6 Areas of Potential Concern, Remedial Action Levels, and Recovery Potential

This section defines the areas of potential concern (AOPCs) with potentially unacceptable risks based on the findings of the baseline ecological and human health risk assessments (ERA and HHRA; Windward 2007a, 2007b). This section also presents the remedial action levels (RALs) designed to address these risks and used in developing the remedial alternatives. Lastly, this section presents categories of recovery potential for sediments in the Lower Duwamish Waterway (LDW) based on physical conditions and empirical trends in contaminant concentrations.

The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Model Toxics Control Act (MTCA) require a feasibility study (FS) to identify volumes and areas of sediment where remedial action may be necessary and applied. Defining these areas requires

> *"…careful judgment and should include a consideration of not only acceptable exposure levels and exposure routes, but also site conditions and the nature and extent of contamination"* (EPA 1988).

Following U.S. Environmental Protection Agency (EPA) guidance (1988, 2005b), this section describes the relationship between location, extent, and concentrations of risk drivers relative to both hot spot areas and areas of lower level contamination. This information is used to delineate areas of sediment with potentially unacceptable risks. These areas are carried forward to Section 8, where technologies are assigned and remedial alternatives are developed. Further, the extent to which natural recovery is potentially viable is evaluated to guide the application of active and passive remedial actions in Section 8.

Hence, consistent with guidance, the steps in the FS process for mapping cleanup areas at the LDW include:

- Delineate AOPCs based on findings of unacceptable risks in the ERA and HHRA (Windward 2007a, 2007b). These areas will require consideration in this FS, and they are described in Section 6.1.
- Define a range of RALs that achieve or make progress toward achieving preliminary remediation goals (PRGs). RALs are contaminant-specific sediment concentrations that trigger the need for active remediation (e.g., dredging or capping). A RAL is equivalent to a "remediation level" under MTCA, which is defined as "…a concentration (or other method of identification) of a hazardous substance in soil, water, air, or sediment, above which a particular cleanup action component will be required as part of a cleanup action at a site" (Washington Administrative Code [WAC] 173-

340-200). A range of RALs, which trigger active remediation, is identified in Section 6.2. The remedial action objectives (RAOs; see Section 4) can be achieved through combinations of active remediation (triggered by the RALs), natural recovery, and institutional controls.

- Define areas within the AOPCs that have similar physical characteristics, engineering considerations, and recovery potential for which particular remedial technologies may be applied. These areas are referred to as recovery categories, which are discussed in Section 6.3.

Collectively, these evaluations are used in the assembly of the remedial alternatives in Section 8. Combinations of active and passive management of the AOPCs are evaluated relative to the RAOs. The AOPC boundaries and the recovery potential within those boundaries will likely need to be refined during remedial design and even, perhaps, during implementation of the remedy.

6.1 Delineating the Areas of Potential Concern (AOPCs)

The AOPCs represent the areas of sediment that have potentially unacceptable risks and will likely require application of active or passive remedial technologies. Defining the AOPC footprints requires: 1) an understanding of the types and levels of estimated risks in the LDW (see Section 3); 2) the RAOs to address those risks and associated PRGs (see Section 4); and 3) the conceptual site model, site conditions, and the data collection and analysis efforts over the past 20 years (see Section 2). The AOPC footprints defined for this FS are discussed in this section, along with a summary of the considerations used in deriving and evaluating these AOPCs. The contaminant concentrations used to develop the AOPC footprints include detected FS baseline surface sediment concentrations of risk drivers above the thresholds described below. The data used to define the AOPCs also include toxicity data and subsurface sediment data, when available (see Section 2).

The AOPCs do not include the five early action areas (EAAs; 29 acres), which are being addressed separately. However, the enhanced natural recovery (ENR) portion of the Duwamish/Diagonal EAA is included in AOPC 1. Evaluations used to define the AOPCs assume cleanup of the five EAAs will be completed prior to cleanup within the AOPCs. The two AOPC footprints developed for this FS are shown in Figure 6-1 and are described below.

