SEDIMENT RECONTAMINATION ANALYSIS APPROACH

TERMINAL 4 REMOVAL ACTION

Port of Portland

Portland, Oregon

8 September 2009

NEWFIELDS

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1.0 INTRODUCTION

In 2003, the Port of Portland ("the Port") entered into an Administrative Order of Consent (AOC) with the USEPA to conduct a Non-Time Critical Removal Action (NTCRA) at Terminal 4 to address contaminated sediment.

Under the AOC, the Port conducted an Engineering Evaluation and Cost Analysis (EE/CA) for the Removal Action. The Removal Action objectives (RAOs), as stated in the EE/CA Workplan (BBL, 2004) include:

- reducing the ecological and human health risks associated with sediment contamination within the Removal Action Area to acceptable levels; and
- limiting the likelihood of recontamination of sediments within the Removal Action Area.

The second RAO established in the EE/CA Workplan is "to limit the likelihood of recontamination of sediments within the Removal Action Area". Specifically, the Recontamination Analysis will be the first step in assessing the progress of meeting this objective.

This document describes the proposed approach to assess the potential for recontamination of sediment in the Removal Action Area after actions have been implemented. The recontamination analysis is planned to be reported as part of the 60% design submittal, currently scheduled for submittal in May 2010.

1.1 Site Description and Project History

The Port owns the Terminal 4 uplands between River Miles (RMs) 4.1 and 4.5 on the Lower Willamette River. The Port acquired Terminal 4 from the City of Portland (City) Commission of Public Docks in 1971. The Port also currently owns a portion of the submersible and submerged lands in Slip 1 and Slip 3 located within the RAA (defined below). The remainder of the submersible or submerged land is owned by the State of Oregon and managed by the Oregon Department of State Lands (DSL).

The Terminal 4 facility itself is within or adjacent to the Portland Harbor Superfund Site. The RAA is defined in the AOC as "that portion of the site adjacent to and within the Port of Portland's Terminal 4 at 11040 North Lombard, Portland, Multnomah County, Oregon, extending west from the ordinary high water line on the northeast bank of the Lower Willamette River to the edge of the navigation channel, and extending south from the downstream end of Berth 414 to the downstream end of Berth 401, including Slip 1, Slip 3, and Wheeler Bay."

Per the AOC, the Port submitted an Engineering Evaluation/Cost Analysis (EE/CA) in 2005 (BBL, 2005a). The EE/CA had a placeholder for Appendix N, the recontamination analysis. The Draft Appendix N/Recontamination Analysis (BBL/Arcadis, 2006) was submitted to EPA in November 2006. The Draft Recontamination Analysis provided the initial analysis approach to support the design. The document also identified stormwater data gaps that would need to be filled to support the final analysis. In December 2006, EPA submitted comments to the Port regarding the Draft Recontamination Analysis. The Port made several recommendations to EPA in a letter sent January 24, 2007. Among those recommendations were:

1) Complete the field work to collect additional data identified in section 6 of the Draft Recontamination Analysis in concert with the EPA/DEQ/LWG stormwater technical group that was designing the RI stormwater sampling program;

2) Update the mass loading evaluation with the new data, incorporating the decisions regarding technical process and procedures made in the LWG technical group into the methodology;

3) Submit a revised Recontamination Analysis Report.

The field work for additional data (discussed above in item #1) was conducted in 2007 and 2008. The data collected from 2007 through 2008 was submitted to EPA and DEQ in two ways: (1) all of the data collected by the Port related to the Terminal 4 recontamination analysis, including the City outfalls, was provided to LWG and LWG reported it to EPA and DEQ in the Round 3A and 3B Upland Stormwater Sampling Data Report (LWG, 2008); and (2) The data specific to Terminal 4 USC was submitted to DEQ (with a copy to EPA) in the Final Stormwater Data Summary Report Terminal 4 Slip 1 and Slip 3 Upland Facilities (ACA/Newfields March 2009).

In addition, the Removal Action project was split into two phases in 2007. The Port implemented Phase I of the Removal Action during the 2008 in-water work window. Phase II includes completion of the recontamination analysis. This report describes the recontamination analysis approach.

1.2 Description of the Removal Action

The location and main features of Terminal 4 are shown in Figure 1-1.

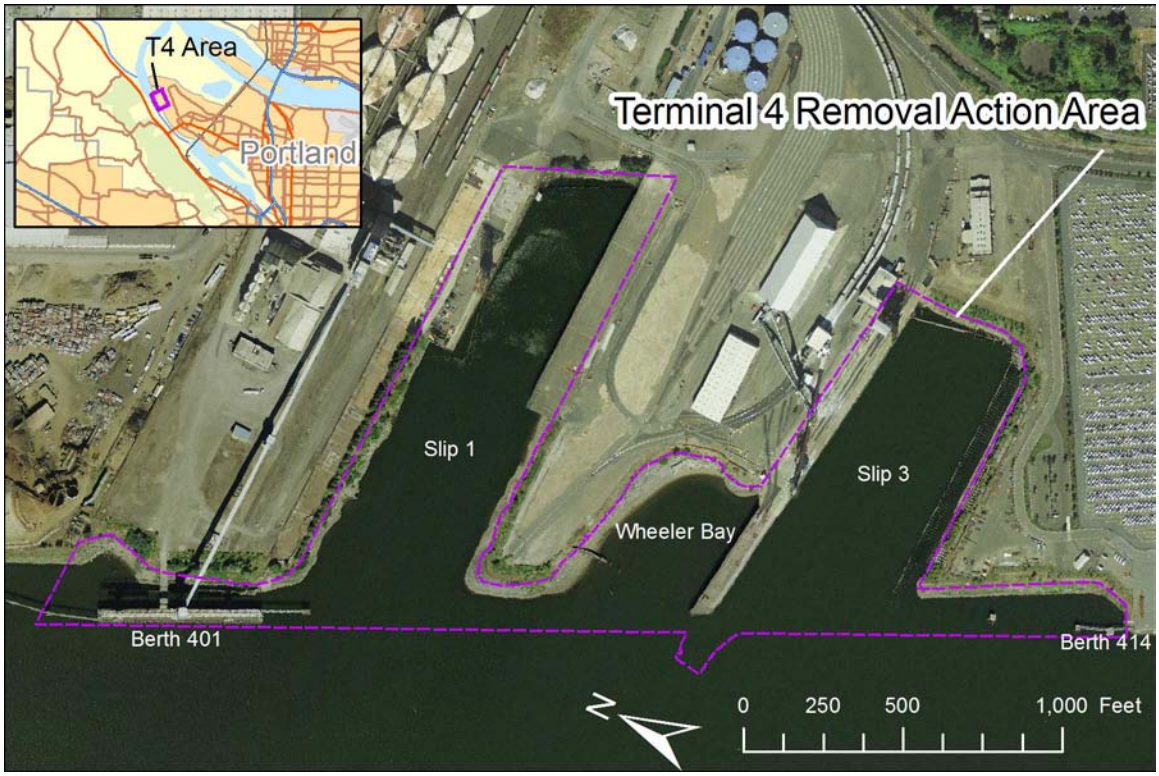

Figure 1-1: Location and main features of the Terminal 4 Removal Action Area.

The selected removal action was outlined in an Action Memorandum in 2006 (EPA, 2006). As described above, the action is being implemented in phases, in order to align the Terminal 4 Removal Action design and construction with the Portland Harbor-wide Remedial Investigation and Feasibility Study (RI/FS) and Record of Decision (ROD). The schedule realignment was proposed in a letter to EPA in August, 2007. The Port also prepared an Abatement Measures Proposal (October 2007), detailing the specific tasks that could be performed in an initial phase to address "imminent health and ecological risks" at Terminal 4 (Anchor, 2007). EPA approved the schedule realignment in November, 2007 on the condition that the abatement measures were carried out. Therefore, a Phase I plan was designed and implemented in 2008. Phase I included dredging of three areas showing the highest contaminant concentrations in Terminal 4; adjacent Berth 411, adjacent Pier 5 and north of Berth 414 (former Berth 413). Dredging was also completed adjacent to Berth 410 in Slip 3 in support of water-dependent maritime use. Dredged material was disposed of off-site. A cap was placed at the head of Slip 3 and the shoreline at Wheeler Bay was stabilized and capped to prevent migration of contaminants to the river (Anchor QEA, Ash Creek Associates and Hickey Marine Enterprises, 2009).

The remaining areas of Terminal 4 will be addressed by the Phase II Removal Action, which will proceed based on coordination with the harbor-wide RI/FS and ROD schedule. Phase II of the plan anticipates additional dredging and capping within Slip 3,

additional dredging and capping north of Berth 414 (former Berth 413), additional capping in Wheeler Bay, and capping adjacent to Berth 401 (see Figure 1-2). Phase II also includes the construction of a confined disposal facility (CDF) in Slip 1 and monitored natural recovery (MNR) of the remaining areas. The status of the Phase II Design as of May 2009 is outlined in the draft Design Status Report (Anchor QEA and NewFields, 2009).

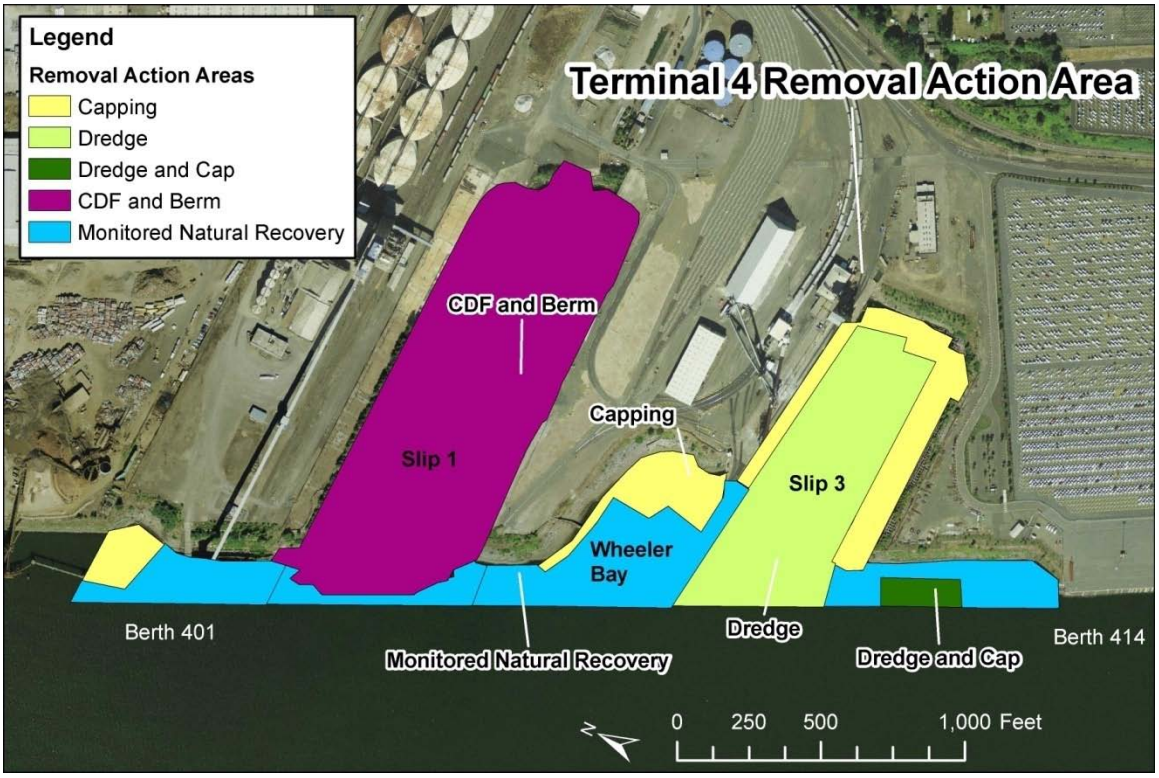

Figure 1-2: Phase II Removal Action Areas (adapted from Anchor QEA and NewFields, 2009).

1.3 Purpose of Recontamination Analysis and Approach

The purpose of this document is to outline the methodology that will be used to assess recontamination potential of sediment in the Terminal 4 Removal Action Area after the removal actions have been implemented. Data gaps that need to be addressed prior to completing the analysis are also reviewed. Comments pertaining to the Draft Recontamination Analysis conducted by BBL/Arcadis in 2006 have been considered and incorporated into the new Recontamination Analysis approach. This document presents the data, methods, and equations to be used in calculations. In addition, an example calculation of recontamination potential is presented for one chemical of interest (COI) and one portion of the Removal Action Area. This calculation is not meant to be a final analysis; rather it is presented to demonstrate the methodology. A final analysis of

recontamination potential for all COIs and the entire Removal Action Area will be presented in the Recontamination Analysis.

