH concentrations remain above the TEC. However, the terms used in the model are conservative and the actual concentrations may be lower. The existing  $\Sigma$  DDTs concentrations were above the TEC. The predicted  $\Sigma$  DDTs concentrations are below the TEC. The existing total PCB concentrations are below the TEC and predicted results remained below the TEC.

## H.2.2.2 SEDCAM Model

### H.2.2.2.1 Model Description

The SEDCAM model, which is accepted and used by Washington State Department of Ecology, was used to evaluate the change in sediment concentrations with time (Jacobs et al., 1988; Ecology, 1991). SEDCAM evaluates source loading, sediment deposition, and chemical specific degradation rates. The concentration at some time after natural recovery begins can be estimated as follows (Jacobs et al., 1988):

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

Where:

C(t) = concentration in surface sediment at time t (mg/kg or  $\mu\text{g}/\text{kg}$ )

M = sedimentation rate ( $\text{g}/\text{cm}^2\text{-yr}$ )

k = combined first order rate constant for contaminant loss through decay and diffusion processes ( $\text{yr}^{-1}$ )

$C_p$  = concentration in particles being deposited on the sediment (mg/kg or  $\mu\text{g}/\text{kg}$ )

t = time (yr)

$C_o$  = initial concentration in surface sediment (mg/kg or  $\mu\text{g}/\text{kg}$ )

The total accumulation of sediment in the mixed layer (S) is calculated as follows:

$$S = MLd(1 - p)$$

Where:

ML = thickness of mixed layer (cm)

d = density of sediment ( $\text{g}/\text{cm}^3$ )

p = porosity of sediment ( $\text{cm}^3/\text{cm}^3$ )

SEDCAM was run for the following constituents: lead, zinc, total PAHs,  $\Sigma$  DDTs, and total PCBs. The existing maximum concentrations in the proposed MNR areas of these constituents were used. Site-specific sedimentation rates, based on the Port's bathymetry report (Port, 2002), range from approximately 5 to 15  $\text{g}/\text{cm}^2\text{-yr}$ . A conservative value of 5  $\text{g}/\text{cm}^2\text{-yr}$  was used for M. A range of k values, based on literature values, is

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presented in Table H-3. The value for  $k$  was set to zero for lead and zinc. For total PAHs,  $\Sigma$  DDTs, and total PCBs, values of 0.0365, 0.003, and 0.003  $\text{yr}^{-1}$ , respectively, were used. These values are conservative because they do not account for diffusion, which the  $k$  term in the SEDCAM model accounts for. The value for  $S$  was calculated using 1 ft for the thickness of the surface layers, a density of 1.922  $\text{g}/\text{cm}^3$  (Glover, 1996), and a porosity of 0.7  $\text{cm}^3/\text{cm}^3$  (Ecology, 1991). Based on hydrodynamic and sediment trap data collected in the Removal Action Area, resuspension is an important factor in the Removal Action Area. The chemistry of depositing sediment was based on average concentrations of modeled post Removal Action sediment. Modeled concentrations contain total calculations that use one half the detection limit for not detected values rather than treating not detected values as zero. The use of one half the detection limit rather than treating non-detects as zero results in higher total concentrations.

#### **H.2.2.2.2 SEDCAM Model Results**

The results were compared to the TECs (MacDonald et al., 2000a). The use of these guidelines does not imply that they should or would be used as cleanup levels for the Removal Action Area. Results of the SEDCAM model are presented in Table H-6. Existing lead and zinc surface sediment concentrations in the proposed MNR areas are below the TEC. Modeled lead and zinc concentrations decreased with time and remained below the TEC. The existing maximum total PAH concentrations are above the TEC. Modeled total PAH concentrations remain above the TEC within years one through five after completion of the Removal Action. However, if the  $k$  term is adjusted to 0.365  $\text{yr}^{-1}$ , within the literature degradation value and still not accounting for diffusion, total PAH concentrations decrease to below the TEC within 4 years (1310  $\mu\text{g}/\text{kg}$ ) of completion of the Removal Action. The existing maximum  $\Sigma$  DDTs concentrations were above the TEC. The predicted  $\Sigma$  DDTs concentration in the predicted depositing sediment was also above the TEC. Although modeled  $\Sigma$  DDTs concentrations decrease with time, because the depositing sediment concentration is greater than the TEC, modeled  $\Sigma$  DDTs concentrations do not go below the TEC. As described above, the predicted depositing sediment concentrations are conservative because of the use of one half the detection limit in the total concentration and actual concentrations may be lower. The existing total PCB concentrations are above the TEC. Modeled total PCB concentrations were below the TEC at year 2 (58.4  $\mu\text{g}/\text{kg}$ ) after completion of the Removal Action.

#### **H.2.2.3 Evaluation of Officer and Lynch and SEDCAM Models**

The concentrations predicted by the Officer and Lynch model and the SEDCAM model are different. However, modeled results from both models indicate the same conclusion that surface sediment concentrations will decrease with time. Both models indicate that lead, zinc, and total PCB surface sediment concentrations will be below the TEC by at least a few years after the Removal Action. The models predicted different results for total PAHs and  $\Sigma$  DDTs concentrations; however both models indicate these concentrations are decreasing with time. Also, the predicted depositing sediment concentrations are conservative because of the use of one half the detection limit in the total concentrations.

If MNR were selected as one of the technologies, monitoring of the MNR area, as proposed in Appendix L and summarized below in Section H.5, would be performed to confirm that the sediment is recovering. If surface sediment concentrations do not recover to agreed upon cleanup criteria within five years, then the MNR areas that do not meet the cleanup criteria would be evaluated for additional removal action (provided upstream source control actions have been accomplished).

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### **H.3 Source Control**

Appendix A of the EE/CA describes potential sources of COPCs to the Removal Action Area from Upland sources. The Port has entered into Voluntary Agreements with the DEQ to investigate and mitigate these potential sources (Oregon DEQ, 2000 and Oregon DEQ, 2003, respectively). The Remedial Investigation and Feasibility Study of the diesel seep at Slip 3 is complete and a Record of Decision was prepared by the DEQ presenting the necessary remedial action to meet remedial goals. Remedial goals included both protection of human and environmental health from the COPCs identified at the facility, and mitigation of ongoing sources to the slip and Willamette River. Remedial action was conducted at Slip 3 in the Fall of 2004 and included excavating soil containing residual petroleum product along the eastern side of the slip and replacing the soil with amended fill to mitigate dissolved or separate phase petroleum from entering the slip. There is an ongoing stormwater and pencil pitch investigation associated with the Terminal 4 Slip 3 upland site. The Remedial Investigation of Slip 1 is ongoing. As described in the Voluntary Agreement with the DEQ, one of the objectives of the Remedial Investigation is to identify potential sources to the slip and/or Willamette River that could contribute chemicals above acceptable levels. If potential sources of concern are present, a feasibility study will be conducted to evaluate and recommend an appropriate remedy to mitigate the source(s) and the Port will implement the approved remedy as required by the DEQ.

In addition to its ongoing work to mitigate and control potential Upland Sources at Terminal 4, the Port is conducting a detailed recontamination analysis that identifies the potential sources (e.g., Upland, resuspension, stormwater, etc.) and evaluates the potential contribution of COPCs to the Removal Action Area following the removal action. Appendix N provides a detailed description of the evaluation process that is being used to complete the recontamination analysis.

### **H.4 Limited COPC Exposure During Recovery**

The Removal Action Area is an industrial site with controlled access thereby limiting human access. The Port conducted an analysis of the potential for exposure in the Removal Action Area. The results of this analysis support only limited human exposure occurs. Additionally, most of the activities occur in areas not proposed for MNR, further supporting that only limited exposure to sediments in the MNR areas will occur during recovery. Ecological exposures are limited within the proposed MNR areas because surface concentrations are low.