Multiple thresholds were developed for each risk driver, and sediment areas were included in the AOPCs if any of the thresholds were exceeded. AOPCs are normally delineated by concentrations of contaminants of concern (COCs) or risk drivers above PRGs. For the LDW, the PRGs for total polychlorinated biphenyls (PCBs) and dioxins/furans (RAO 1) and for arsenic (RAO 2) are set at natural background for final cleanups, as required by MTCA. Model predictions indicate that natural background for these three risk drivers is unlikely to be achieved because of the concentrations of these risk drivers in incoming Green/Duwamish River suspended solids and because of practical limitations on control of lateral sources from the generally urban LDW drainage basin. For these reasons, it was not possible to use the RAO 1 PRGs for total PCBs or dioxins/furans or the RAO 2 PRG for arsenic to develop the AOPCs. Thus, a modified objective of getting those three risk-driver concentrations as close as possible to the natural background values (i.e., as low as practicable) was used to delineate the AOPCs. For the purposes of the FS, this is assumed to be the long-term model-predicted concentrations. These concentrations are believed to be the lowest technically achievable concentrations based on the available data and analyses conducted to date. These long-term model-predicted concentrations are uncertain, because future risk-driver concentrations in upstream- and lateral-source sediments are uncertain and may change in the future. The term "cleanup objective" in this FS is used to mean the PRG or as close as practicable to the PRG where the PRG is not predicted to be achievable. This FS uses long-term model-predicted concentrations as estimates of “as close as practicable to PRGs”.[1] AOPC 1 was designed to achieve this objective using a combination of active cleanup and natural recovery, and AOPC 2 was designed to achieve this objective using only active cleanup.

6.1.1 AOPC 1 Footprint

As noted above, natural background is unlikely to be achieved, and both the sediment transport model (STM) and bed composition model (BCM) predict that, in the long term, the LDW will reach concentrations similar to those incoming from the upstream Green/Duwamish River system. For these reasons, the FS has adopted an incremental approach to delineate AOPCs and to develop remedial alternatives with varying degrees of active remediation and natural recovery.

The AOPC 1 footprint is based on the PRGs that are not set at natural background (i.e., the PRGs associated with RAO 2 for risk drivers other than arsenic and with RAOs 3 and 4). Natural recovery is assumed to be required following active remediation of the AOPC 1 footprint to reduce site-wide average total PCB, dioxin/furan, and arsenic concentrations to the cleanup objective as defined above.

Interpolated surface sediment concentration maps for total PCBs, arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), dioxins/furans, and contaminants that exceed the Sediment Management Standards (SMS) were the primary sources of information used to delineate the AOPC 1 footprint. In addition, shallow subsurface sediment contaminant concentrations were considered in areas prone to scour and disturbance and in intertidal areas where the point of compliance for human health direct contact risk drivers (PCBs, arsenic, cPAHs, and dioxins/furans) is the upper 45 cm of sediment. As described in Section 2, inverse distance weighting (IDW) was used for interpolating total PCBs, arsenic, and cPAHs, and Thiessen polygons were

1 For further information on cleanup objectives, see Section 9.1.2.3.

used to interpolate dioxins/furans and SMS exceedances in surface sediment. Each data layer was mapped independently. AOPC 1 was delineated where any of the layers exceeded the threshold concentrations described below.