1.4 Defining Recontamination

Recontamination is significant if concentrations on the remediated surfaces (e.g., dredged area, caps, and MNR areas) exceed the cleanup goals that are identified in the Harborwide RI/FS process. The final cleanup goals for sediments will be established as a result of the Harborwide Record of Decision (ROD). In the interim, preliminary remediation goals (PRGs) and "hilltopping" values provide the target concentrations for analysis of the recontamination. Hilltopping values are established for bioaccumulative COIs and represent the concentrations that are to be addressed with active remedies in order to reduce average concentrations for a river segment to acceptable levels based on risk to humans and ecological receptors.

In the context of the Recontamination Analysis, the following decision criteria will be addressed:

- If concentrations in surface sediment are predicted to decrease from the initial post-construction value, then recontamination will not occur.
- If concentrations are predicted to increase, then the effectiveness of the source control action(s) will be assessed against cleanup goals to determine if additional action could be necessary.

1.5 Report Structure

Section 2 of this report reviews the site conceptual model, including the removal action, the COIs, and identification of potential sources of recontamination. Section 3 describes the overall methodology for recontamination assessment, including the mathematical model SEDCAM (Jacobs et al., 1988), the model inputs, the primary data sources to be used in the analysis, equations, uncertainties, and data gaps. Finally, Section 4 includes an example application of the described methodology for one COI and one subarea of the Terminal 4 Removal Action Area.

2.0 CONCEPTUAL SITE MODEL

The conceptual site model is described in the following sections. The main pertinent features are the areas of concern (Removal Action Areas), COIs, the potential sources of sediment, and the potential sources of COIs to the sediment.

2.1 Removal Action Area

The Removal Action chosen for Terminal 4 consists of a combination of MNR, capping and dredging, with dredged material being disposed of in a CDF to be built on site (Anchor QEA and NewFields, 2009). Multiple areas of planned MNR, capping and dredging occur in the Removal Action Area. In order to evaluate recontamination, areas affected by different removal actions will be evaluated separately. For example, the post-Removal Action concentration of a particular COI in surface sediment will be different in a capped area than in an area that was dredged. Post-Removal Action concentrations will be generated after Phase II of the Removal Action is complete. The Removal Action Area will be subdivided into nine subareas for the Recontamination Analysis, as shown in Figure 2-1.

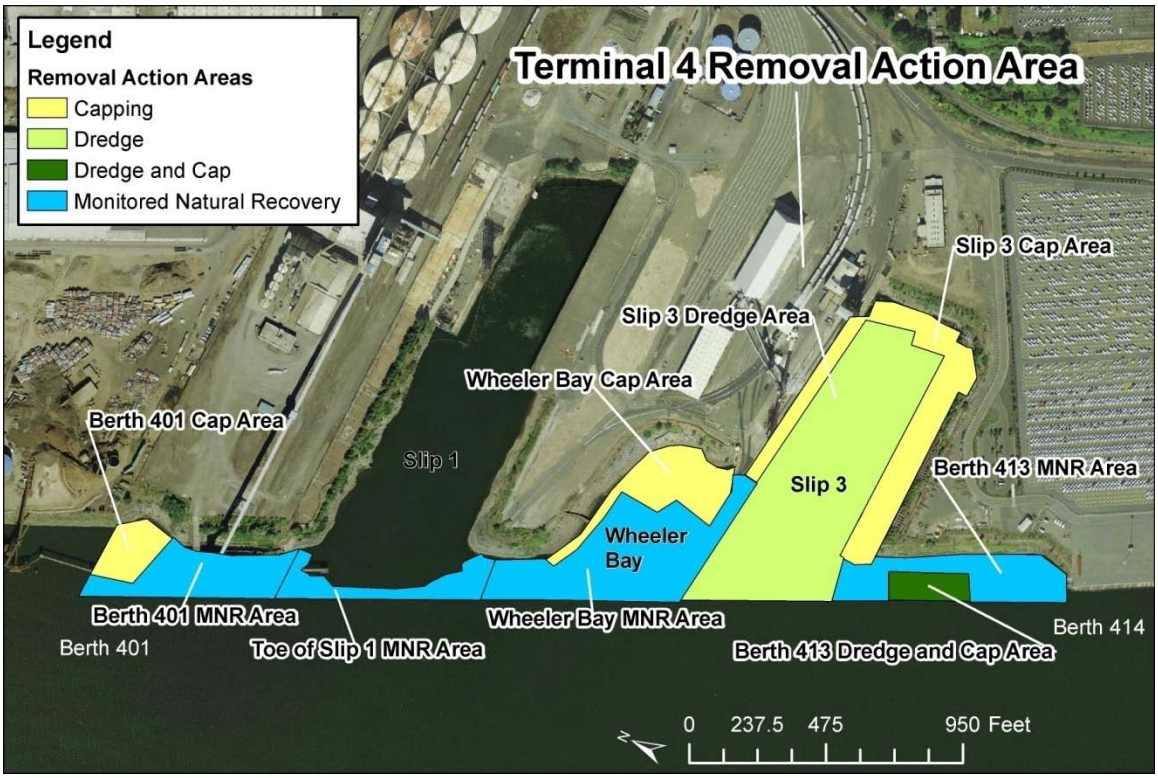

Figure 2-1: Phase II Removal Action sub-areas.

Three areas will be unaffected (MNR), three areas will be capped, one area will be dredged, one area will be dredged and capped, and one area will be converted into a CDF. These subareas are listed in Table 2-1 with their respective areas in square feet.

Table 2-1: Removal Action subareas and their approximate areas in square feet.

Removal Action Subarea	Approximate Area (sq ft)
1 – Berth 413 MNR Area	95,000
2 – Berth 413 Dredge and Cap Area	30,000
3 – Slip 3 Cap Area	165,000
4 – Slip 3 Dredge Area	385,000
5 – Wheeler Bay Cap Area	85,000
6 – Wheeler Bay MNR Area	195,000
7 – Toe of Slip 1 MNR Area	55,000
8 – Berth 401 MNR Area	90,000
9 – Berth 401 Cap Area	40,000

The subareas were delineated based on their different planned actions and their locations relative to potential sources of sediment recontamination (i.e. stormwater outfalls or river influence). All areas will be considered in the Recontamination Analysis, except Slip 1. The design plan for Slip 1 consists of converting it into a CDF to contain dredged material from other areas of Terminal 4 and Portland Harbor.

2.2 Identification of COIs

The COIs that will be considered for the Removal Action Area at Terminal 4 include:

- Benzo(a)pyrene
- Benzo(a)anthracene
- Dibenzo(a,h)anthracene
- Pyrene
- Indo(1,2,3)pyrene
- Cadmium
- Lead
- Total PCBs

These chemicals were identified in the Remedial Investigation and risk assessments as the primary chemicals driving risk in Terminal 4 (due to be submitted in October 2009) (LWG, *in preparation*).

2.3 Screening of potential sources

Potential sources of COIs to the Terminal 4 Removal Action Area sediments have been identified as follows:

- upstream suspended sediment,
- stormwater outfalls,
- groundwater,
- bank erosion,
- overland flow,
- existing structures,
- sediment resuspension, and
- atmospheric sources.

These are discussed in more detail in the following subsections.

Upstream Suspended Sediment

Sediment is transported in the river, either in suspended form or as bed load. In general terms, the Willamette River is relatively low energy in the Superfund Site study area and tends to accumulate sediment over time (LWG *in preparation*). There are various sources of sediment and COIs upstream of Terminal 4. The total effect of these has been characterized by the RI in-river sediment sampling. This potential COI source will be evaluated in the recontamination analysis.

Stormwater Outfalls

Recent in-line stormwater sampling at Terminal 4 and at other locations at the Superfund Site have demonstrated that sediment suspended in stormwater discharges is a potential source of COIs to sediment. This will be evaluated in the recontamination analysis.

Groundwater

A previous analysis of groundwater contribution showed that the relative load of COIs from groundwater was low (BBL/Arcadis, 2006). Hydraulic gradients measured near Slip 3 are only 0.2 ft/ft and groundwater flow paths near Slip 3 are variable in direction (ACA 2009a). The Bank Excavation and Backfill Remedial Action (BEBRA) project, completed in 2004, involved excavation of petroleum contaminated soils from approximately 200 ft along the head of Slip 3 and replacement with an organoclay material. A portion of this area overlaps with the cap placed at the head of Slip 3 as part of the Phase I Removal

Action in 2008. Groundwater modeling showed that placement of the organoclay material effectively met the compliance levels at the point where groundwater reaches the surface water at the head of Slip 3 (ACA 2009a). The most recent quarterly report for the Terminal 4 upland facility shows that groundwater flow paths in the area south of Slip 3 are directed toward the west, however have very low hydraulic gradients, so likely produce only a negligible input to the main channel of the Willamette River (ACA 2009b). Groundwater flow modeling for the proposed CDF in Slip 1 also suggests negligible contribution by groundwater to downstream Removal Action Areas (Anchor 2009). Thus, groundwater sources will not be considered in the recontamination analysis.

Bank Erosion

No significant bank erosion will exist at Terminal 4 following the Phase II Removal Action. The shoreline along Wheeler Bay was stabilized as part of the Phase I Removal Action, and erodible soil and source control work at the head of slip 3 is slated for fall 2009. The observed erosion at former Pier 5 in Slip 3 and former Berth 413 upland source area has been identified for action. While erodible soils in Slip 1 were sampled and found to not require any source control action, bank erosion in Slip 1 will be halted by its conversion to a CDF. Bank erosion sources will not be considered in the recontamination analysis.

Overland Flow

The majority of Terminal 4 is drained by stormwater outfalls. Overland flow in the Terminal 4 area is not significant and will not be considered in the recontamination analysis.

Existing Structures

Some creosote-treated pilings exist at the Pier 4 area of Slip 3, and some pilings in the former Pier 5 area also may have been treated with creosote. Creosote is an oil-borne wood treatment product made from coal tar, and is primarily composed of polycyclic aromatic hydrocarbons (PAHs) (Stratus Consulting, 2006). PAHs can leach from treated wood that is exposed in the environment. Numerous laboratory and field studies have been conducted on PAH leaching rates and factors that affect these rates. Studies generally agree that a series of factors can affect the leaching rate:

- wood species,
- density,

- surface area exposed,
- treatment formula,
- PAH compounds present,
- water temperature chemistry,
- temperature and flow,
- disturbance/abrasion, and
- time since treatment.

Multiple models designed to predict leaching rates of creosote from pilings have been developed (for example Brooks, 1994; 1997; Poston, 1996; Xiao et al., 2002). The Brooks (1994, 1997) model (CREOSS) is well-documented, and provides reasonable agreement with field observations. The CREOSS model estimates a leaching rate based on a migration factor (water temperature and salinity), piling retention factor, and a piling age factor. The age factor is 1 at the time of treatment, and decays in an exponential fashion. Leaching rate is proportional to the age factor. The model estimates that after 20 years, the leaching rate would be 14% of the original rate and after 40 years, the leaching rate would be 2% of the original. Given the much higher rate of leaching in the years just following piling installation, the amount of leachable PAH mass left in the pilings will be greatly reduced. For example, using the numbers above, approximately 96% of the leachable PAH mass would be estimated to have leached from the pilings after 40 years. Therefore, even if the pilings were a historical source of PAHs to sediments, the remaining mass and leaching rate would be almost two orders of magnitude lower than initial rates and below levels of concern for future sediment recontamination.

Pilings were installed in 1961 at Pier 5 and in 1959 at Pier 4. Some of the original pilings have been replaced over time with non-creosote treated pilings for maintenance purposes. With respect to the original pilings that remain, given the time that has elapsed, they are not predicted to be a significant potential sources of PAHs in the future and are not considered further in the recontamination analysis.

Sediment Resuspension

Sediment resuspension due to propeller wash has been observed to be a significant process occurring in Slip 3 and the Terminal 4 area (BBL, 2004a; BBL, 2005a). Although sediment resuspension may cause redistribution of sediment near the vessel travel path, resuspension of existing sediment is not a significant source of new COI mass to sediment in the Removal Action Area. Since sediment traps placed within the Removal Action Area collect both resuspended sediment and sediment entering the Area from outside sources, the sedimentation rate in the traps was not used to estimate net sedimentation rate for the Removal Action Area.

Sedimentation rates measured in sediment traps placed at Terminal 4 range from approximately 18.3 to 84.3 cm/yr (based on a sediment density of 1.53 g/cc). In contrast, the net sedimentation rate for Terminal 4 estimated based on bathymetric surveys is approximately 4 cm/yr (see Section 3.1.1.2). This suggests that a significant amount of sediment is disturbed by propeller wash or river currents, which supports the assumption of a mixed surface sediment layer for Removal Action subareas.