### **H.5 Ability to Monitor Sediment Recovery**

The areas proposed for MNR are accessible for ongoing monitoring following the Removal Action. Post-Removal Action monitoring for MNR may consist of periodic surface sediment sampling.

These monitoring activities would likely be performed shortly after completion of the Removal Action and periodically thereafter. The frequency of the periodic monitoring would be determined during detailed design of the selected remedy. The frequency may also be modified based on performance. If the MNR area is performing as expected, the length of time between monitoring events may increase. If surface sediment concentrations in MNR areas do not recover to agreed upon cleanup criteria within five years, then the MNR areas that do not meet the cleanup criteria will be evaluated for additional removal action.

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**Table H-1  
Qualitative Evaluation of MNR**

<b>Subarea</b>	<b>Surface Sediment Concentrations and Potential Risk</b>	<b>COPC Concentration Profile with Depth</b>	<b>Sedimentation Rates</b>	<b>Resuspension Rates and Advection</b>	<b>Diffusion and Bioturbation</b>	<b>Degradation of Organic Compounds</b>	<b>Sediment/Water Partitioning</b>
Berth 401	high	high	high	high	unknown	high	high
Slip 1	high	moderate	high	high	unknown	high	high
Wheeler Bay	high	high	high	high	unknown	high	high
North of Berth 414	high	high	high	high	unknown	high	high

High = indicates MNR is feasible.

Moderate = indicates MNR may be feasible.

Unknown = no data to indicate if MNR is feasible.

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**Table H-2**  
**Range of Variables for Officer and Lynch Model**

<b>Variable</b>	<b>Description</b>	<b>Unit</b>	<b>Minimum Value</b>	<b>Mean Value</b>	<b>Maximum Value</b>	<b>Source</b>
v	mass accumulation rate	g/cm <sup>2</sup> /yr	5	10	15	Port, 2002
V	interface concentrate exchange coefficient	g/cm <sup>2</sup> /yr	20	65	85	sediment traps
d	mixed layer sediment particle accumulation	g/cm <sup>2</sup>	0.24	1	4.7	sediment traps
D	diffusion parameter	g <sup>2</sup> /cm <sup>4</sup> /yr	1	2	5	Officer and Lynch, 1989

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**Table H-3**  
**Range of k Values for Officer and Lynch Model**

	<b>Minimum Value (yr<sup>-1</sup>)</b>	<b>Mean Value (yr<sup>-1</sup>)</b>	<b>Maximum Value (yr<sup>-1</sup>)</b>	<b>Source</b>
Lead	0	0	0	NA
Zinc	0	0	0	NA
Total PAHs	0.0153	0.5	10	Geiselbrecht, 2000; Lun et al, 1998; Herbes and Schwall, 1978; Heitkamp and Cerniglia, 1987; Mackay et al, 2000; Shiaris, 1989; Krieger-Brockett et al, 1999
Total DDT	0.003	0.077	0.77	Connor et al, 2004; Huang et al, 2001
Total PCBs	0.0014	0.05	5	Van Dort et al, 1997; Hollifield et al, 1995; Lake et al, 1991; Beurskens and Stortelder, 1995; Fish, 1997

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**Table H-4  
Input Parameters and Calibration of Officer and Lynch Model**

	<b>d</b> (gm/cm <sup>2</sup> )	<b>D</b> (gm <sup>2</sup> /cm <sup>4</sup> -yr)	<b>v</b> (gm/cm <sup>2</sup> -yr)	<b>V</b> (gm/cm <sup>2</sup> -yr)	<b>z</b> (gm/cm <sup>2</sup> )	<b>k</b> (yr <sup>-1</sup> )	<b>C<sub>0</sub></b> (µg/kg)	<b>C<sub>1</sub>(z,t)</b> (µg/kg)	<b>C<sub>1</sub></b> (µg/kg)	<b>Percent Difference between C<sub>1</sub>(z,t) and C<sub>1</sub></b>
Lead	4	5	15	20	4	0	33,400	19,144	18,000	6%
Zinc	4	5	15	20	4	0	145,000	83,112	81,000	3%
Total PAHs	4	5	15	20	4	0.0365	4,000	2,272	2,982	24%
Total DDT	4	5	15	20	4	0.003	12	6.87	12	43%
Total PCBs	4	5	15	20	4	0.003	39.6	22.7	43	47%

d = mixed layer sediment particle accumulation.

D = diffusion parameter.

v = mass accumulation rate.

V = interface concentrate exchange coefficient.

z = total sediment particle accumulation.

k = inherent decay constant for the constituent.

C<sub>0</sub> = concentration in depositing sediment before Removal Action. Based on average sediment trap concentration from proposed MNR areas.

C<sub>1</sub>(z,t) = modeled existing mixed layer concentration.

C<sub>1</sub> = existing mixed layer concentration. Based on average surface sediment concentration from proposed MNR areas.

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**Table H-5  
Officer and Lynch Model Results**

	<b>Unit</b>	<b>TEC (a)</b>	<b>Year 1</b>	<b>Year 1 Adjusted (b)</b>	<b>Year 2</b>	<b>Year 2 Adjusted (b)</b>	<b>Year 3</b>	<b>Year 3 Adjusted (b)</b>
Lead	mg/kg	35.8	9.74	9.16	9.74	9.16	9.74	9.16
Zinc	mg/kg	121	46.4	45.0	46.4	45.0	46.4	45.0
Total PAHs	ug/kg	1,610	1694	2100	1694	2100	1694	2100
Total DDT	ug/kg	5.28	3.44	4.91	3.44	4.91	3.44	4.91
Total PCBs	ug/kg	59.8	17.8	26.1	17.8	26.1	17.8	26.1

- a. Development and Evaluation of Consensus-based Sediment Quality Guidelines for Freshwater Receptors (MacDonald et al., 2000a). Consensus based threshold effect concentrations (TEC). Represents concentration below which toxicity is unlikely to be observed.
- b. Results adjusted based on percent differences presented in Table H-4.

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**Table H-6  
SEDCAM Change in Surface Sediment Concentration in MNR Area with Time**

Compound	Unit	TEC (a)	Existing Maximum Concentration in Surface Sediment	Concentration in Post Removal Action Depositing Sediment	Year 1	Year 2	Year 3	Year 4	Year 5
Lead	mg/kg	35.8	33.7	17	29.6	26.5	24.1	22.4	21.0
Zinc	mg/kg	121	96.9	72	90.7	86.1	82.6	80.0	78.0
Total PAH (d,e)	µg/kg	1,610	7,988	1,750	6,229	4,945	4,013	3,338	2,847
ΣDDTs (d,f)	µg/kg	5.28	37.2	6	29.4	23.5	19.1	15.8	13.4
Total PCB (d,g)	µg/kg	59.8	80	31	67.7	58.4	51.5	46.3	42.4

Year 1, year 2, etc. indicate number of years after completion of removal action.

Shaded values indicate first year in which concentration is less than TEC.

a. Development and Evaluation of Consensus-based Sediment Quality Guidelines for Freshwater Receptors (MacDonald et al., 2000a).

Consensus based threshold effect concentrations (TEC). Represents concentration below which toxicity is unlikely to be observed.

b. Mass of constituent in surface sediment. Based on maximum concentration of constituent in proposed MNR areas.

c. Mass of constituent in depositing sediment. Based on average concentration of post removal action sediment for Removal Action Area.

d. Total concentrations are calculated using the detected concentrations of individual constituents. Non-detects are treated as zeros. If all the individual constituents are non-detect, the total concentration is reported as non-detect using the highest detection limit.