RAO 3. AOPC 1 was first delineated for benthic community risk drivers with detected concentrations in surface sediments exceeding the sediment quality standards (SQS) (the RAO 3 PRGs). Each Thiessen polygon was classified as an SQS exceedance if one or more detected SMS contaminants exceeded this criterion. In addition, cleanup screening level (CSL) exceedances are also shown to indicate more highly contaminated areas. Toxicity test results, if available, were used in the final classification. If the Thiessen polygon exceeded the SQS, it was included in AOPC 1. Because total PCBs were spatially interpolated as dry weight concentrations (see Section 2 and Appendix A), the area with total PCB concentrations greater than 240 micrograms per kilogram dry weight (µg/kg dw; the dry weight equivalent of the 12 milligrams per kilogram organic carbon [mg/kg oc] SQS value, assuming 2% total organic carbon [TOC]) derived with IDW rather than Thiessen polygons was also used to delineate AOPC 1. Best professional judgment was used for mapping in cases where the total PCB IDW-based layer resulted in small, isolated areas exceeding 240 µg/kg dw. These small areas were not included in AOPC 1 if, using the sample-specific TOC data, they did not exceed the SQS on an organic-carbon normalized basis.

RAO 2. The AOPC 1 footprint was then evaluated for compliance with RAO 2. Active remediation of the AOPC 1 footprint achieves the total PCB PRGs (1,300 µg/kg dw for netfishing site-wide; 1,700 µg/kg dw for beach play areas; and 500 µg/kg dw for clamming areas). The footprint was expanded to achieve human health direct contact PRGs on a SWAC basis for cPAHs and dioxins/furans (380 µg toxic equivalent [TEQ]/kg dw and 37 nanograms [ng] TEQ/kg dw for netfishing [site-wide]; 90 µg TEQ/kg dw and 28 ng TEQ/kg dw for beach play; and 150 µg TEQ/kg dw and 13 ng TEQ/kg dw for clamming, respectively). The RAO 2 PRGs for arsenic are natural background over all three exposure areas (netfishing, clamming, and beach play), and therefore these PRGs are not likely to be achieved based on the model predictions. The AOPC 1 footprint was expanded to achieve site-wide and area-wide arsenic SWACs within the limits of what the long-term model predicts is achievable over time when natural recovery across the entire LDW is included. Also, to address beach play PRGs (RAO 2), individual beaches were included in AOPC 1 whenever the total direct contact excess cancer risks based on the beach play RME scenario (for all four human health risk drivers) exceeded 1×10^{-5}.

In intertidal areas, the point of compliance for human health risk drivers for clamming and beach play is assumed to be the upper 45 cm of sediment, because of potential exposures to people through direct contact with sediments during clamming or beach play activities. Average sediment concentrations from this interval[2] were considered and compared to the PRGs for direct contact tribal clamming and beach play RME scenarios. However this did not affect the designation of the AOPC footprint because the existing footprint covered these areas.

RAO 4. Active remediation of the AOPC 1 footprint achieves a site-wide spatially-weighted average concentration (SWAC) for total PCBs less than the RAO 4 PRG range of 128 to 159 µg/kg dw, and therefore no adjustment to AOPC 1 was required to meet RAO 4.

RAO 1. The AOPC 1 footprint was evaluated for compliance with RAO 1 PRGs, which are natural background concentrations on a site-wide basis for total PCBs and dioxins/furans. The footprint was not expanded for RAO 1. The FS assumes that remediation of AOPC 1 makes progress toward RAO 1 goals by achieving the long-term model-predicted sediment concentrations for total PCBs and dioxins/furans over time. Neither arsenic nor cPAHs have seafood consumption PRGs[3] for RAO 1, but remediation of AOPC 1 also reduces sediment concentrations for these risk drivers. Refer to Section 9 for predicted outcomes of the remedial alternatives.

Subsurface Contamination in Potential Scour Areas. Lastly, subsurface contamination was considered in the delineation of AOPC 1. Areas with SQS exceedances in the top 2 ft of sediment that are potentially subject to 100-year high-flow scour deeper than 10 centimeters (cm; as predicted by the STM; see Figure 2-9) or that are subject to vessel scour (see Figure 2-10) were added to the AOPC 1 footprint. In an area with an SQS exceedance in the top 2 ft of a core, the spatial extent was defined by the extent of the predicted high-flow scour area or the potential vessel scour area around that core. The spatial extent of the SQS exceedance within potential scour areas was conservatively assumed to be the entire extent of the potential scour area if there was only one core within that area (in part because there are relatively few subsurface sediment cores compared with surface sediment samples). If more than one core was located in a scour area, the spatial extent of the RAL exceedance was governed by the nearest core.