Atmospheric Sources

Chemicals present in the atmosphere as a result of emissions from stationary sources (e.g., industrial smokestacks), mobile sources (e.g., vehicle emissions) and non-point sources (e.g., fugitive dust) produce a load to the river through the processes of dry and wet deposition. Dry deposition refers to the deposition of air pollutants from atmospheric suspension in the absence of precipitation. Wet deposition refers to deposition of air pollutants from atmospheric suspension via liquid and/or frozen precipitation.

Deposition occurs throughout the Portland Harbor Superfund Site study area. Particles that are deposited on the land can be transported to the river by stormwater. Particles deposited in the river will be represented by sediment load within the river (both upstream and downstream of Terminal 4). Atmospheric deposition to the entire Portland Harbor Site is being assessed in the Remedial Investigation (RI) Report (due to be submitted in October 2009) (LWG, *in progress*). The RI will be used to form the basis for evaluation of atmospheric deposition as a potential recontamination source, however it is anticipated that it will not be a significant source for the Portland Harbor Site, and even less so for Terminal 4 Removal Action because of the relatively small area where removal actions will occur. Based on the current operations and activities at Terminal 4, there are no localized atmospheric sources of COIs.

Summary

Potential sources to be carried forward for further evaluation in the Recontamination Analysis are as follows:

- Upstream sources, and
- Stormwater sources.

A more detailed screening to eliminate minor or insignificant sources will be performed in the Recontamination Analysis.

2.4 Description of Removal Action Subareas and Primary Potential Sediment Recontamination Sources

As discussed above, the primary sources of potential sedimentation recontamination are anticipated to be upstream sediment and stormwater sediment. Upstream sediment sources will be characterized using the same upstream data for all Removal Action subareas (see Section 3.1.3.1). Stormwater sediment sources, however, will vary in load based upon which stormwater basins discharge to each subarea.

2.4.1 Subarea 1 – Former Berth 413 MNR Area

The MNR Area located adjacent to the former Berth 413 receives sediment input from upstream, in addition to sediment input from the primary outfall of stormwater Basin D (Figure 2-2). Basin D is approximately 17 acres. The former Berth 413 MNR area is the closest Removal Action subarea to the City of Portland stormwater outfall 53, which discharges to the Willamette River main channel approximately 1800 feet upstream of the former Berth 413. Stormwater from an offsite residential area discharges through this outfall and becomes part of the upstream source component at the former Berth 413 area.

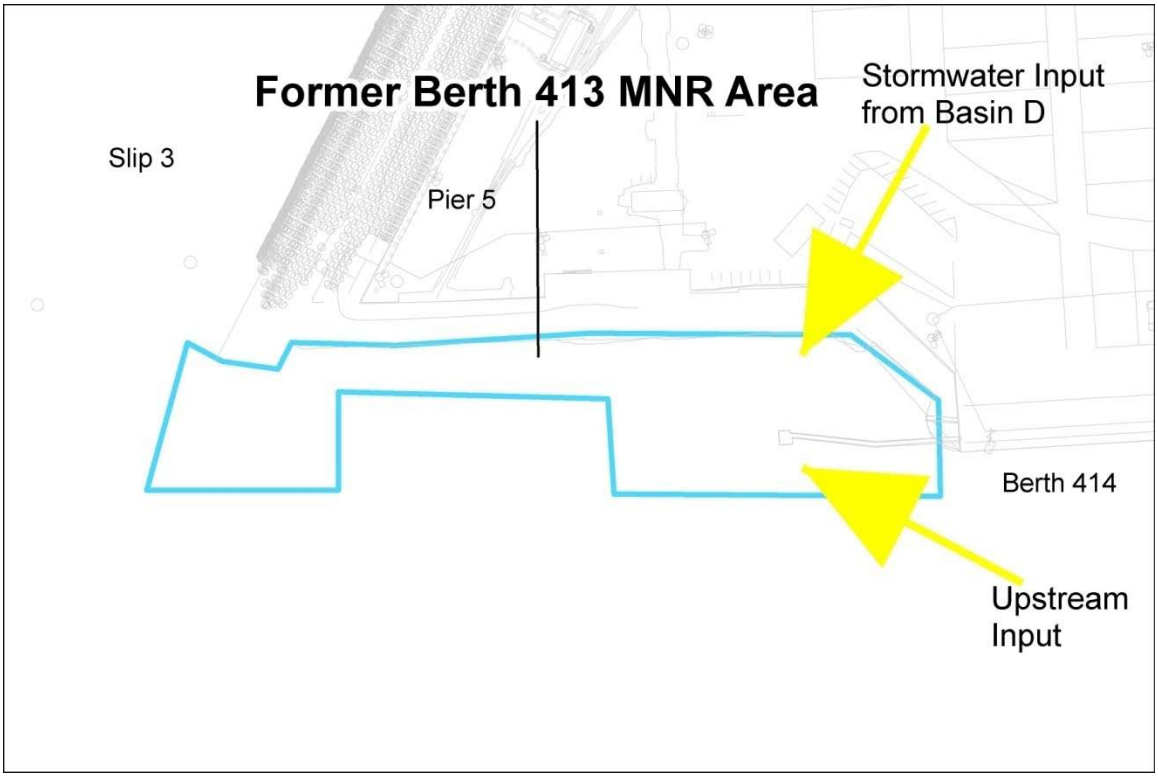

Figure 2-2: Former Berth 413 MNR subarea and potential recontamination sources.

2.4.2 Subarea 2 – Former Berth 413 Dredge and Cap Area

The dredge and cap area located adjacent to the former Berth 413 (north of Berth 414) receives sediment input from upstream, in addition to sediment input from the primary outfall of stormwater Basin D (Figure 2-3). Basin D is approximately 17 acres.

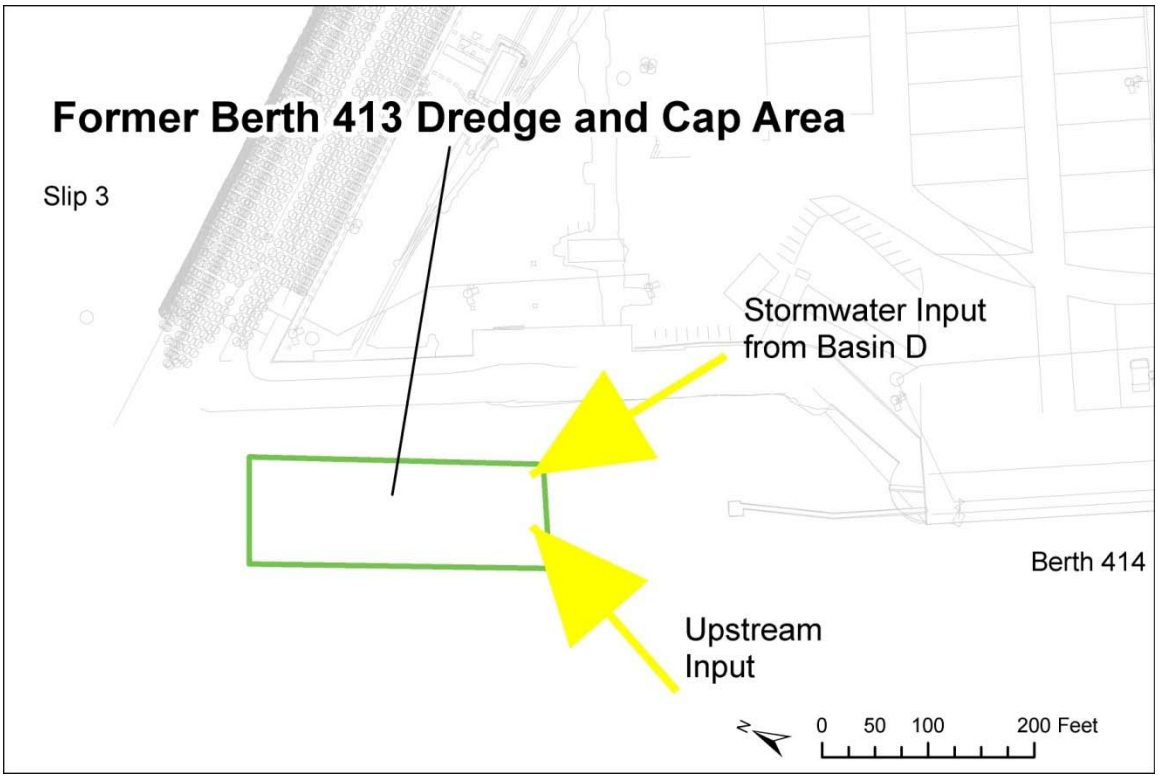

Figure 2-3: Former Berth 413 dredge and cap subarea and potential recontamination sources.

2.4.3 Subarea 3 – Slip 3 Cap Area

The capped area in Slip 3 receives sediment input from upstream and stormwater sediment from outfalls (Figure 2-4). Stormwater sediment in Slip 3 comes from Basins J, K and three minor catchments from Basin D. Basins J and K are 2.6 and 1.5 acres, respectively. Basin D is 17 acres total, however the catchments draining to Slip 3 are relatively small.

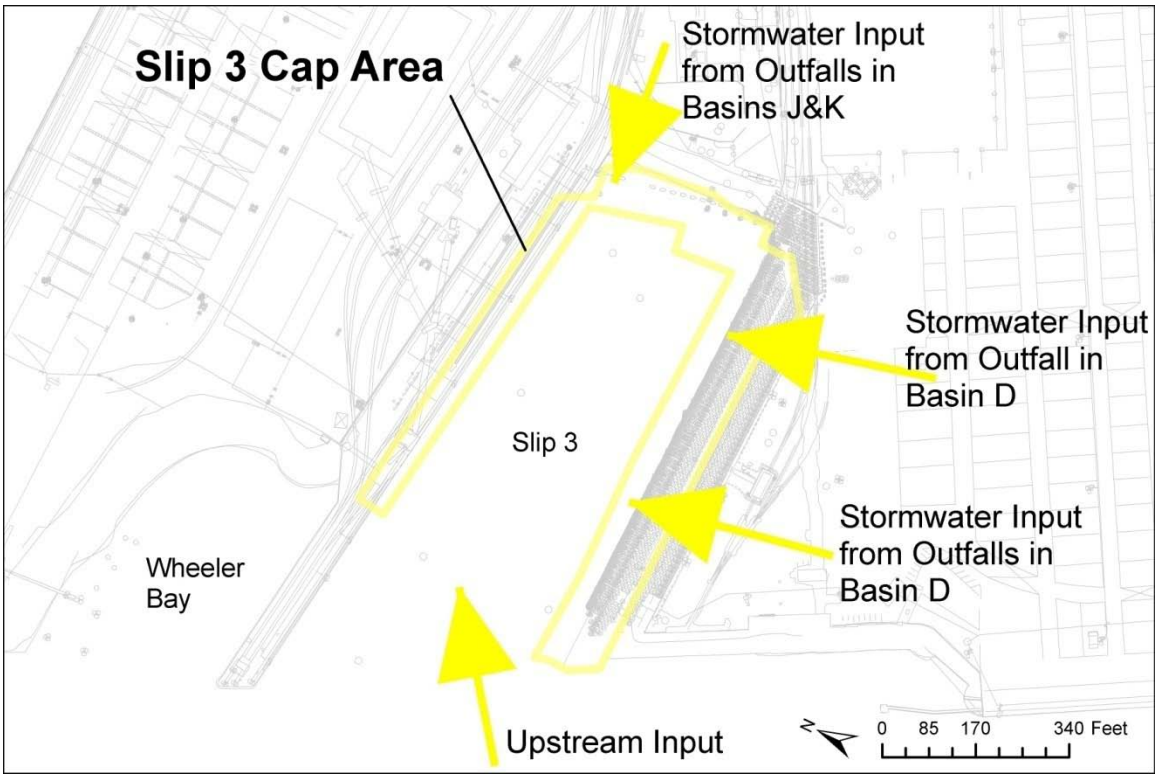

Figure 2-4: Slip 3 cap subarea and potential recontamination sources.

2.4.4 Subarea 4 – Slip 3 Dredge Area

The dredged area in Slip 3 receives sediment input from upstream and stormwater sediment from outfalls (Figure 2-5). Stormwater sediment in Slip 3 comes from Basins J, K and three minor catchments from Basin D. Basins J and K are 2.6 and 1.5 acres, respectively. Basin D is 17 acres total, however the catchments draining to Slip 3 are relatively small.