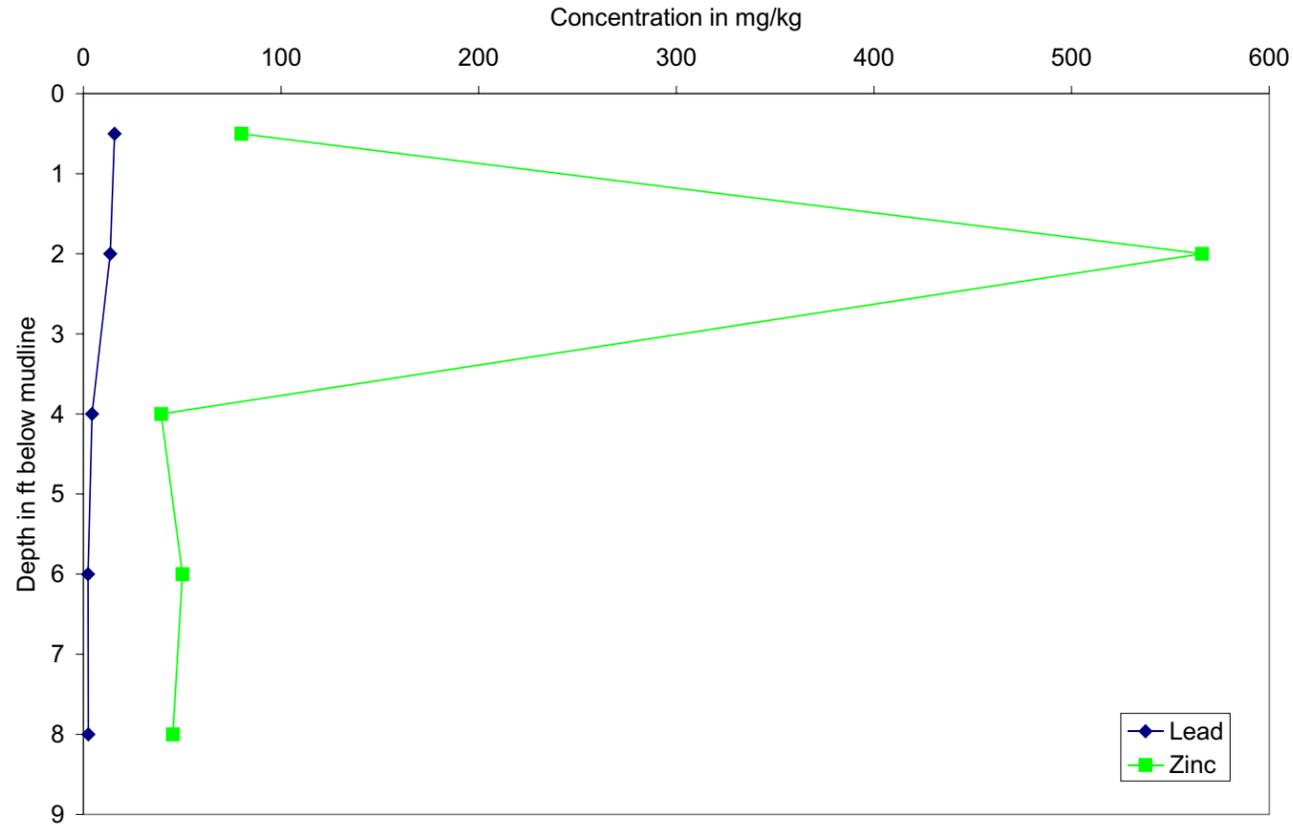
e. Swartz, 1999, which MacDonald et al., 2000a references as the source of the PAH screening levels, describes the total PAH criteria as the sum of the following polycyclic aromatic compounds: naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benz(a)anthracene, chrysene, benzo(b)fluoranthene, benzo(k)fluoranthene, and benzo(a)pyrene.

f. ΣDDTs criteria represent the sum of the following compounds: total DDD, total DDE, and total DDT. of total DDD, total DDE, and total DDT, respectively.

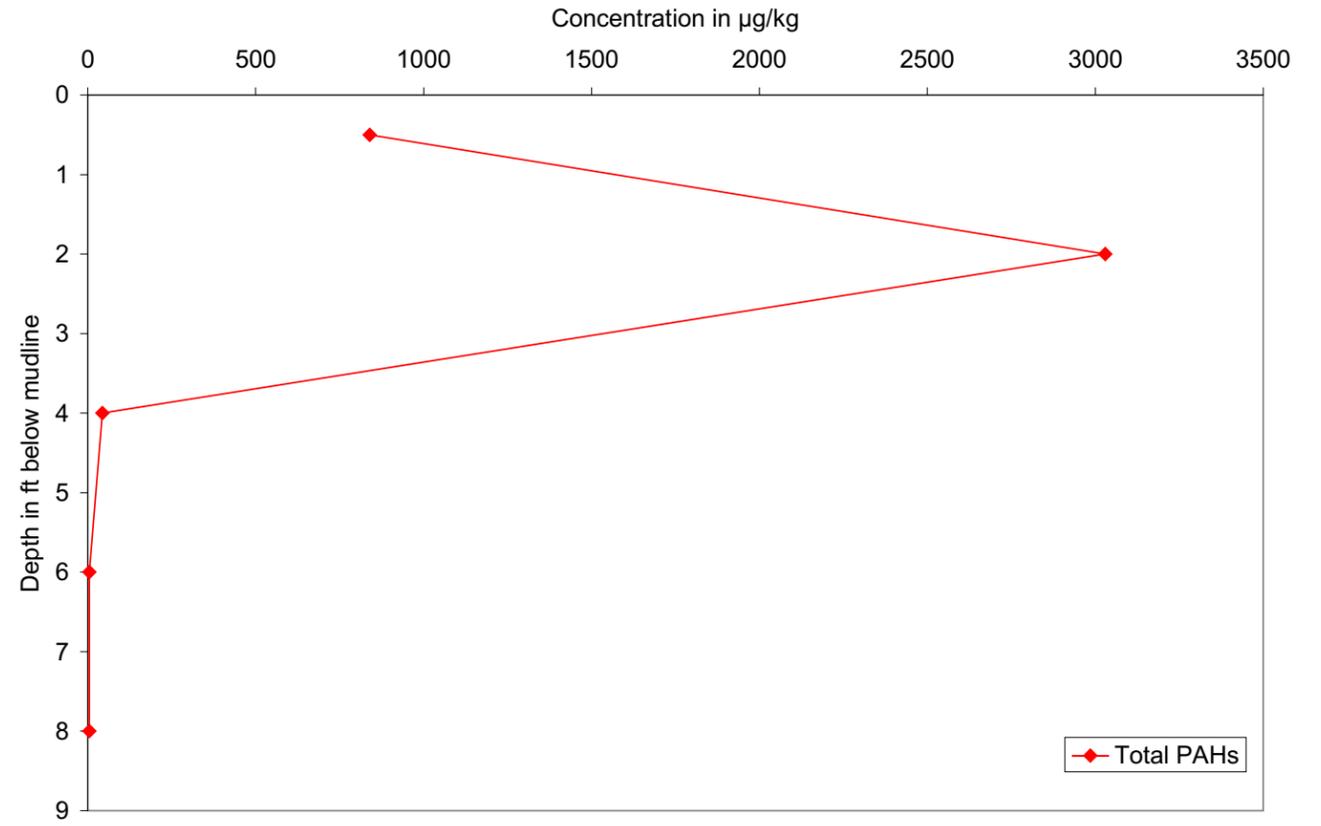
g. MacDonald et al., 2000b, which MacDonald et al., 2000a references as the source of the PCB screening levels, does not describe which individual Aroclors make up the total PCB criteria. It was assumed that total PCBs consisted of all the Aroclors that were analyzed for (Aroclor 1016, Aroclor 1221, Aroclor 1232, Aroclor 1242, Aroclor 1248, Aroclor 1254, Aroclor 1260, Aroclor 1262, and Aroclor 1268).