Summary. Table 6-1 lists the lowest risk-driver concentrations identified in surface sediment that were used to delineate AOPC 1 and the estimated post-construction

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2 Sediment data used to evaluate this interval included the following: surface sediment grabs in the top 10-cm, which were assumed to represent the top 45-cm; 0 to 45-cm depth samples in beaches; and where available the top 6-in or 1-ft core interval from subsurface sediment cores in intertidal areas.

3 Based on data collected during the RI, relationships between clam tissue and surface sediment concentrations of arsenic and cPAHs were too uncertain to develop quantitative risk-based threshold concentrations in sediment; therefore, no seafood consumption (RAO 1) PRGs were developed for these risk drivers.

SWACs if the entire AOPC 1 footprint was actively remediated.[4] It also compares those SWACs to the PRGs.

In summary, outside of the EAAs, the considerations used to delineate AOPC 1 were:

- Surface sediments with:
  - Areas delineated by Thiessen polygons that exceed the SQS criteria detected in surface sediment. Sediment toxicity data override chemical SQS or CSL exceedances and chemical passes, as described in Section 2.
  - Total PCB concentrations greater than 240 µg/kg dw
  - Arsenic concentrations greater than 57 mg/kg dw
  - cPAH concentrations greater than 1,000 µg TEQ/kg dw
  - Dioxin/furan concentrations greater than 25 ng TEQ/kg dw
  - Arsenic concentrations greater than 28 mg/kg dw in intertidal areas
  - cPAH concentrations greater than 900 µg TEQ/kg dw in intertidal areas.
- Areas with SQS exceedances in the top 2 ft of subsurface sediment that are predicted to be subject to 100-year high-flow scour deeper than 10 cm or are potentially subject to vessel scour based on empirical evidence.

AOPC 1 represents the maximum extent of any exceedance delineated by the layers described above. Therefore, the AOPC 1 footprint is larger than the area defined by the concentration for any one risk driver. Overall, the AOPC 1 footprint (Figure 6-1) represents about 180 acres or about 41% of the entire LDW site (441 acres).

The AOPC 1 footprint encompasses the initial area designated in the FS for remedial alternative development. Cleanup of the EAAs and all of AOPC 1, through a combination of active cleanup, verification monitoring, and natural recovery, is predicted to achieve cleanup objectives for RAOs 1, 2, 3, and 4. PRGs based on natural background for RAO 1 (total PCBs and dioxins/furans) and for RAO 2 (arsenic) are not predicted to be technically practicable, and thus, the cleanup objectives are to achieve long-term model-predicted concentrations that are as close to natural background as technically practicable.

6.1.2 AOPC 2 Footprint

In addition to AOPC 1 shown on Figure 6-1, EPA and the Washington State Department of Ecology (Ecology) required that an incrementally larger remedial footprint (outside of AOPC 1) be evaluated, called AOPC 2. The goal for final cleanup is to achieve

[4] The resulting SWACs were calculated by replacing the risk-driver concentrations in the AOPC 1 footprint with a post-remedy bed sediment replacement value, which is provided in Table 6-1. The SWACs do not assume any natural recovery.

concentrations as close to the natural background concentrations as technically practicable for total PCBs and dioxins/furans (RAO 1) and arsenic (RAO 2). Natural background for these three risk drivers is unlikely to be achieved because of incoming contaminant concentrations from the Green/Duwamish River and practical limitations on control of lateral sources. Instead, AOPC 2, when actively remediated along with AOPC 1, achieves the lowest long-term model-predicted SWACs for total PCBs, dioxins/furans, and arsenic[5] immediately after construction. AOPC 2 also addresses all areas outside AOPC 1 with subsurface contamination above the SQS. The AOPC 2 footprint is 122 acres. The AOPC 1 and AOPC 2 footprints combined encompass 302 acres (or approximately 68% of the LDW study area).