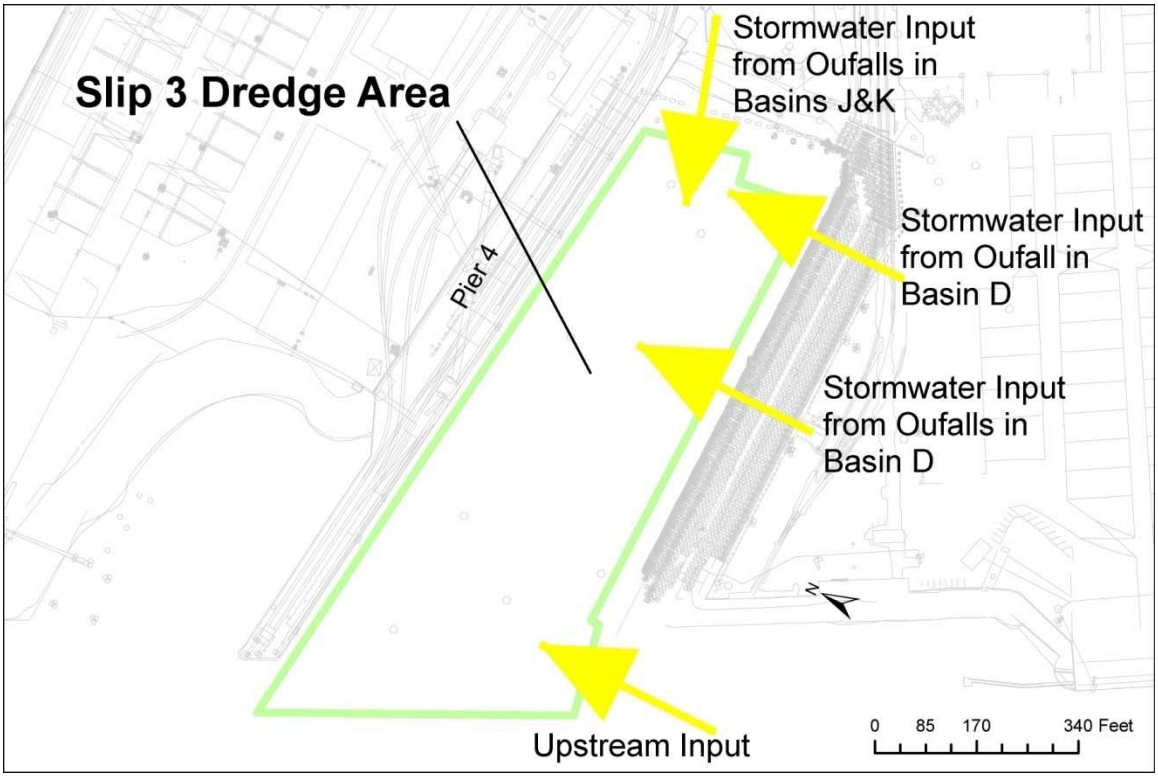

Figure 2-5: Slip 3 dredge subarea and potential recontamination sources.

2.4.5 Subarea 5 – Wheeler Bay Cap Area

The Wheeler Bay capped area receives sediment from upstream and stormwater outfalls (Figure 2-6). The outfall for Basin L discharges to Wheeler Bay. Basin L covers approximately 17.2 acres, and is the third largest stormwater basin in Terminal 4.

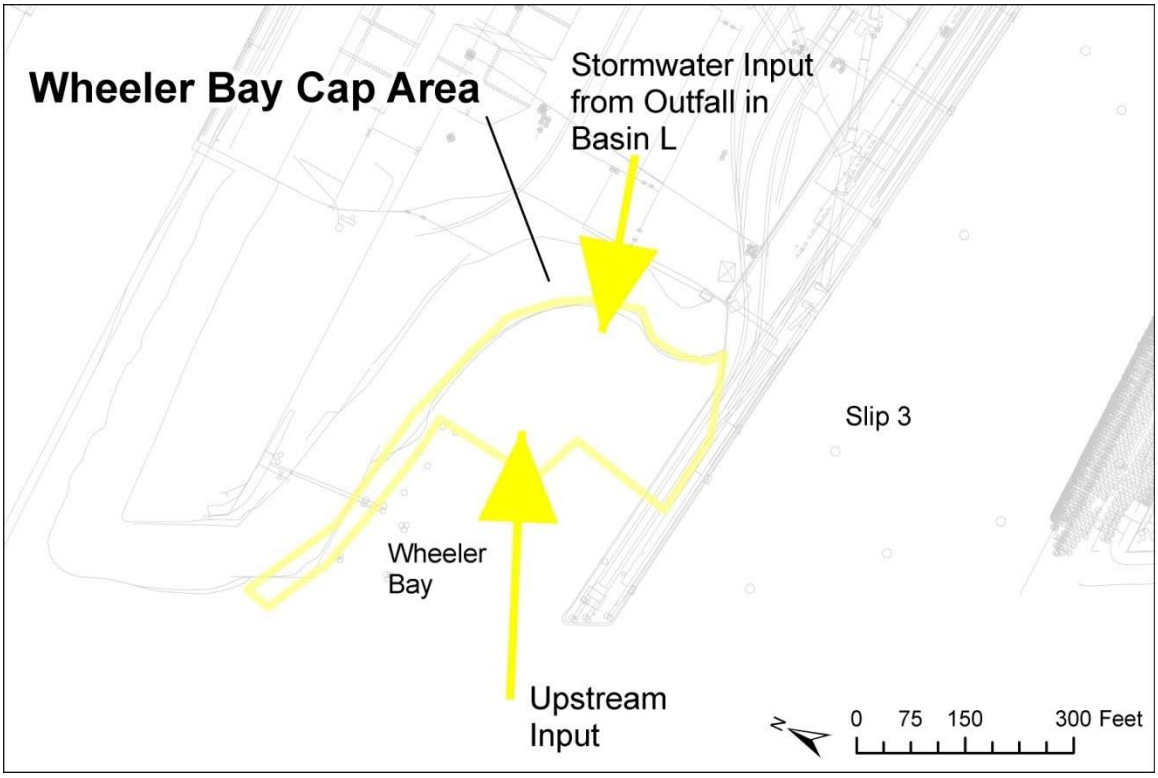

Figure 2-6: Wheeler Bay cap subarea and potential recontamination sources.

2.4.6 Subarea 6 – Wheeler Bay MNR Area

The Wheeler Bay MNR area receives sediment from upstream and stormwater outfalls, and may be affected by sediment input from upstream and stormwater outfalls (Figure 2-7). This area includes all MNR areas downstream of the Slip 3 dredged area. Following the construction of the CDF, the proposed relocation of the outfall for Basin M is downstream of Wheeler Bay. The outfall for Basin L discharges to Wheeler Bay. Basin L covers approximately 17.2 acres, and is the third largest stormwater basin in Terminal 4.

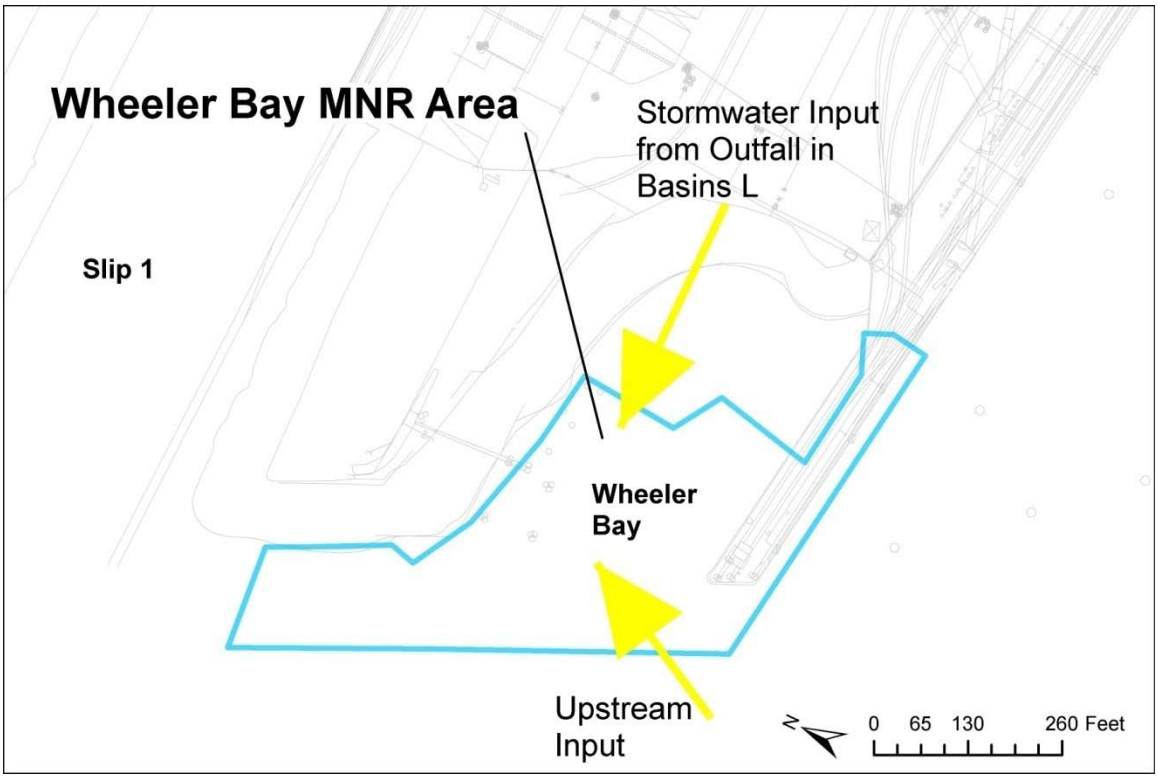

Figure 2-7: Wheeler Bay MNR subarea and potential recontamination sources.

2.4.7 Subarea 7 – Toe of Slip 1 MNR Area

The toe of slip 1 MNR area extends from the proposed reroute location for the stormwater outfall for Basin M to the reroute location for the outfall servicing Basins N, O, Q, R and T (Figure 2-8). Under the rerouted stormwater piping plan, this area will be affected by sediment input from upstream and stormwater from Basin M. Basin M covers approximately 29.1 acres. All of the sediment transported by stormwater will be assumed to affect this area.

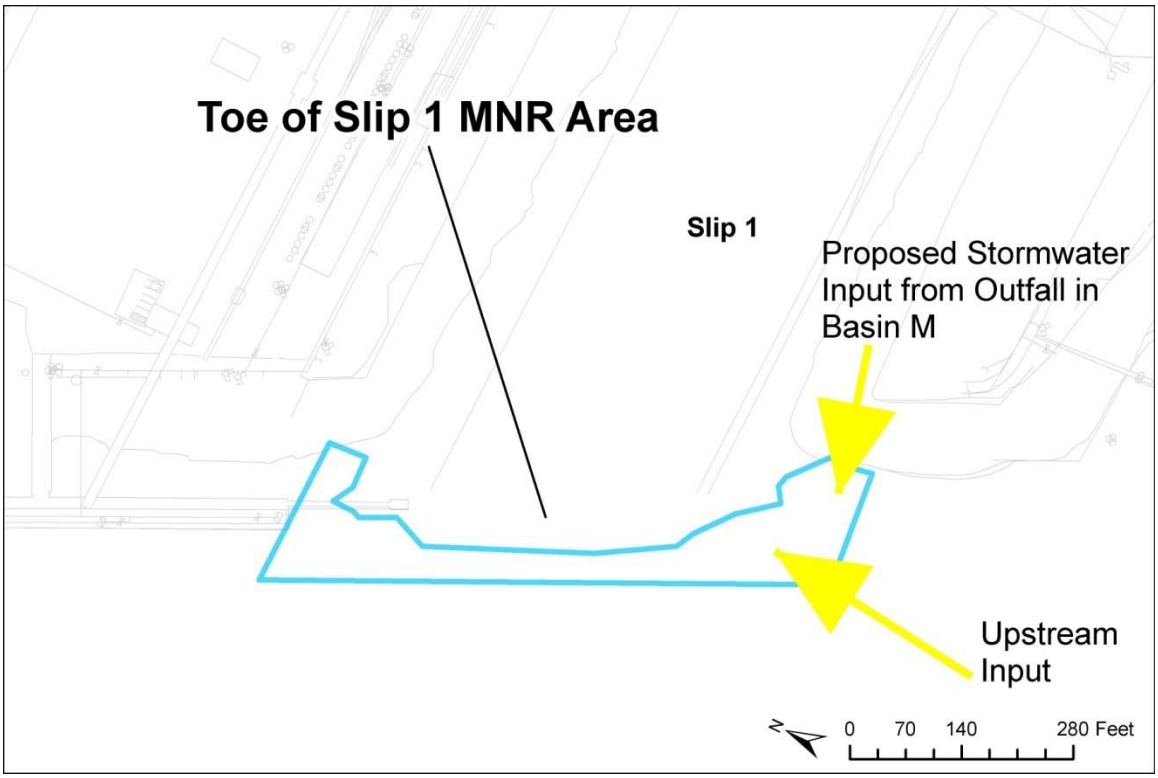

Figure 2-8: Toe of Slip 1 MNR subarea and potential recontamination sources.