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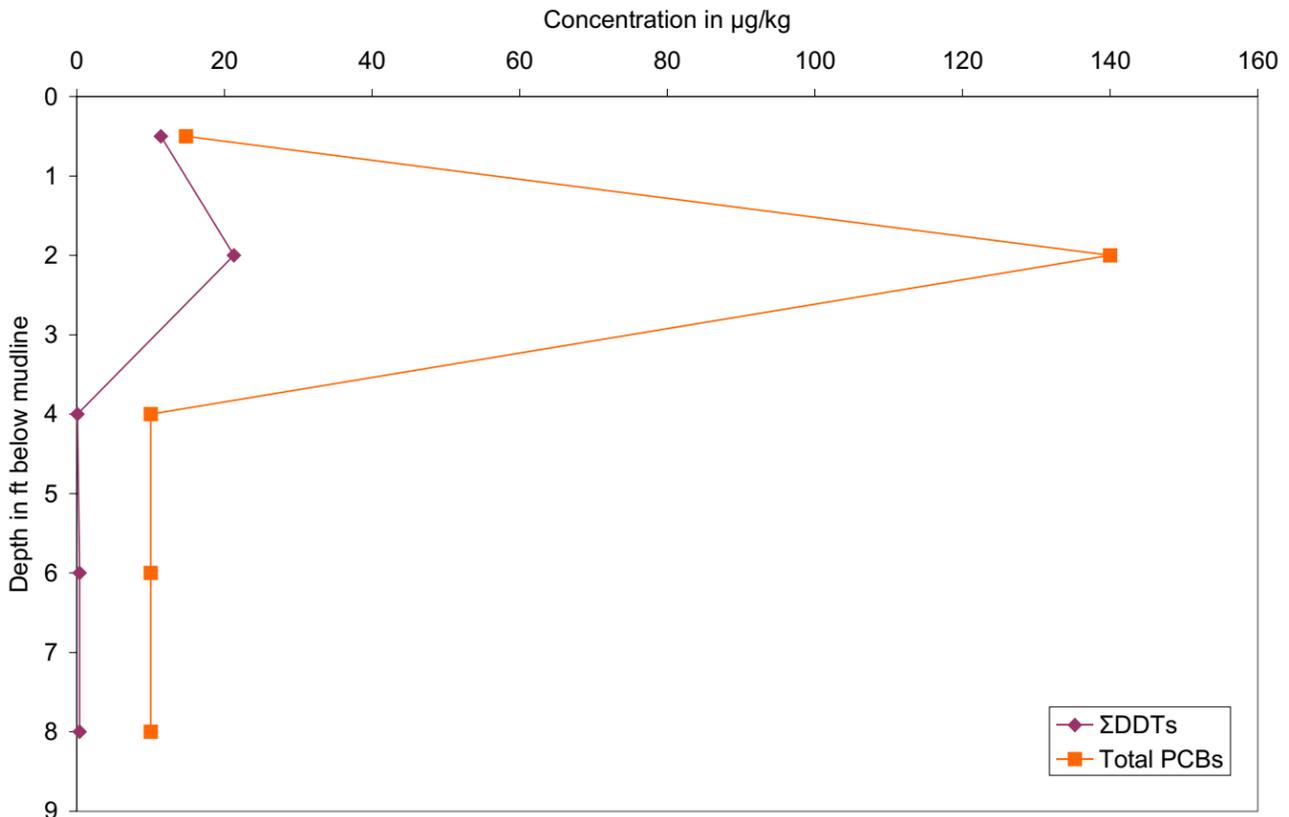
T4-VC02 Metal Concentrations with Depth



T4-VC02 Total PAH Concentrations with Depth



T4-VC02 Pesticide and PCB Concentrations with Depth



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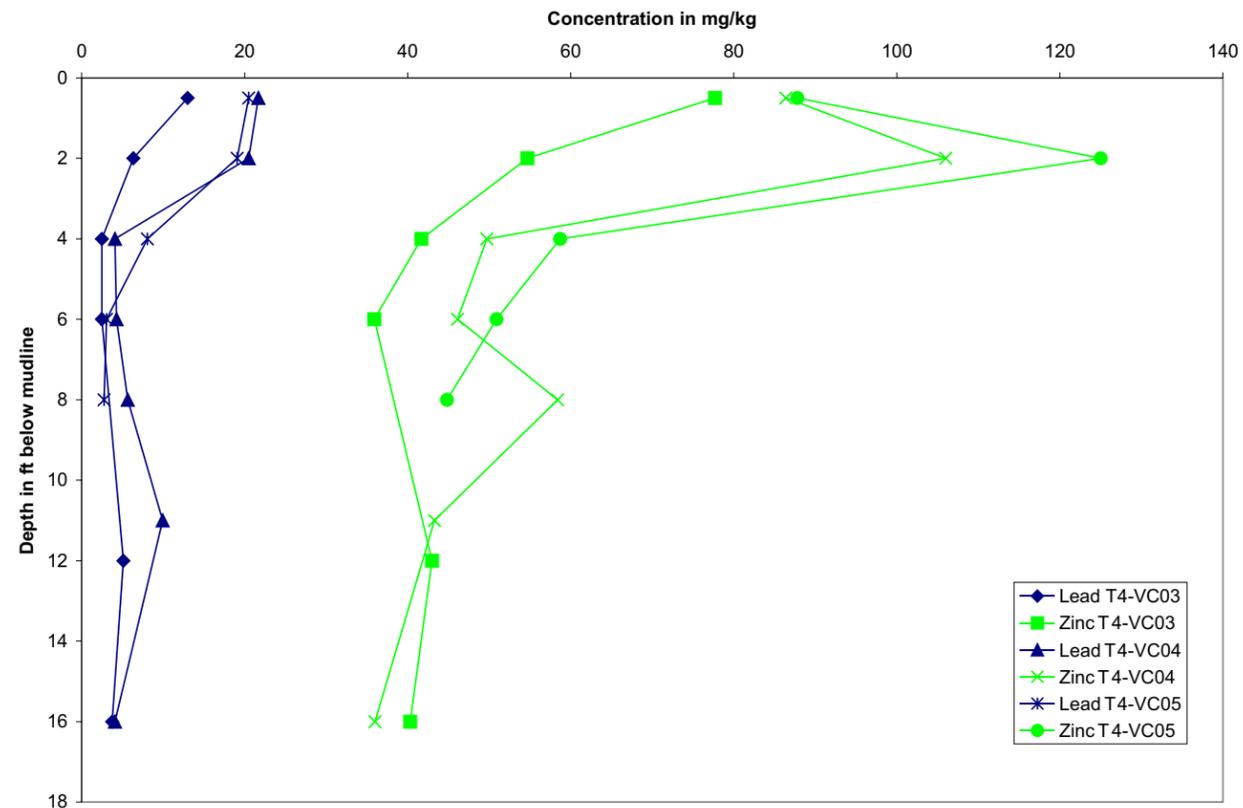
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PORTLAND, OREGON  
TERMINAL 4 EARLY ACTION  
EE/CA REPORT