The AOPC 2 footprint was explored through a step-wise evaluation in which active remediation was first assumed for AOPC 1 plus every point with a total PCB concentration above 100 µg/kg dw. Second, site-wide SWACs for dioxins/furans and arsenic were calculated by changing the surface sediment concentrations in this larger footprint to the post-remedy bed sediment replacement values[6] and assuming no natural recovery. Based on these SWACs, the AOPC 2 footprint was then expanded to capture areas with:

- Arsenic concentrations greater than 15 mg/kg dw to achieve the long-term model-predicted site-wide SWAC.
- Dioxin/furan concentrations greater than 15 ng TEQ/kg dw to achieve the long-term model-predicted site-wide SWAC.

Finally, the footprint was again expanded to include remaining sediment cores with detected SQS exceedances at any depth (regardless of scour potential).[7]

The results of this analysis indicated that active remediation of AOPCs 1 and 2, using the post-remedy bed sediment replacement values for total PCBs, arsenic, and dioxins/furans, yields site-wide SWACs within the range of the long-term model-predicted concentrations (Table 6-1) immediately after construction. This analysis indicates:

1) Active remediation of the entire 302-acre AOPC 1 and AOPC 2 footprints would result in the lowest long-term model-predicted concentrations, and

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[5] A cPAH threshold was not needed for AOPC 2 delineation because all areas where remediation is needed to meet cPAH PRGs are included in AOPC 1.

[6] Post-remedy bed sediment replacement values in AOPCs 1 and 2 (respectively) for each risk driver are: total PCBs = 60 and 20 µg/kg dw; arsenic = 10 and 9 mg/kg dw; and dioxins/furans = 4 ng TEQ/kg dw (mid-range and low values, respectively, from Table 5-1c).

[7] The exception is three cores collected from the Upper Turning Basin in 2009. Sediment in this area had not exceeded the SQS in previous samples, and data were not received in time to include in the AOPC 2 delineation. The sediment represented by these cores was dredged in 2010.

the model predicts that further changes over time after the cleanup through natural recovery would be minimal.

2) Any further active remediation would not yield additional sustainable SWAC reduction or risk reduction, because sediments from upstream and lateral sources would continue to deposit onto remediated areas.

It is important to recognize that, as with other input parameters, values used as post-remedy bed sediment replacement values for this analysis are uncertain. A range of replacement values was developed for each human health risk driver in this FS. The sensitivity of post-remedy sediment concentration predictions to the range of replacement values is described in Section 9. Based on this analysis, active remediation of the AOPC 1 and 2 footprints is predicted to reach long-term model-predicted concentrations. Cleanup of the EAAs and active remediation of the AOPC 1 and 2 footprints is predicted to achieve the maximum technically practicable degree of SWAC risk reduction. The areas beyond the AOPCs are not considered for active cleanup in this FS (but may be subject to sampling and verification monitoring during remedial design).

In summary, active remediation of AOPC 1 achieves the PRGs for RAOs 2 (for all human health risk drivers except arsenic), 3, and 4. The combined footprint of AOPCs 1 and 2 results in the lowest model-predicted SWACs for RAO 1 (total PCBs and dioxins/furans) and RAO 2 (arsenic) immediately after construction without consideration of natural recovery. Therefore, the AOPC 1 and 2 footprints are considered appropriate to identify alternatives that achieve the PRGs or make substantial risk reduction toward achieving the PRGs. The footprints have been defined with enough rigor to facilitate a detailed evaluation of remedial alternatives (in Section 8) for the purposes of this FS.

6.2 Remedial Action Levels

RALs are contaminant-specific sediment concentrations that trigger the need for active remediation (i.e., dredging, capping, or ENR). RALs define the active remediation footprint within the AOPCs for each remedial alternative (Section 8).