2.4.8 Subarea 8 – Berth 401 MNR Area

The Berth 401 MNR area includes the MNR designated area downstream of the proposed reroute location for the stormwater outfall servicing Basins N, O, Q, R, and T (Figure 2-9). Basin T is drained by city outfall 52-C. This area ends downstream when the action becomes capping or the Removal Action Area terminates. Stormwater from Basins N, O, Q, R, and T drains approximately 63.5 acres in total.

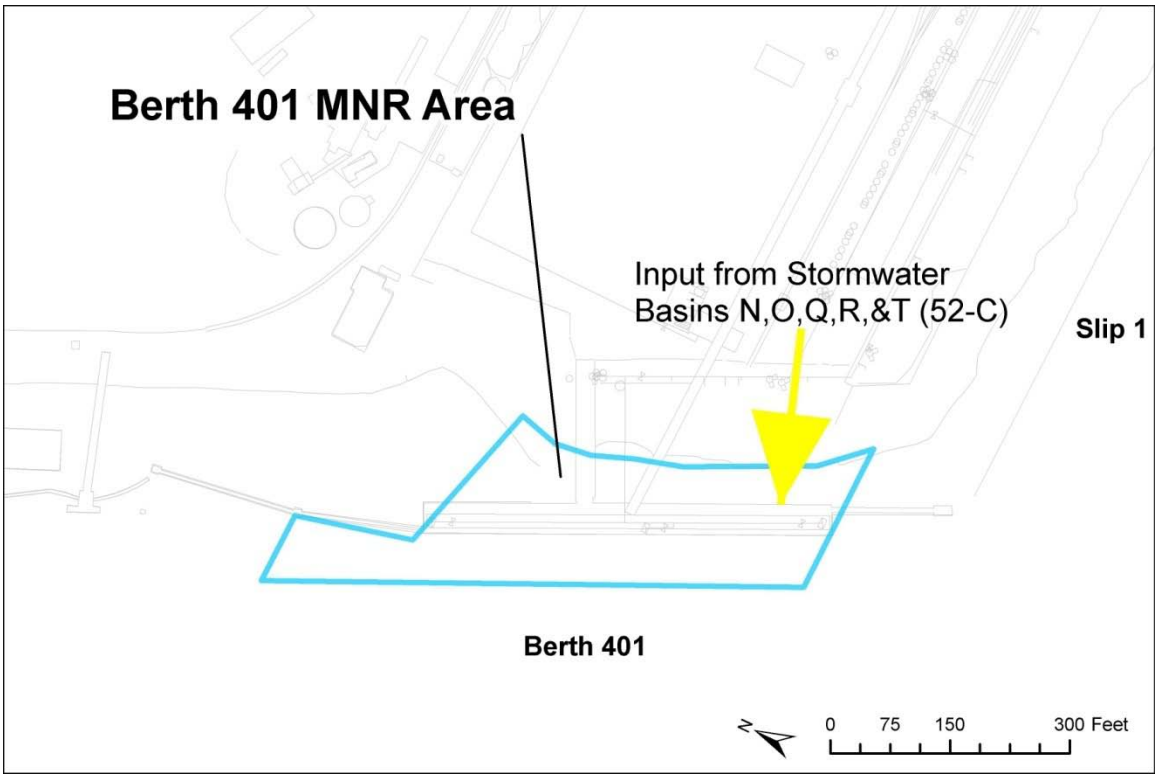

Figure 2-9: Berth 401 MNR subarea and potential recontamination sources.

2.4.9 Subarea 9 – Berth 401 Capped Area

The Berth 401 capped area is the furthest downstream Removal Action subarea. It will be affected by upstream and stormwater deposited sediment (Figure 2-10). Stormwater from Basins N, O, Q, R, T and S drains approximately 64.5 acres in total.

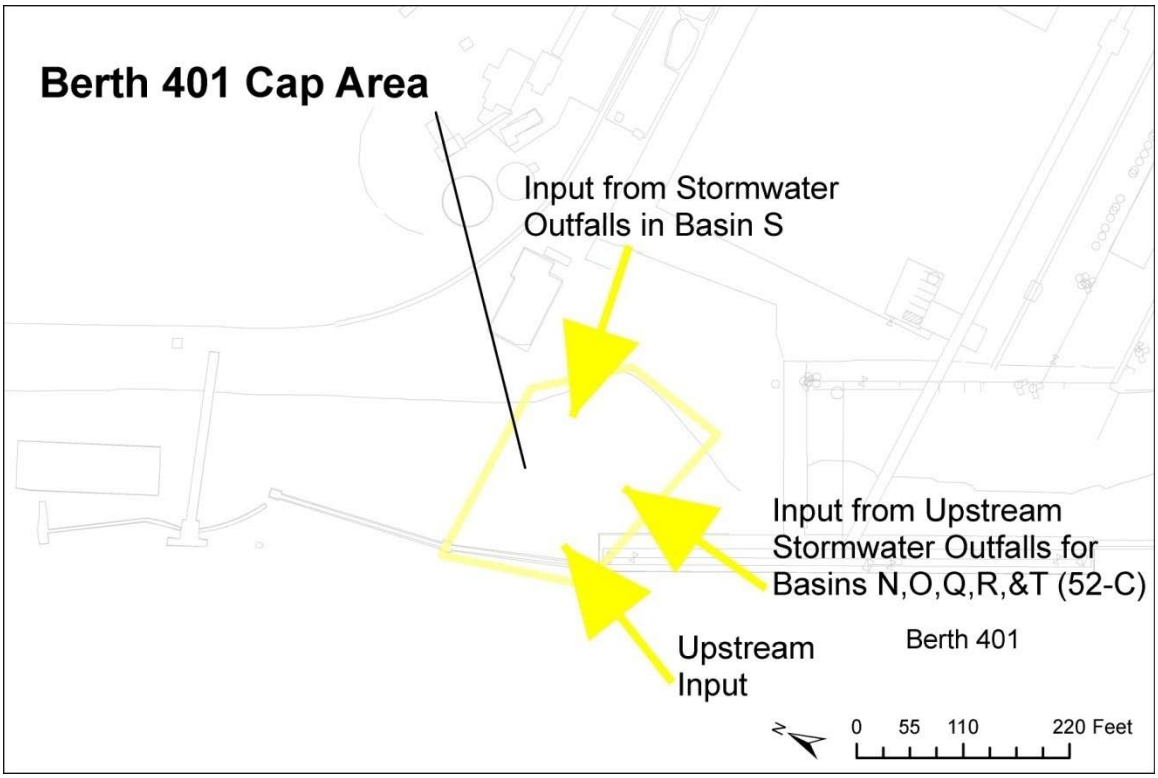

Figure 2-10: Berth 401 cap subarea and potential recontamination sources.

3.0 RECONTAMINATION ANALYSIS METHODOLOGY

The overall methodology for assessing sediment recontamination potential is described in the following sections, including the equations to be used in calculation of predicted COI concentrations in surface sediments after removal action construction is complete.

3.1 Overall Approach

The overall recontamination approach will consist of using the mathematical model, SEDCAM, to predict COI concentrations in surface sediments over time after the removal action construction is complete, considering sediment accumulation, mixing, and contaminant degradation (Jacobs et al., 1988). Source inputs and predicted concentrations over time will depend on the assumption of complete mixing within the Removal Action subarea, however, the recontamination analysis will be conducted on a point-by-point basis. The required inputs to the SEDCAM model are initial COI concentrations in surface sediment present after Phase II Removal Action construction is completed, estimated sediment and COI loads from primary sources, estimated degradation rates for each COI, and an assumed thickness of sediment mixing. Predicted concentrations will be assessed for decreasing trend, and if shown to increase will be compared to harbor-wide cleanup goals for each COI.

3.1.1 Sedimentation Rate

The first step in the analysis is to estimate net sedimentation rates in each of the Removal Action subareas. Available bathymetric, sediment trap and sediment stake data will be reviewed to provide an estimate of the annual average net sedimentation rate.

3.1.1.1 Methodology

An annual net sedimentation rate will be estimated for the Removal Action Area. The net mass of sediment deposited will be equal to the sum of the mass of sediment contributed by the upstream and stormwater sources:

$$M_{net\ gain,RAA} = M_{upstream} + M_{stormwater}$$

where

$M_{net\ gain,\ RAA}$ is the net mass of sediment gained annually in the RAA,

$M_{upstream}$ is the mass of sediment contributed annually by upstream sources and

$M_{stormwater}$ is the mass of sediment contributed annually by stormwater sources.

The net mass gain of sediment ($M_{net\ gain,\ RAA}$) in the Removal Action Area can be calculated from the deposition rate ($R_{deposition}$), area of the Removal Action subarea (A_{RAA}) and bulk density of sediment (p_b):

$$M_{net\ gain,RAA} = R_{deposition} * A_{RAA} * \rho_b$$

Data to be used

Data sources used to estimate the annual net sedimentation rate at Terminal 4 primarily include bathymetric surveys. In-water sediment traps were deployed in 2004 to 2005 by BBL (BBL/Arcadis, 2006), however sedimentation in traps will represent both net sedimentation and sediment resuspended due to propeller wash. Since propeller wash is a significant contributor to water velocities in Slips and other waters at Terminal 4, these data will not be used to evaluate the net sedimentation, since the combination with resuspended sediment would over-estimate the net sedimentation rate. Bathymetric surveys have been conducted at Terminal 4 on a regular basis since 2000. There have been multiple studies attempting to evaluate the sedimentation behavior indicated by these surveys (Port of Portland, 2002; Striplin, 2002; Striplin, 2003; Integral Consulting and David Evans Associates, 2004). Only a subset of the data acquired from these studies was available for quantitative review. In review of the data, it was necessary to ensure that dredged areas were not evaluated in net sedimentation estimates. Table 3-1 summarizes the available bathymetric data that was reviewed and the indicated annual net sedimentation rates. A preliminary average net sedimentation rate for Terminal 4 was calculated from this data to be 4 cm/yr. Due to the limited amount of data available for subareas, an average net sedimentation rate was calculated for the entire Removal Action Area. As additional bathymetric or other datasets become available, this estimate will be revisited to be more specific to subareas. Also, the Lower Willamette Group is currently preparing a harborwide RI/FS that will consider sedimentation over the greater Portland Harbor site (LWG, *in preparation*). Estimated sedimentation rates from the harborwide RI/FS will be used to guide the sedimentation rate used in the recontamination analysis for Terminal 4.

Table 3-1: Summary of sedimentation rates for Terminal 4.

Source	Method	Time Frame	Location	Sedimentation Rate (cm/yr)
Port of Portland, 2002	bathymetric surveys[1]	2000 - 2001	Berth 401	-3.6
Port of Portland, 2002	bathymetric surveys[1]	1999 - 2000	Berth 401	9.6
Port of Portland, 2002	bathymetric surveys[1]	1998 - 1999	Berth 401	1.2
Striplin, 2002	bathymetric surveys	Jan 2002 - July 2002	Berth 401	15.6
Port of Portland, 2002	bathymetric surveys[1]	2000 - 2001	Slip 3	-8.3
Port of Portland, 2002	bathymetric surveys[1]	1999 - 2000	Slip 3	10.3
Port of Portland, 2002	bathymetric surveys[1]	1998 - 1999	Slip 3	-4.2
Port of Portland, 2002	bathymetric surveys[1]	1995 - 1997	Slip 3	-3.0
Striplin, 2002	bathymetric surveys	Jan 2002 - July 2002	Slip 3	7.3
Port of Portland, 2002	bathymetric surveys[1]	2000 - 2001	north of Berth 414	-10.2
Port of Portland, 2002	bathymetric surveys[1]	1999 - 2000	north of Berth 414	15.9
Port of Portland, 2002	bathymetric surveys[1]	1998 - 1999	north of Berth 414	11.5
Port of Portland, 2002	bathymetric surveys[1]	1995 - 1997	north of Berth 414	36.3
Striplin, 2002	bathymetric surveys	Jan 2002 - July 2002	former Berth 413	-23.1

[1]*Bathymetric surveys were evaluated for dredge prism areas only.*

A sediment stake study was conducted by the LWG (Anchor, 2003) in order to assess sediment elevation changes in near-shore environments, which bathymetric surveys are not able to capture. Sediment stakes were placed at low, medium and high locations relative to the shoreline at eight locations along the Willamette River. One stake was located in Wheeler Bay. Results from the five month sediment stake deployment showed relatively little change. However, no correlation was apparent between sediment stake results and bathymetric surveys. The sediment stake deployment did not capture the high-stage timeframe, and sediment stakes in different locations were subject to varying wetted periods.