BERTH 401 SEDIMENT  
CONCENTRATIONS WITH DEPTH

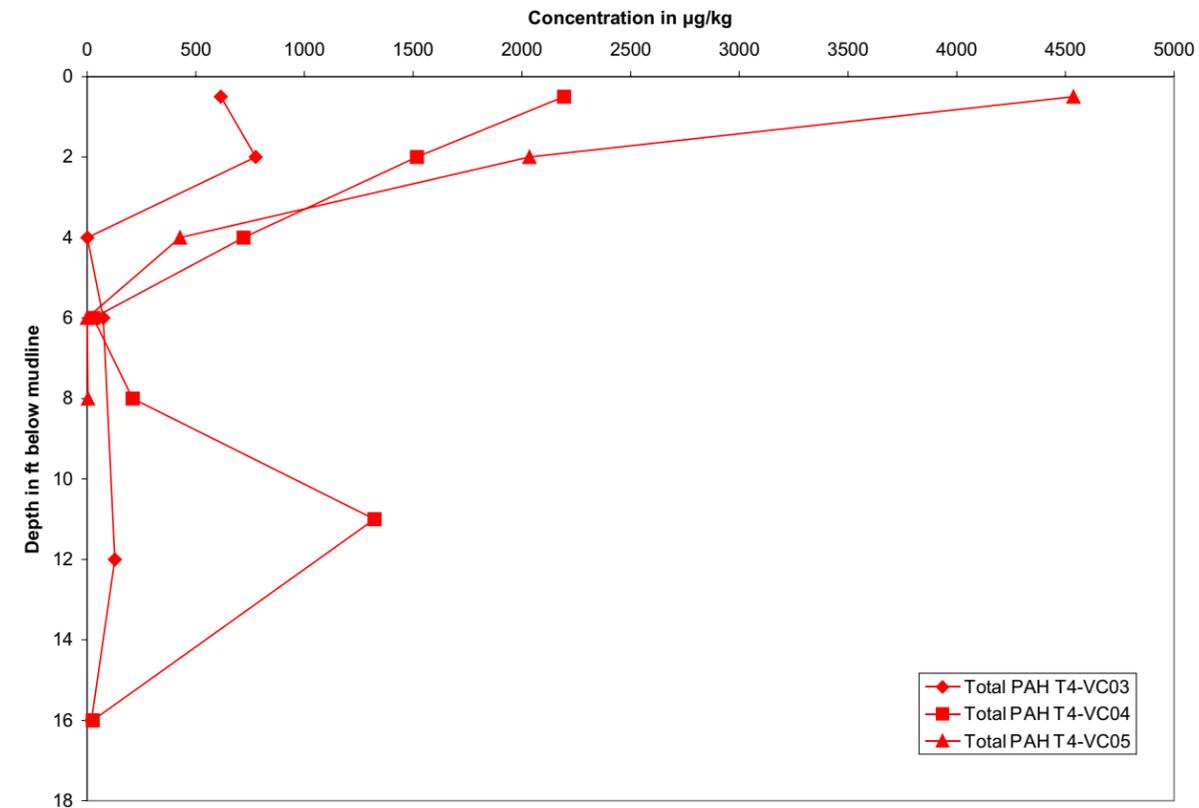


FIGURE  
H-1

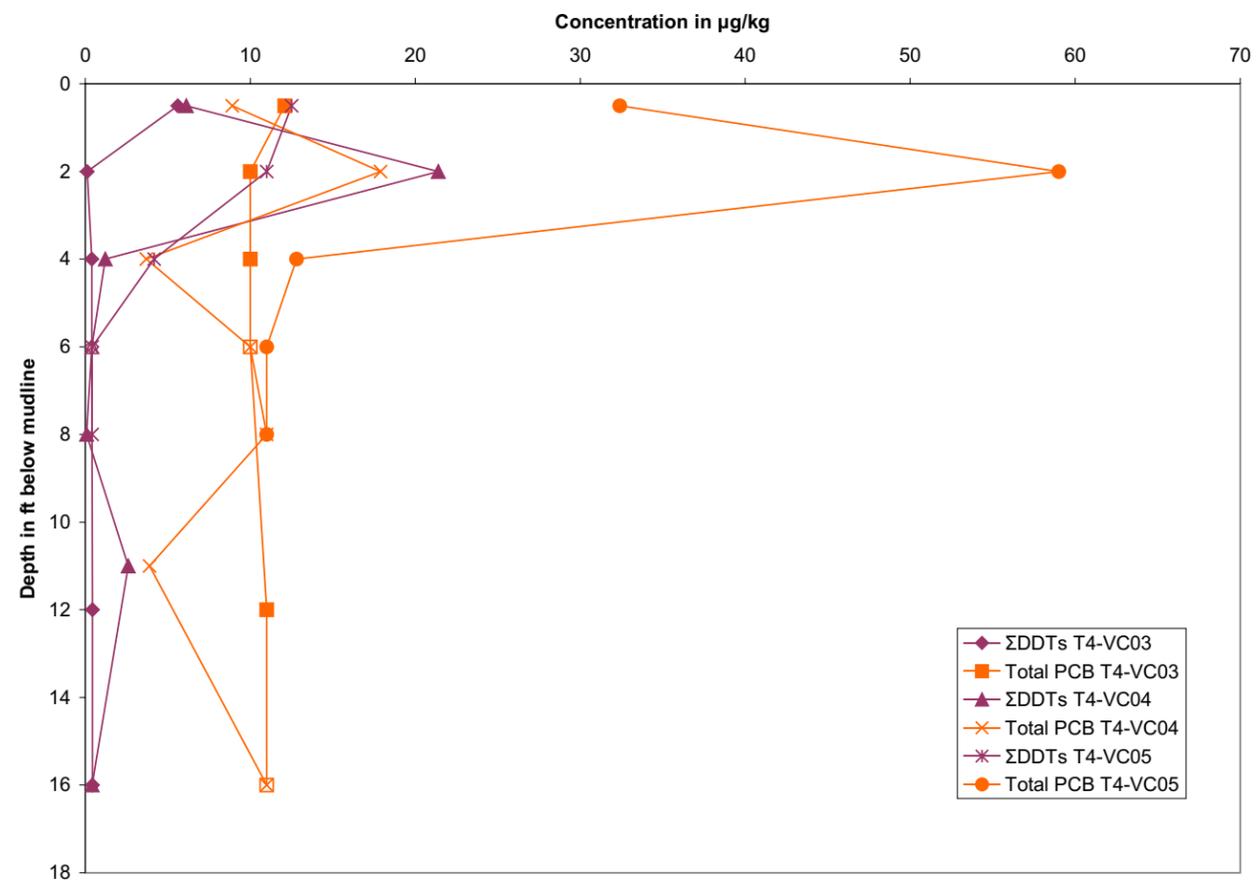
Slip 1 Metal Concentrations with Depth



Slip 1 Total PAH Concentrations with Depth



Slip 1 Pesticide and PCB Concentrations with Depth