Uncertainty

Sedimentation rates will be based primarily on bathymetric survey data. Bathymetric surveys were conducted using high-resolution multibeam sonar technology. Horizontal positioning was conducted using GPS. Vertical accuracy of the survey data is within +/- 0.25 ft. Post-processing errors may include positioning differences of vessels over time, outer sonar beam noise, and errors near vertical structures (Integral and David Evan Associates, 2004). Data processing produced contoured bathymetry grids with 3 ft by 3 ft cells using inverse distance weighting and beam grazing angle algorithms (Integral and David Evan Associates, 2004). The analysis of data from 2002 (Striplin, 2002) limited the analysis areas in order to minimize the inclusion of data errors near vertical structures. Data reviewed by the Port (Port of Portland, 2002) limited the analysis extent to dredge prisms only. The spatial restrictions applied to the data analysis improves accuracy by reducing the inclusion of data errors, but may decrease accuracy by limiting the spatial extent to areas that may experience preferential deposition or scour due to vessel traffic or river currents.

3.1.2 Sediment Mass Balance

While COI mass can be input to the system from various sources (see Section 2.3 for an example list), the primary sources of sediment are typically limited to upstream river sediment and suspended sediment in stormwater runoff. For the Terminal 4 removal action areas, stormwater sediment loads can be estimated from the recent sampling effort, which included in-line sediment traps and collection of water samples for analysis of COIs and TSS. Therefore the sediment input from the upstream river can be estimated by subtracting the stormwater sediment load from the total sediment load (from the average sedimentation rate and depositional area). As well as providing necessary input parameters for the SEDCAM model, this step provides an indication of the relative sediment load coming from upstream.

3.1.3 Quantify Primary Potential Recontamination Sources

Initial screening (Section 2.3) suggests that upstream and stormwater sediment are potentially significant sources. The load of sediment contributed by stormwater can be calculated based on TSS measurements collected during the recent sampling events. Stormwater sediment contributions to Removal Action subareas located in the main channel of the Willamette River (i.e. Berth 401 and Berth 414) will be adjusted based on their proximity to the outfall. Using the net mass of sediment gained/lost and the stormwater sediment load, the upstream sediment contribution can be calculated, as described above.

Next, concentrations of COIs in stormwater and upstream sediment inputs will be assigned. A combined input concentration to Removal Action subareas will be calculated based on a weighted average of the source input concentrations and relative sediment loading. Stormwater COI concentrations were measured in 2007 through 2008 (Ash Creek, 2008). An upstream in-water sediment trap (dry weather data) and stormwater data from immediately upstream will be used to estimate the concentration of COIs in the upstream suspended sediment.

3.1.3.1 Upstream

The upstream source includes all sediment originating upstream of Terminal 4 that gets deposited in the Removal Action Areas. Upstream sediment may have been impacted by other site activities, including stormwater runoff, atmospheric deposition, bank erosion, overwater spills, or other activities occurring upstream of Terminal 4.

Data to be used

COI concentrations for the upstream contribution will be obtained from the mid-Willamette sediment trap. This sediment trap was located toward the center of the river, slightly upstream of Berth 414 and Terminal 4.

Deployment of the mid-Willamette sediment trap was conducted as part of the BBL Supplemental Field Work (BBL, 2005b). Details regarding the location selection, sediment trap deployment, preparation and trap recovery can be found in the Terminal 4 Early Action Characterization Report (BBL, 2004a). The trap was deployed from January to March 2005, however, this deployment interval represents primarily dry weather conditions. COI concentrations in the river may be higher during wet weather conditions, primarily due to increases in upstream inputs to the river (i.e. upstream stormwater outfalls). Data from outfall 53, located upstream of the mid-Willamette sediment trap, will be used to determine if the mid-Willamette concentrations would be impacted during wet weather conditions. COI concentrations from the mid-Willamette sediment trap and the outfall 53 stormwater sediment trap are shown in Tables 3-1 and 3-2.

Table 3-2: Upstream COI concentrations measured in the mid-Willamette sediment trap from the January to March 2005 deployment.

COI	Mid-Willamette Sed Trap, Jan-Mar 2005
Benzo(a)pyrene	54 µg/kg
Benzo(a)anthracene	52 µg/kg
Dibenzo(a,h)anthracene	6 µg/kg
Pyrene	110 µg/kg
Indo (1,2,3) pyrene	57 µg/kg
Cadmium	0.48 mg/kg
Lead	27.1 mg/kg
Total PCBs	64 µg/kg

Table 3-3: Stormwater COI concentrations measured in the Outfall 53 sediment trap in February 2008.

COI	Outfall 53 Sed Trap, Feb 2008
Benzo(a)pyrene	830 µg/kg
Benzo(a)anthracene	510 µg/kg
Dibenzo(a,h)anthracene	150 µg/kg
Pyrene	1100 µg/kg
Indo (1,2,3) pyrene	790 µg/kg
Cadmium	1.04 mg/kg
Lead	97.3 mg/kg
Total PCBs	377 µg/kg

The COI concentrations in stormwater from outfall 53 are higher than those measured in the mid-Willamette trap. These data will be used to adjust the mid-Willamette data to account for wet-weather flow in the annual average upstream load estimate.

Evaluating load

The contribution of COIs by upstream sources will be calculated by first estimating the sediment load due to upstream sources. The net sedimentation rate estimated for the subarea can be used to calculate a net mass of sediment gained/lost from the subarea on an annual basis, as:

$$M_{net\ gain,RAA} = R_{deposition} * A_{slip} * \rho_b$$

where the net gain of sediment in the Removal Action subarea is $M_{net\ gain,\ RAA}$,

$R_{deposition}$ is the average annual rate of sediment deposition,

A_{RAA} is the area of the Removal Action subarea, and

p_b is the sediment bulk density.

The net sediment gain should then equal the sum of the individual source sediment contributions:

$$M_{net\ gain,RAA} = \sum M_{sources}$$

The primary sources of sediment to the Removal Action Areas are upstream and stormwater. The load of sediment contributed by upstream sources can be deduced by subtracting the sediment load from stormwater sources from the total net sediment gain for the Removal Action subarea.

Uncertainty

Use of the average annual sedimentation rate to calculate the net sediment gained in the Removal Action subarea and ultimately to deduce the sediment load contributed by the upstream sources make this source load term dependent on the accuracy of the average annual net sedimentation rate. Uncertainties related to this value are described in Section 3.1.1.1. Deployment of the mid-Willamette sediment trap extended from January to March 2005 only. This time interval does not span the season flow changes in the river, when more or less sediment may be transported. However, since the sediment trap data is being used for the COI concentration only, and not the mass loading, the extent of this uncertainty should be minimized.

3.1.3.2 Stormwater

Stormwater runoff suspends sediment from paved and unpaved areas and transports this sediment through the stormwater drainage system to the Removal Action Areas.

The effects of stormwater discharge will be evaluated based on the revised configuration proposed as discussed in the 60% Design Analysis Report (Anchor, 2006). Table 3-3 summarizes which basins discharge stormwater to which Removal Action subareas under the reconfigured plan.

Table 3-4: Summary of stormwater basins and the Removal Action subareas that they may affect.

Removal Action Subarea	Stormwater Basin
1 – Berth 414 MNR Area	D
2 – Berth 414 Dredge and Cap Area	D
3 – Slip 3 Cap Area	J, K, part of D
4 – Slip 3 Dredge Area	J, K, part of D
5 – Wheeler Bay Cap Area	L
6 – Wheeler Bay MNR Area	L
7 – Toe of Slip 1 MNR Area	M
8 – Berth 401 MNR Area	N, O, Q, R, S
9 – Berth 401 Cap Area	N, O, Q, R, S

Data to be used

Stormwater and stormwater sediment was sampled as part of a stormwater characterization program conducted by the Port between 2007 and 2008. This program is summarized in the Final Terminal 4 Slips 1 and 3 Stormwater Data Summary Report (ACA, 2009). The stormwater characterization program was conducted in response to stormwater data gaps identified in the Recontamination Analysis prepared by BBL in 2006. Sampling procedures were based on the field sampling plan developed by Anchor Environmental and Integral Consulting for the LWG Round 3A stormwater sampling (LWG, 2007). In-line sediment traps were deployed twice in Basins D, L, M, and R for a period of approximately five months (January to June 2007) and another period of approximately five months (September/October 2007 to February 2008). Bulk stormwater samples were retrieved from drainage lines in Basins D, L, M, Q and R using programmable composite samplers. The composite samplers collected samples on a flow- or time-weighted basis to capture multiple storm events throughout the sampling period. Stormwater from basins J, K, O, N, and S was not sampled, based on a combination of the following factors: similar land use to other basins, limited historical and current land use, a small percentage of the overall drained area, and a lack of surface sources. The rationale for selection of basins for additional sampling is due to their potential to be significant sources of COIs and is described further in the DEQ approved Storm Water Evaluation Work Plan (ACA and NewFields, 2007). City outfall 53 was sampled by the City of Portland in February 2008. The Final Terminal 4 Slips 1

and 3 Stormwater Data Summary Report provides concentrations of COIs and TSS in stormwater lines (ACA, 2009).

BBL also collected stormwater sediment data for the Recontamination Analysis conducted in 2006, however, since the 2007-2008 dataset is more complete and seasonally non-biased, this data will be utilized for the analysis. Annual rainfall was measured by the Portland HYDRA network data. The average annual rainfall from the 50th percentile flow year, 2002, was used in the loading calculation (Anchor QEA, 2009). The land cover impervious fraction is estimated in the Removal Action Area EE/CA (BBL, 2005a). Basin areas are provided in the Final Terminal 4 Slips 1 and 3 Stormwater Data Summary Report (ACA, 2009).

Evaluating load

The SIMPLE method (Schueler, 1987) is a runoff model that estimates pollutant loading. The SIMPLE method is a simple spreadsheet model that is appropriate for smaller watersheds (less than 640 acres) with limited site data. The entire Terminal 4 facility covers less than 300 acres. The SIMPLE model is the runoff model being used in the harborwide RI/FS for Portland Harbor (LWG *in preparation*). The SIMPLE model will be used to estimate the load of suspended COIs in stormwater caused by storm events, using the total suspended solids (TSS) concentration and the measured concentration of COIs in sediment from traps. Storm events are assumed to produce most of the COI load. The SIMPLE method modifies the volume of water or suspended sediment produced by rainfall events by a runoff coefficient and a fraction of annual rainfall that produces runoff. The runoff coefficient takes the surface cover type into account (i.e. fraction that is impervious). The TSS load will be calculated as:

$$TSS_{load} = RO * C_{TSS} * A_{basin}$$

where RO is runoff, C_{TSS} is the concentration of TSS in stormwater, and A_{basin} is the area of the basin being drained. Runoff can be described as:

$$RO = R * R_v * 0.9$$

where R is the annual rainfall, R_v is the runoff coefficient, and 0.9 is a standard factor representing the percentage of rainfall that produces runoff. The runoff coefficient can be described as:

$$R_v = 0.05 + 0.9 * I_a$$

where I_a is the fraction of surface area in the basin that is impervious.

The TSS load represents the sediment contributed to the Removal Action Area by stormwater sources. This load will then be used to calculate the load of each COI

contributed by stormwater sources. The assumption that all of the stormwater sediment from the outfall lands in the nearby Removal Action subareas provides a conservative estimate of its recontamination potential.

Uncertainty

The sediment trap deployment period was extended based on data gaps identified during the Recontamination Analysis conducted by BBL in 2006. Two deployment periods were used in order to obtain enough sample mass for analysis and to capture the "first flush" storm events that occur in the fall season. The deployment periods adequately (January through June and September/October through February) cover seasonal variations. The dataset used represents only one year, so annual variations may still exist. The SIMPLE model is based on urban land use so the runoff coefficient contains uncertainty when applied to an industrial site, however the harborwide RI/FS has determined that the SIMPLE model is the most appropriate for the site (LWG *in preparation*). COI loads from stormwater basins that were not directly sampled were estimated from other basins with similar land use. Basin sampling was determined based primarily on areas that were likely sources of contamination due to historical activities (ACA/NewFields, 2007). Therefore, when substituting these values for other basins, the resulting total COI load estimate will be conservative. The rationale for selection of basins for additional sampling is due to their potential to be significant sources of COIs and is described further in the DEQ approved Storm Water Evaluation Work Plan (ACA and NewFields, 2007).