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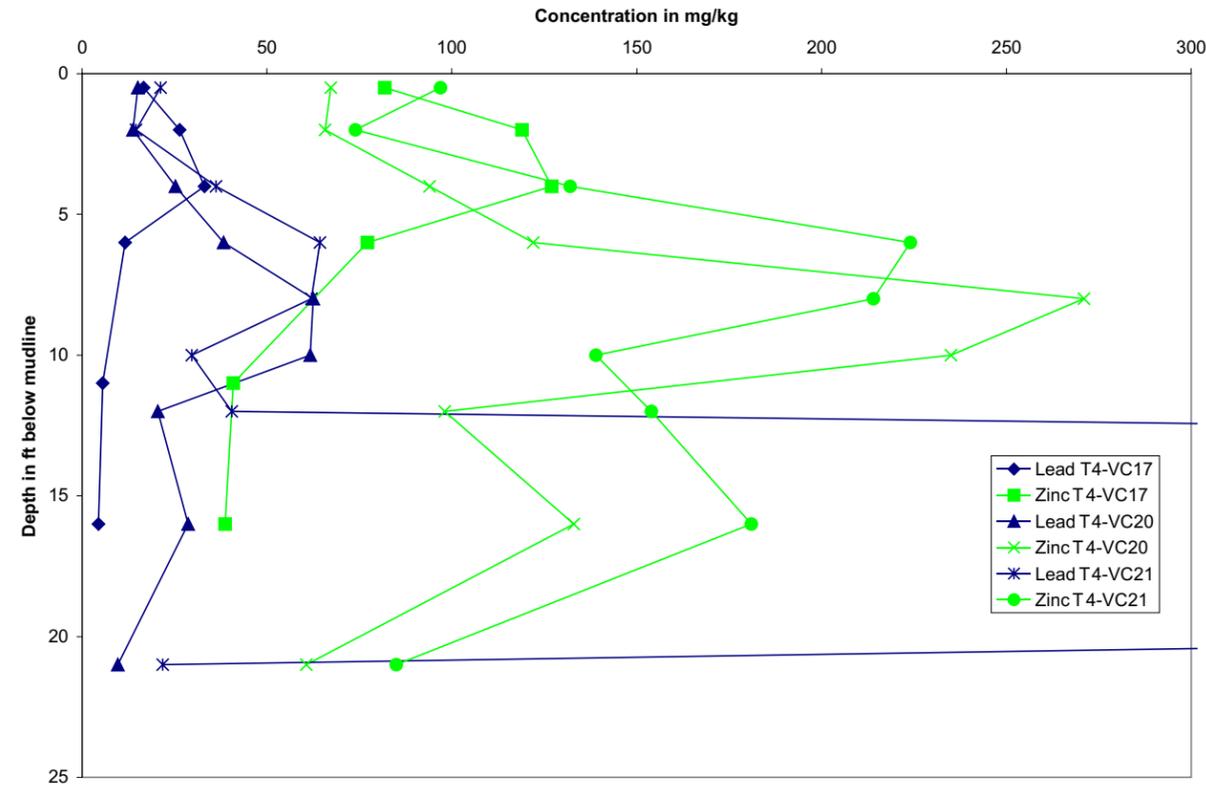
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SLIP 1 SEDIMENT  
CONCENTRATIONS WITH DEPTH

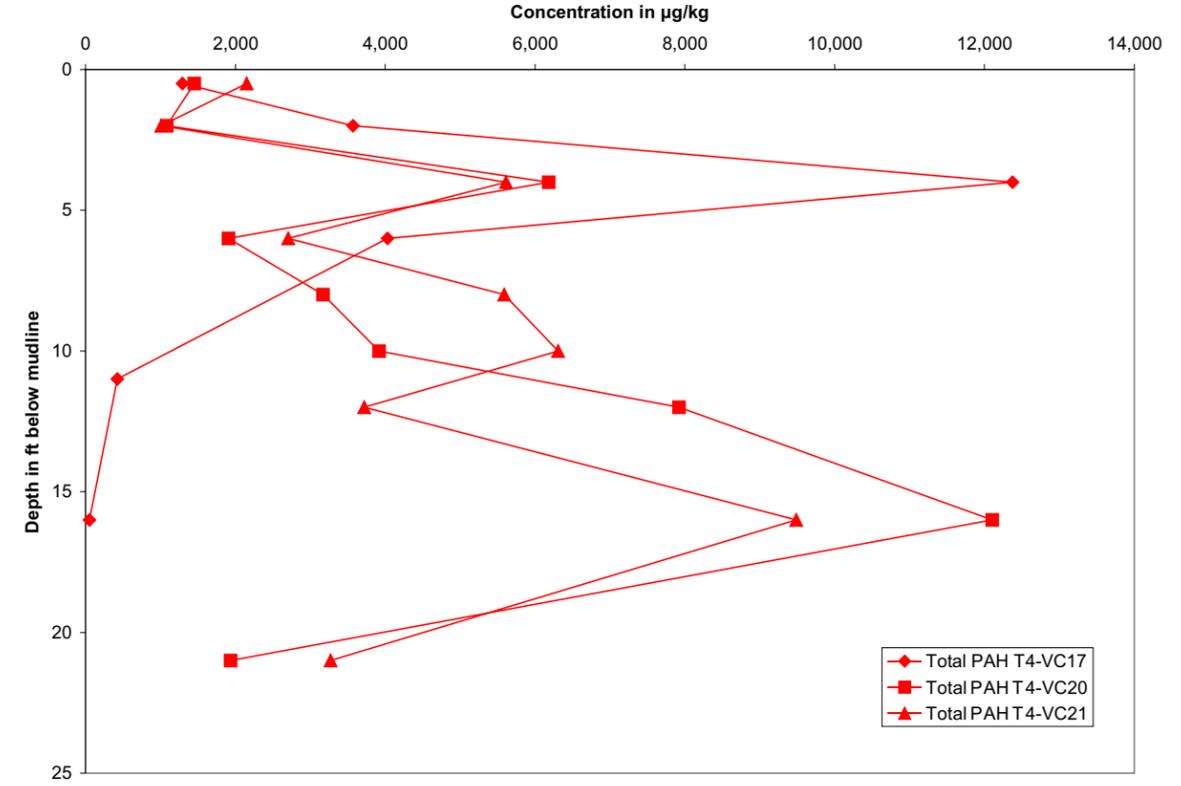


FIGURE  
H-2

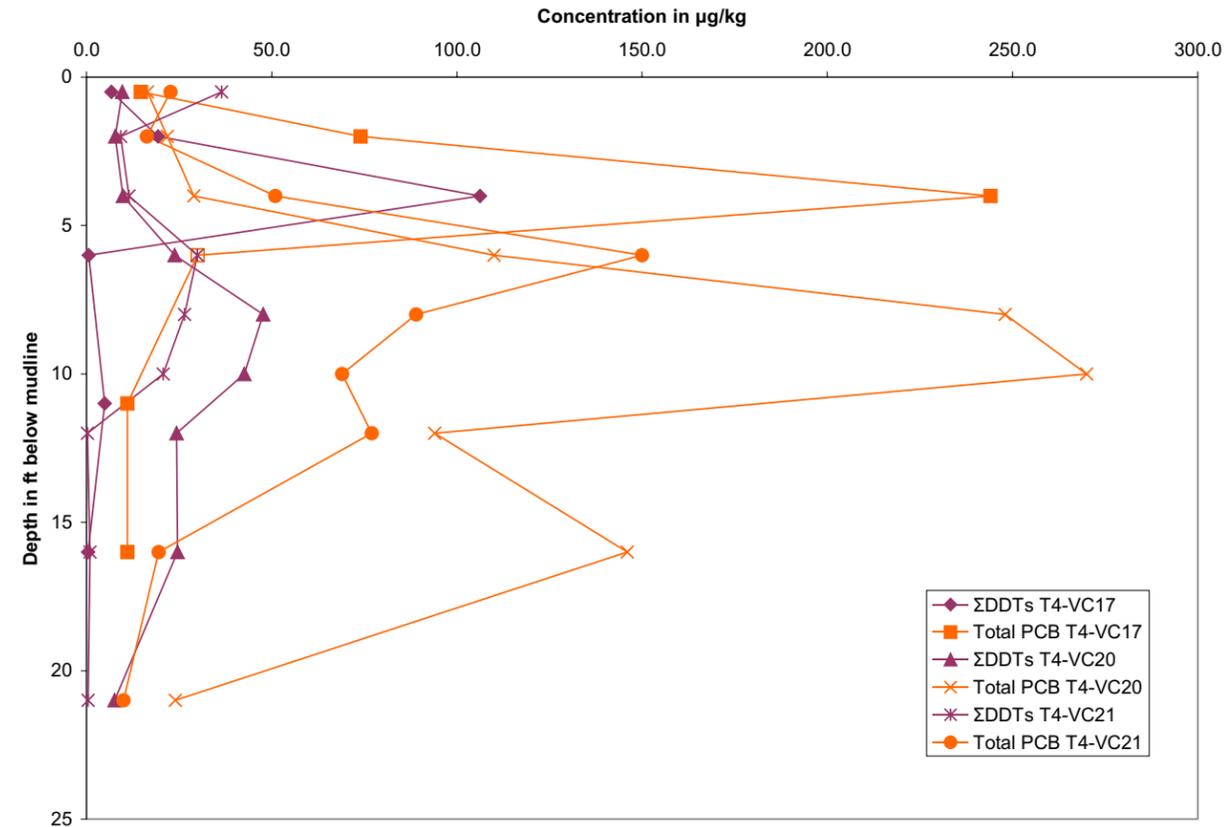
**Wheeler Bay Metal Concentrations with Depths**



**Wheeler Bay Total PAH Concentrations with Depths**



**Wheeler Bay Pesticide and PCB Concentrations with Depths**



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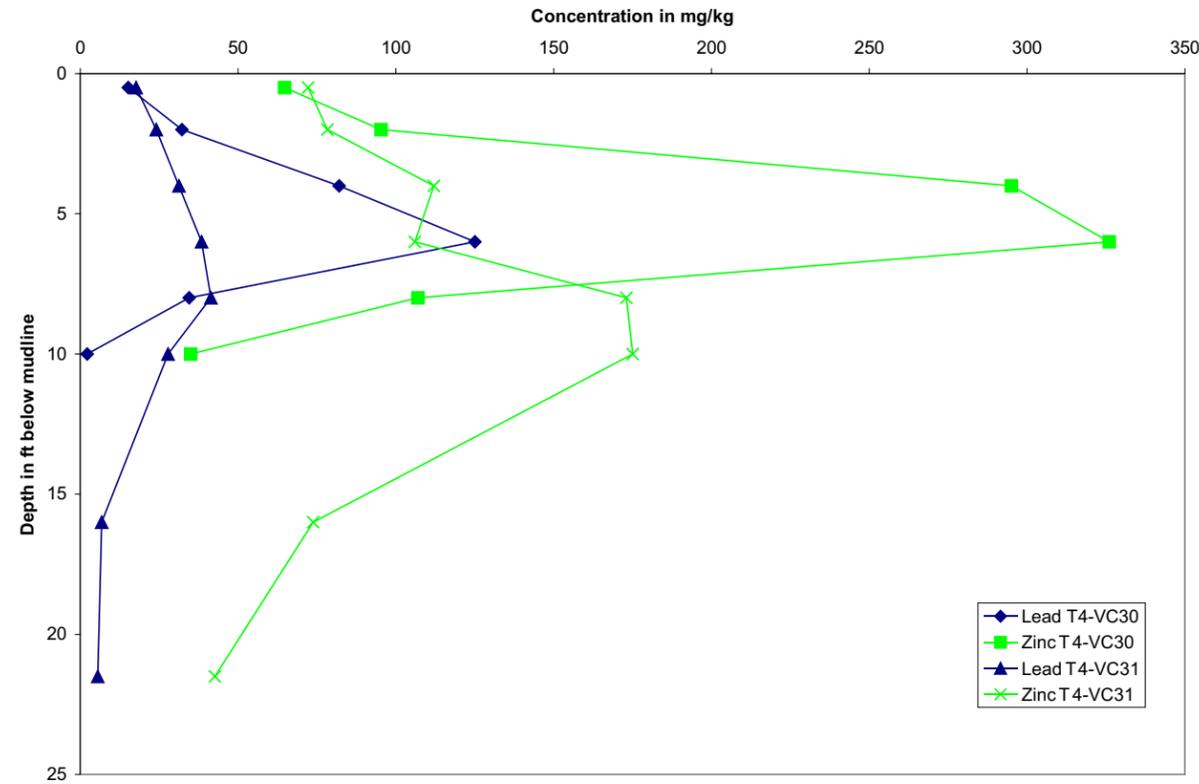
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WHEELER BAY SEDIMENT  
CONCENTRATIONS WITH DEPTH