3.2 SEDCAM Recontamination Model for Removal Action Areas

The recontamination analysis assesses the potential for post-Removal Action recontamination of surface sediment within the Removal Action Area using the SEDCAM model (Jacobs et al., 1988). The model estimates COI concentrations in surface sediments (a "mixed layer" of defined thickness) by considering initial conditions (i.e., concentrations immediately after removal action construction is complete) and changes with time due to accumulation, burial and loss from diffusion and chemical degradation (see Figure 3-1).

The model contains several simplifying assumptions, such as a well-mixed surface sediment layer of defined thickness and a single term covering chemical degradation and diffusion. However, the model's relative simplicity is one of its main strengths and it has been used for sediment evaluations at multiple sites (Jacobs et al., 1988; Ecology, 1991), and in preliminary evaluation of monitored natural recovery at the Portland Harbor Superfund Site (Anchor, 2005).

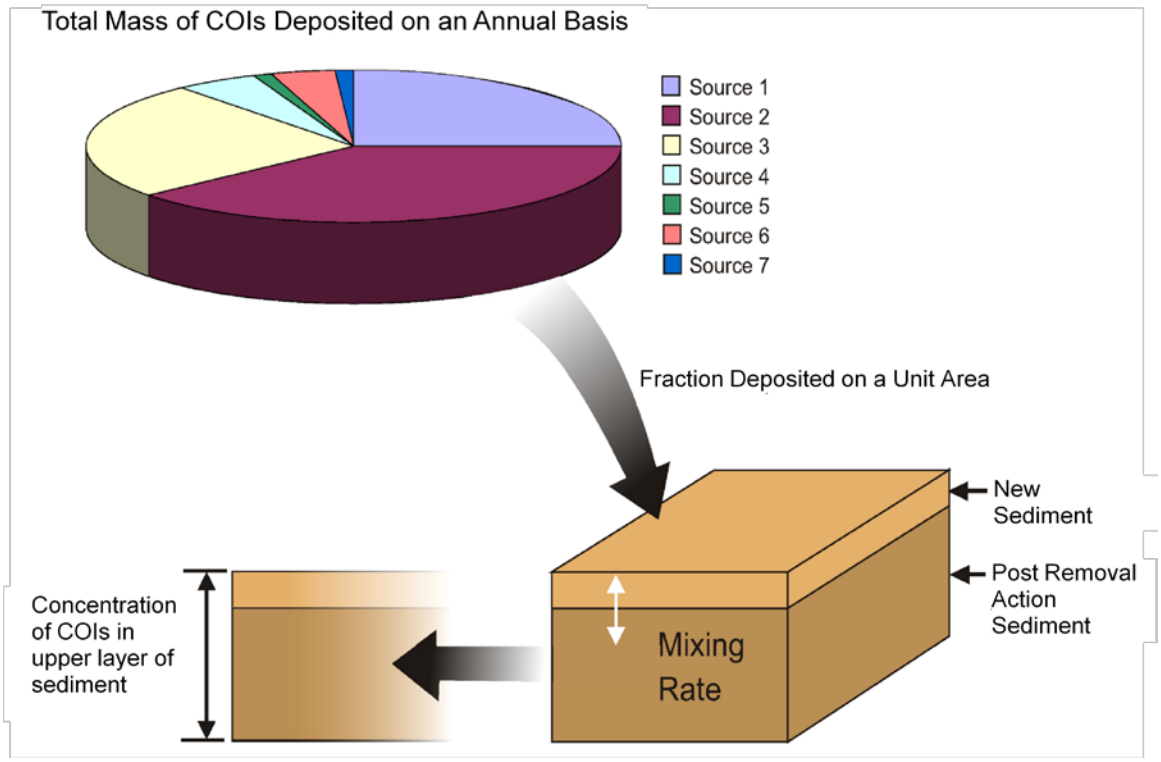

Figure 3-1: Schematic explaning the SEDCAM model.

The form of the SEDCAM model equation presented in the draft Recontamination Analysis (BBL/Arcadis, 2006) was:

$$M_C(t) = \frac{M}{(M+kS)} M_p \left[1 - e^{\frac{-(kS+M)t}{S}} \right] + M_o e^{\frac{-(kS+M)t}{S}}$$

where:

$M_C(t)$ = mass of COI in surface sediment at time t (mg or µg)

M = sedimentation rate (g/cm^2 -yr)

k = combined first-order rate constant for contaminant loss through decay and diffusion processes (yr-1)

M_p = mass of COI in particles being deposited on the sediment (mg or µg)

t = time (yr)

M_o = initial mass of COI in surface sediment (mg or µg)

S = sediment accumulation in the mixed layer (g/cm^2)

To provide clarity on how collected data are used in the analysis, this equation has been converted as follows (see Appendix A):

$$C_C(t) = \frac{1}{(1+kTs)} C_p \left[1 - e^{\frac{-(1+kTs)t}{Ts}} \right] + C_o e^{\frac{-(1+kTs)t}{Ts}}$$

Ts = ML/Rs

where:

$C_c(t)$ = concentration of COI is surface sediment (mixed layer) at time t (mg/kg or µg/kg)

C_p = average concentration of COI in particles being deposited on the sediment (mg/kg or µg/kg)

C_o = average concentration of COI in surface sediment (mixed layer) at time zero (i.e., immediately after sediment removal or capping activities are completed) (mg/kg or µg/kg)

ML = thickness of mixed layer (cm)

Rs = sedimentation rate (cm/year)

C_p represents the average COI in new particles deposited on the sediment. The mass of COI in particles being deposited on the sediment (M_p) is related to concentration (C_p) as follows:

$$M_p = C_p \; M_s$$

where C_p = Average COI concentration on sediment particles

M_s = Mass of sediment particles deposited.

Further

$$C_p = \Sigma C_i M_i / \Sigma M_i$$

where C_i = COI concentration on sediment particles from source "i" (mg/kg)

M_i = mass of sediment particles from source "i" (kg)

And $\Sigma C_i M_i$ is therefore the sum of particulate-based COI load (COI concentration on the particulate multiplied by mass of particulate) for all sources (i.e., individual stormwater upstream sources etc.)

The sediment mass input to the system is equal to the sum of all inputs (i.e., $M_s = \Sigma M_i$) and further for an individual area, the sum of the sediment particle inputs must balance with the total sedimentation rate, such that

$$M_s = Rs \ A_{dep} \ \rho_b$$

3.2.1 SEDCAM Model Parameters

The following sections discuss the remaining input parameters necessary for the SEDCAM model.

3.2.1.1 Sediment mixed layer thickness

The mixed layer thickness depends on water velocities, ship traffic, and activity of benthic organisms. This value typically ranges between 0 and 25 cm thick (Ecology, 1991). For Slip 3, a value of 15 cm was chosen based on the low current velocities within the slip, coupled with periodic redistribution of sediment due to propeller wash which affects areas well beyond the path of the vessel (BBL, 2005a). For example, using an estimated net deposition rate of 4 cm/yr and density of 1.53 g/cc, sediment trap data from 2004 through 2005 suggests that propeller wash may disturb a thickness of 14.3 to 80.3 cm/yr. For Removal Action subareas that lie within the main channel of the Willamette River, a mixed layer thickness of 25 cm will be used, since these areas are affected both by propeller wash and the Willamette River current, which can reach 1.5 feet per second (BBL, 2005a).

3.2.1.2 Sediment density

The estimated sediment density used in the Recontamination Analysis will be based on the analysis presented in the harborwide RI/FS (LWG, *in progress*). As a preliminary

estimate, all available sediment specific gravity measurements from river mile 4 to 5 of the Willamette River were considered. An average of 100 specific gravity measurements for surface sediment from 0 to 30 cm deep was calculated to be 1.53 g/cc.

3.2.1.3 Initial COI concentration in surface sediment

The initial COI concentration in surface sediment will be characterized by sampling after the Phase II Removal Action construction is complete. Recontamination will be assessed on a point-by-point basis using the maximum observed value for each COI by subarea.

3.2.1.1 Degradation Rate

Degradation rates will be based on the values presented in the harborwide RI/FS (LWG, *in progress*).

3.2.1.2 Area

The area of each sub-area used for calculation in the SEDCAM model will be estimated in ArcGIS.

3.3 Primary data sources

Data sources to be used for the Recontamination Analysis may include previous reports, site field data, and bathymetric survey data. The following list provides the main data sources available for use in the Recontamination Analysis, organized by data type:

Sedimentation:

- Port of Portland, 2002. Sedimentation at the Port of Portland Terminals. February.
- Anchor Environmental, LLC, 2003. Draft Sediment Stake Erosion/Accretion Monitoring Report, Round 1A, Portland Harbor RI/FS. May.
- Striplin, 2002. Draft Integration of Sediment Trend Analysis Survey Results with Historic Bathymetry in the Lower Willamette River. Striplin Environmental Associates, Inc. April 26.
- Striplin, 2003. Draft Lower Willamette River May 2003 Multibeam Bathymetry Survey Report. Stripling Environmental Associates, Inc. October 8.
- Integral Consulting, Inc. and David Evans Associates, Inc., 2004. Lower Willamette River, Winter 2004, Multibeam Bathymetric Survey Report. September.
- Field sediment trap data acquired by BBL from 2004 to 2005 for Terminal 4.

River dynamics:

- BBL, 2004a. Terminal 4 Early Action Characterization Report. September.

- Appendix G: Summary of Hydraulics and Sedimentation Characteristics, in BBL, 2005a. Engineering Evaluation and Cost Analysis.

River COI concentrations:

- In-water sediment traps (Mid-Willamette location) deployed during 2004 and 2005.

Stormwater COI concentrations:

- Stormwater in-line sediment traps deployed during 2007 and 2008 (ACA and NewFields, 2009).

Additional data sources regarding the evaluation of additional sources of COIs will be evaluated as needed. For example, the Port is currently preparing a storm water source control evaluation report for the Oregon Department of Environmental Quality on the Terminal 4 Slip 1 and Slip 3 Upland Facilities.

4.0 EXAMPLE RECONTAMINATION ANALYSIS

To show how the methods and data explained above will be used to estimate sediment recontamination potential at Terminal 4, an example calculation is described below. Although the example follows the prescribed methodology, it is included only for demonstrative purposes and does not represent the final recontamination analysis for this subarea. As additional data are acquired, implementation of the methodology will adapt to accommodate the new information.

4.1 Example Setup

The recontamination assessment was conducted for the dredged area of Slip 3 to demonstrate implementation of the methodology. Since post-Phase II Removal Action Area surface sediment concentrations have not yet been obtained, the maximum post-Phase I Removal Action dredging in Slip 3 was used as a conservative initial level for this example. The recontamination methodology calls for comparison of sediment concentrations predicted by the SEDCAM model to harborwide cleanup goals, however, since these were not available, the Terminal 4 hill-topping benchmark value was used for the example.

A net average sedimentation rate of 4 cm/yr was estimated for Terminal 4 based on review of the available local bathymetric survey data. Although the sedimentation patterns in Slip 3 consist of preferential scour near Pier 4 and accumulation toward Pier 5, the average net sedimentation rate for the slip should represent long-term conditions. Using this rate, a net annual sediment load was calculated for Slip 3 as:

$$M_s = R_s * A * \rho_b$$

where M_s is the annual net mass of sediment deposited, R_s is the average sedimentation rate, A is the area of the Removal Action sub-area and p_b is the sediment bulk density. Using this equation, a net sediment load of 2,188,981 kg/yr was estimated based on a preliminary estimate of sediment density of 1.53 g/cc (see Section 3.2.1.2).

Sediment load due to stormwater was estimated based on Basins J and K which discharge to Slip 3. Three small catchments from Basin D also discharge into Slip 3, however these are negligible in size compared to the sum of Basins J and K. The total annual sediment load from stormwater was calculated from measured total suspended solids concentration from a stormwater trap in Basin L (see Section 3.1.3.2). The total sediment load was estimated to be 769 kg/yr. Subtracting the stormwater sediment load from the net sedimentation leaves an upstream sediment input of 2,188,212 kg/yr. This indicates that upstream sediment contributes 99.96% of the sediment to Slip 3, while stormwater contributes 0.04%. Because the upstream source dominates, it allows flexibility with respect to estimation of where sediment from individual stormwater outfalls

settles. In particular, conservatively assuming that all stormwater sediment settles in a particular area does not affect the outcome of the analysis and therefore detailed modeling to refine those estimates is not required.

The example calculation was conducted for benzo(a)pyrene. The input concentrations of benzo(a)pyrene from stormwater (31,000 µg/kg) and upstream sources (54 µg/kg from the mid-Willamette sediment trap) were used to calculate a weighted average benzo(a)pyrene concentration based on their relative sediment contributions. The SEDCAM model was conducted for 10 years on a 1-year time step.

4.2 Recontamination Analysis for Slip 3 dredged area

The following sections describe the data input into the SEDCAM model as well as the example model results, uncertainties and a brief sensitivity analysis. Input values used in this example are not necessarily the final input values for this subarea. The example is to demonstrate the implementation of the methodology, not to provide recontamination analysis results.

4.2.1 Summary of model inputs

Model inputs are summarized in Table 4-1. The mixed layer thickness is an assumed value of 0.5 feet (15.24 cm). The degradation rate for benzo(a)pyrene was extrapolated from literature values for degradation of total PAHs. Since grain size information has not been acquired for stormwater transported sediment, a conservative assumption was made that all stormwater solids from the applicable basins would land in the Slip 3 dredged area.

Table 4-2 shows the calculation used to estimate the weighted average COI concentration from the two input sources: stormwater and upstream. As the Table 4-2 shows, the estimated sediment input from upstream sources is four orders of magnitude larger than the measured stormwater sediment input. Based on the relative magnitude of the upstream and stormwater sources, the upstream sediment input will dominate the sedimentation in the Removal Action Area, thus detailed stormwater sediment deposition modeling is not warranted.

Table 4-1: Summary of model input values for the example calculation.

Model Input Values		
Area of Removal Action subarea	385,000	ft^2
Total load of sediment to subarea[1]	2,188,981	kg/yr
Weighted average input BaP concentration[2]	64.87	µg/kg
Mixing layer thickness[3]	15.24	cm
BaP degradation rate[4]	0.5	yr^{-1}
Initial concentration at maximum point in subarea[5]	41,100	µg/kg
Time step	1	yr

[1]Based on an annual net sedimentation rate of 4 cm/yr.
[2]Weighted average of stormwater and upstream source inputs based on relative magnitude of sediment load (see Table 4-2).
[3]Assumed value.
[4]Mean degradation rate for Total PAHs from BBL/Arcadis, 2006. This rate will be revised for the Recontamination Analysis based on the harborwide RI/FS.
[5]Maximum post-Phase I construction concentration for Slip 3.This value will be revised for the Recontamination Analysis based on post-Removal Action construction sampling at Terminal 4.

Table 4-2: Weighted average COI concentration calculation.

	Sedimentation Rate (kg/yr)	COI Concentration (µg/kg)	Weighted COI load (kg/yr)
Stormwater sedimentation input rate	769	31,000	0.024
Upstream sedimentation input rate	2,188,212	54	0.118
Net sedimentation rate	2,188,981	***64.87***	0.142

4.2.2 SEDCAM modeling results

The SEDCAM model was conducted for a 10 year time period on a 1-year time step. Table 4-3 summarizes the predicted surface sediment concentration by year. Figure 4-1 shows the results graphically, compared to the Terminal 4 hill-topping benchmark value.

The results show that for benzo(a)pyrene, surface sediment concentration will decrease from the initial concentration used in this example. The initial benzo(a)pyrene concentration exceeded the goal concentration, however decreasing concentrations will allow for achievement of the goal concentration in less than four years. Based on the definition of recontamination presented in section 1.4, decreasing concentrations indicate no recontamination.

Table 4-3: SEDCAM model predicted sediment concentrations of benzo(a)pyrene (BaP) in the Slip 3 dredged area.

Years elapsed	Maximum concentration of BaP at any point in Slip 3, Cc(t) (µg/kg)
0	41,100
1	16,701
2	6,797
3	2,776
4	1,144
5	482
6	213
7	103
8	59
9	41
10	34

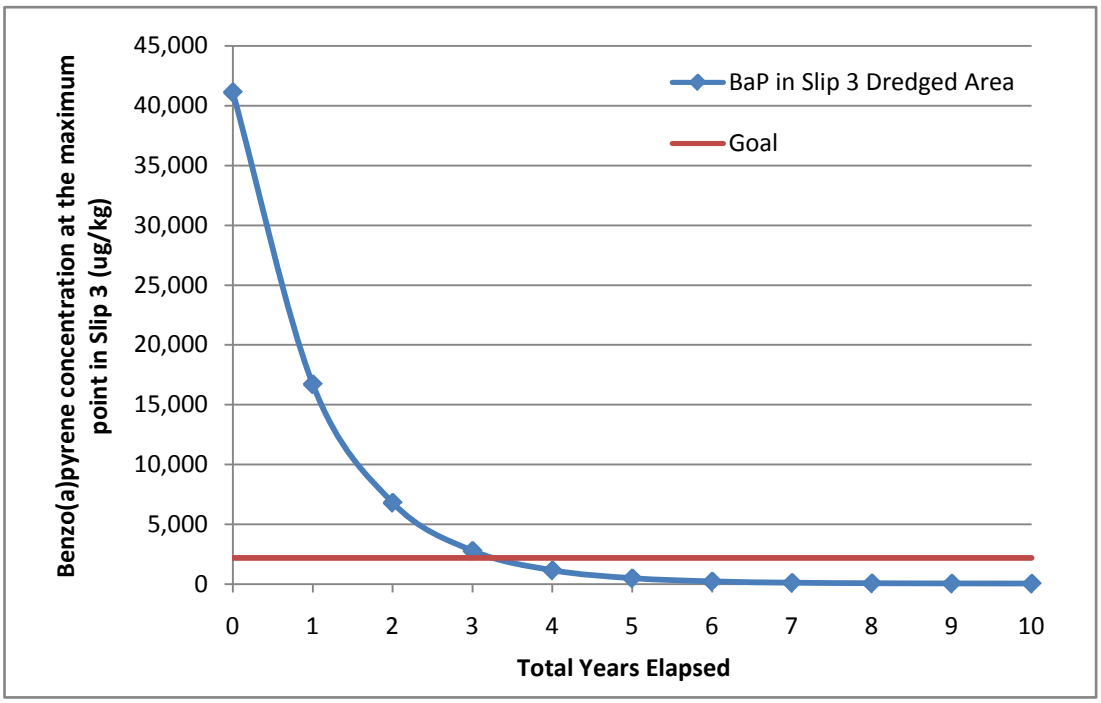

Figure 4-1: Results of example SEDCAM recontamination analysis for benzo(a)pyrene in the dredged area of Slip 3. The goal level indicates the Terminal 4 hill-topping benchmark value.

4.2.3 Uncertainties

The SEDCAM model requires that a number of assumptions be made. It was assumed that sediment in the top 0.5 feet throughout the Removal Action subarea would be completely mixed. This assumption is supported by observations indicating that propeller wash affects areas within the slip beyond the direct line of vessel traffic, and may be responsible for significant sediment resuspension (BBL, 2005a). Although the net deposition in Slip 3 is estimated at 4 cm/yr, sediment trap data from 2004 through 2005 suggests that propeller wash may disturb a thickness of 14.3 to 80.3 cm/yr. The weighted average input concentration also assumes that stormwater sediment input and upstream sediment input is completely mixed within the Removal Action subarea. The degradation rate for benzo(a)pyrene was estimated based on the mean degradation rate for Total PAHs from the literature (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). Loading of upstream sediment into Slip 3 was estimated based on the net sedimentation rate, calculated by comparison of available bathymetric surveys over time. The multibeam sonar technology used for obtaining bathymetric measurements has a vertical measurement error of +/- 0.25 ft. The estimated value of 4 cm/yr was chosen as a conservative estimate based on the available data. Other data uncertainties were reviewed in Section 3.

4.2.4 Sensitivity analysis

A simple sensitivity analysis was performed on the SEDCAM model using the example from the previous sections. The mixed layer thickness, COI degradation rate, input COI concentration and net sedimentation rate were tested. Table 4-4 summarizes the results of the sensitivity analysis.

The results show that the model is most sensitive to an increase in the COI degradation rate and an increase in the net sedimentation rate. However, for these variables, an increase would create an overall reduction in recontamination potential. The results suggest that the estimated values used in the example analysis provide a conservative estimation of recontamination potential.

Table 4-4: Results of sensitivity analysis performed on SEDCAM model using benzo(a)pyrene as an example COI and the Slip 3 dredged area as an example analysis subarea.

Sensitivity analysis	**Increase/Reduction in predicted concentration and number of orders of magnitude of change from original scenario after:**	
	1 year	**10 years**
Mixed layer thickness		
Reduce by half (7.62 cm)	Reduction, 1	Reduction, 1
Double (30.48 cm)	Increase, <1	Increase, <1
Degradation rate		
Decrease 10x (0.05 yr^{-1})	Increase, <1	Increase, 1
Increase 10x (5 yr^{-1})	Reduction, 2	Reduction, 1
Input Concentration		
Increase 10x (649 µg/kg)	Increase, <1	Increase, 1
Net sedimentation rate		
Decrease 10x (0.4 cm/yr)	Increase, <1	Increase, 1
Increase 10x (40 cm/yr)	Reduction, 2	Increase, <1

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APPENDIX A

SEDCAM Model Equation Conversion

APPENDIX A – SEDCAM Model Equation Conversion

For this analysis, the SEDCAM model was used to estimate future sediment COI mass. The mass of COI at some time after natural recovery begins can be estimated as follows (Jacobs et al., 1988):

$$M_C(t) = \frac{M}{(M + kS)} M_p \left[1 - e^{\frac{-(kS+M)t}{S}} \right] + M_o e^{\frac{-(kS+M)t}{S}}$$

Where:

$M_C(t)$ = mass of COI in surface sediment at time t (mg or µg)

M = sedimentation rate (g/cm^2-yr)

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

M_p = mass of COI in particles being deposited on the sediment (mg or µg)

t = time (yr)

M_o = initial mass of COI in surface sediment (mg or µg)

S = sediment accumulation in the mixed layer (g/cm^2)

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

$$S = ML \times \rho_b$$

Where:

ML = thickness of mixed layer (cm)

ρ_b = bulk density of sediment (g/cm^3)

Bulk density is related to particle density (ρ_p) as follows

$$\rho_p = \rho_b \times (1-\Phi)$$

where Φ = porosity of sediment (cm^3 voids/cm^3 material)]

This equation was converted to physical/chemical parameters that are directly measured or estimated in the recontamination study:

$C_C(t)$ = concentration of COI in surface sediment at time t (mg/Kg or µg/Kg)

C_p = concentration of COI in particles being deposited on the sediment (mg/Kg or µg/Kg)

C_o = initial concentration of COI in surface sediment (mg/Kg or µg/Kg)

Rs = sedimentation rate (cm/year)

The relationships used in the conversions were:

$$Mc\ (t) = Cc(t) \times A_{dep} \times ML \times \rho_b$$

$$M = Rs \times \rho_b$$

Where:

Cc(t) = concentration of a contaminant in sediment at time t (mg/kg or µg/kg)

A_{dep} = area of the sediment deposition in Removal Action Subarea (cm^2)

ML = thickness of mixed layer (cm)

Conversion of the individual terms is as follows:

$$M/(M + kS) = Rs\ \rho_b / (Rs\ \rho_b + k\ ML\ \rho_b)$$

$$= Rs/(Rs + k\ ML)$$

Defining a parameter that is the number of years of sedimentation that corresponds to the thickness of the mixed layer:

$$Ts = ML/Rs$$

Therefore

$$M/(M + kS) = 1/(1 + kTs)$$

Similarly

$$(kS + M)/S = (k\ ML\ \rho_b + Rs\ \rho_b)/ ML\ \rho_b$$

$$= (k\ ML + Rs)/ML$$

$$= (k\ Ts + 1)/ Ts$$

Inserting these terms into the SEDCAM equation yields.

$$C_C(t) = \frac{1}{(1+kTs)} C_p \left[1 - e^{\frac{-(1+kTs)t}{Ts}} \right] + C_o e^{\frac{-(1+kTs)t}{Ts}}$$

The mass of COI in particles being deposited on the sediment (Mp) is related to concentration (Cp) as follows:

Mp = Cp Ms

Where Cp = Average COI concentration on sediment particles

Ms = Mass of sediment particles deposited.

Further

Cp = Σ Ci Mi / Σ Mi

And Ms = Σ Mi

Where Ci = COI concentration on sediment particles from source i (mg/Kg)

Mi = mass of sediment particles from source i (Kg)

The sum of the sediment particle inputs must balance with the total sedimentation rate, such that

$Ms = Rs \ A_{dep} \ \rho_b$