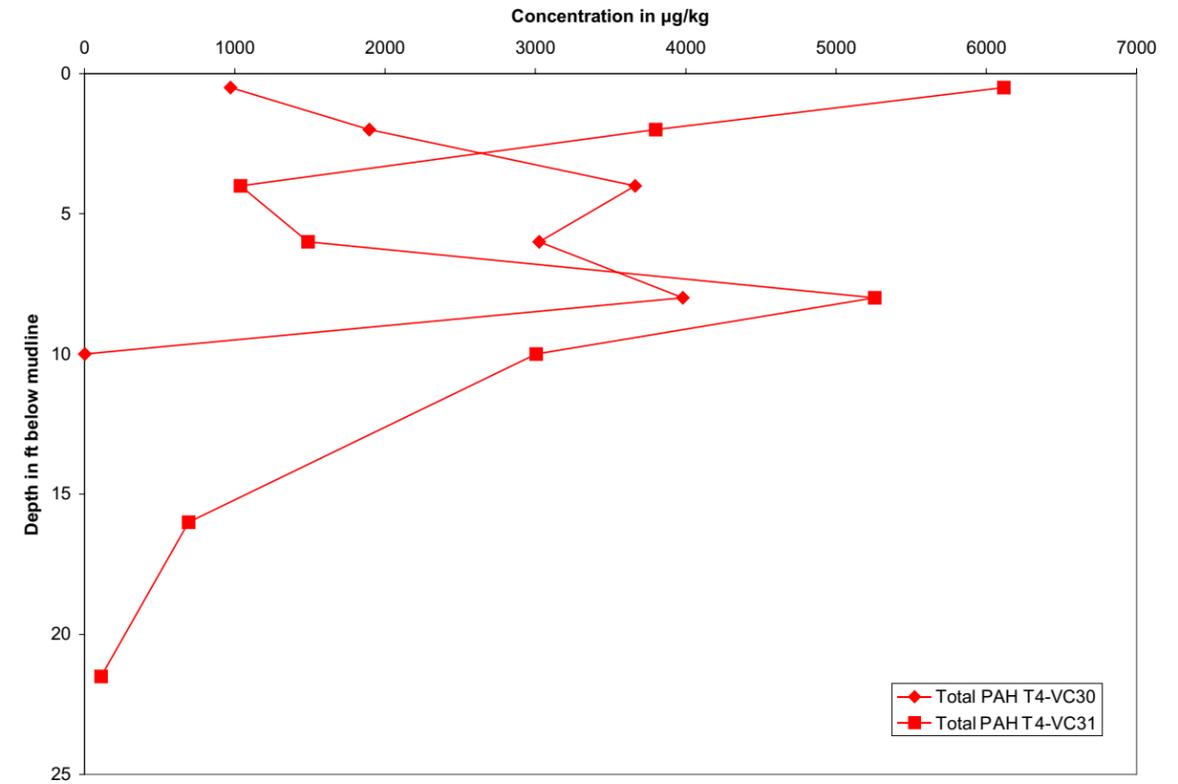


FIGURE  
H-3

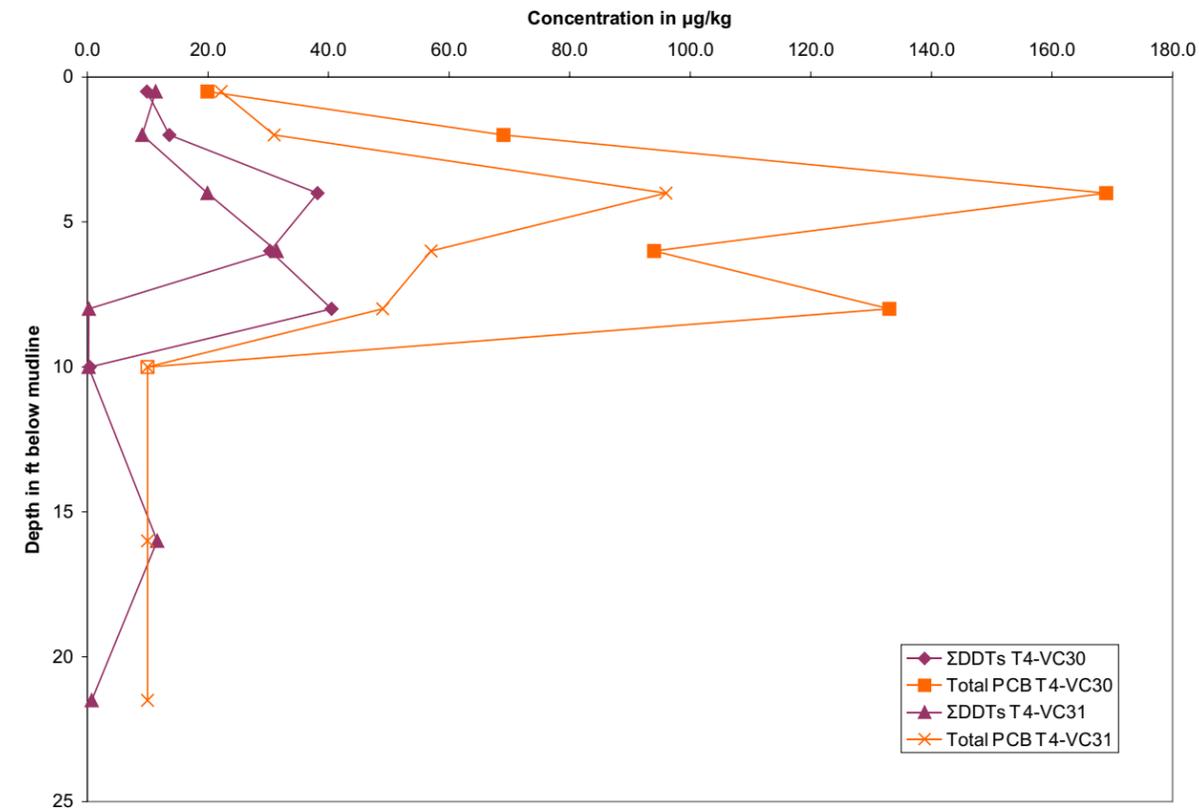
North of Berth 414 Metal Concentrations with Depth



North of Berth 414 Total PAH Concentrations with Depth



North of Berth 414 Pesticide and PCB Concentrations with Depth



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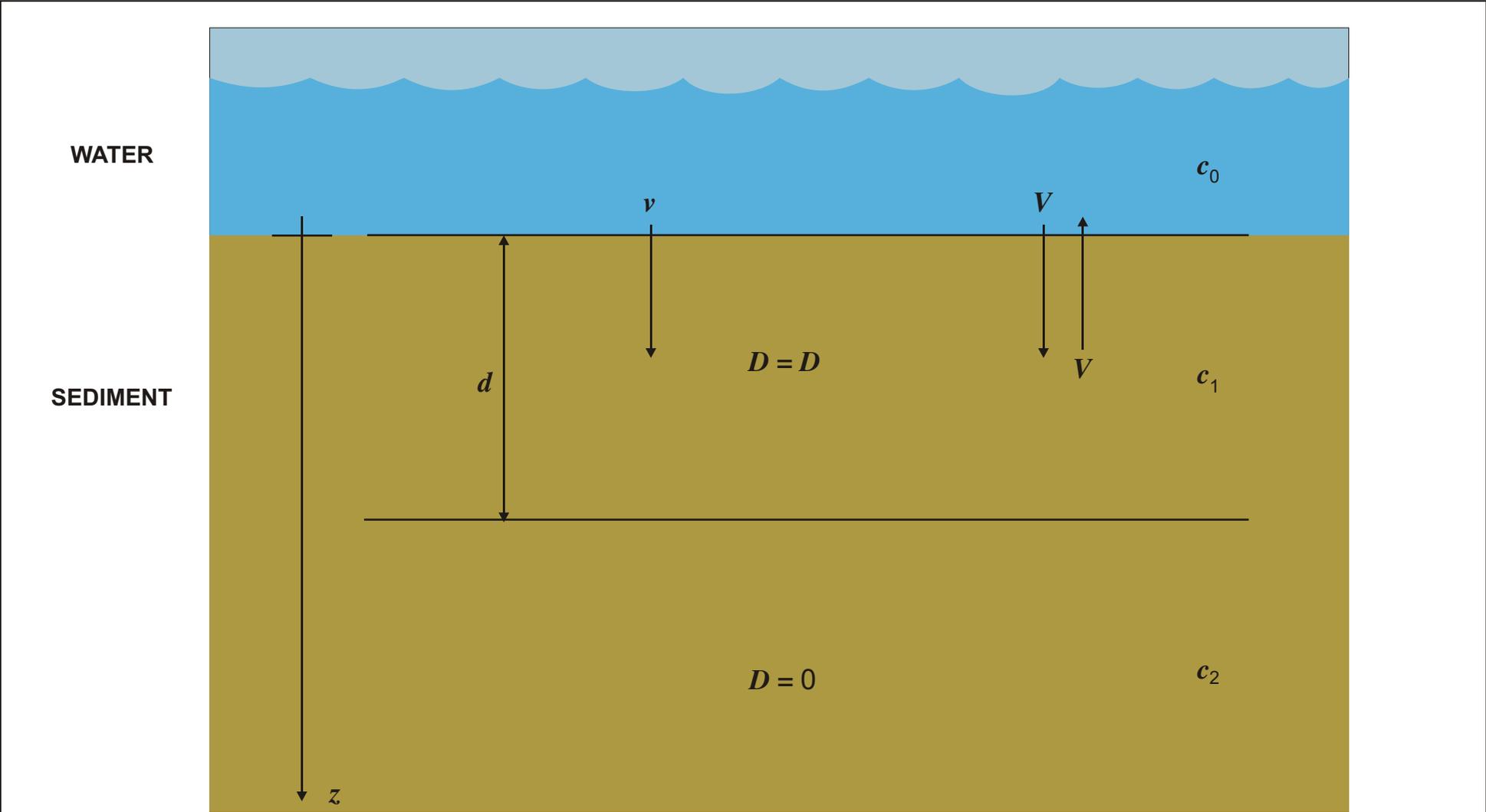
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NORTH OF BERTH 414 SEDIMENT  
CONCENTRATIONS WITH DEPTH



FIGURE  
H-4



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FIGURE  
 H-5

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