RALs are very different from PRGs. PRGs are the long-term cleanup levels and goals for the project, whereas RALs are point-based values that define where active remediation is to occur for a given alternative. PRGs are the same for all alternatives, whereas RALs vary among alternatives. RALs are also used as the compliance concentration to verify that active remediation for an alternative is complete, or successful, before equipment is demobilized from an area.

The development and use of RALs for this FS is based on the premise that once active remediation is complete (in areas where the RALs are exceeded), SWACs for human health risk drivers immediately following construction will be considerably lower than those for baseline conditions. The cleanup objectives are achieved either immediately after construction or over time through natural recovery. Higher RALs are associated with higher post-construction SWACs and larger areas that rely on natural recovery to achieve cleanup objectives. The evaluations of risk reduction over time and the time to achieve cleanup objectives are presented in Section 9.

For this FS, ranges of RALs are developed for the risk drivers (total PCBs, arsenic, cPAHs, dioxins/furans, and SMS contaminants [i.e., detected risk drivers that exceeded the SQS in surface sediments]) for which PRGs were presented in Section 4 (see Figures 6-2a through 6-2d for the human health risk drivers). RALs are developed with the understanding that remediation of these risk drivers will also address the remaining COCs (see Table 3-16) that do not have PRGs.

6.2.1 Methods Used for Development of RALs

This section briefly summarizes the methods used to develop a range of RALs that serve to define a range of active remedial footprints and a corresponding range of expected outcomes. The range of RALs allows a broad array of remedial alternatives to be defined in Section 8, each with differing:

- Areas/volumes of sediment to be actively remediated
- Levels of risk reduction immediately after construction
- Time frames for achieving cleanup objectives.

The residual risks remaining immediately after construction of each remedial alternative and additional risk reduction predicted over time through natural recovery are discussed in Sections 9 and 10 of this FS.

RAL development considers only individual COCs and does not consider the extent to which COCs are commingled. Because many of the LDW COCs have some commingling and co-occurrence, it is reasonable to expect that by remediating an area to address one risk driver exceeding a RAL, some reduction in other COCs will also occur. Thus, the remediation of sediments exceeding RALs may result in risk reduction not accounted for when only individual COCs are evaluated. Section 9.11 describes how the remedial alternatives address COCs other than the risk drivers. In addition, natural recovery is predicted to further reduce sediment concentrations over time below the reduction achieved by active remediation alone.

The approaches used to select RALs and to develop an array of remedial alternatives require best professional judgment. The RALs for this FS were selected based on the following considerations:

- **Achievement of PRGs.** Certain sediment PRGs can directly translate into RALs, such as SMS criteria applied on a point basis, which directly relate to protection of benthic receptors (RAO 3). RALs for RAO 3 were defined using two time points: at the end of construction and 10 years after construction, in accordance with SMS guidelines. Although not defined in the RAL development process, some RALs may require more than 10 years after construction to achieve PRGs. Area-based PRGs (SWACs) for certain direct contact scenarios (RAO 2) are the basis for point-based RALs for this FS.

- **Range of RALs**. By definition, the RALs are point concentrations that exceed PRGs and require active remediation. However, a direct comparison of point concentrations (at specific sample locations) to PRGs is not appropriate for RAO 1 (seafood consumption), RAO 2 (direct contact), and RAO 4 (wildlife consumption of prey) because these RAOs have SWAC-based PRGs. Therefore, each SWAC-based PRG needs to be "converted" to a not-to-exceed point concentration (RAL). To accomplish this "conversion" from SWACs to point concentrations, human health risk drivers were evaluated in an iterative fashion (called "hilltopping") by ranking their concentrations from highest to lowest (using interpolated grid cells). The highest values were sequentially replaced with a post-remedy bed sediment replacement value until the appropriate site- or area-wide PRG was achieved. The highest concentration remaining then becomes the RAL for the SWAC-based PRG.

  A range of RALs was selected for each human health risk driver by comparing the highest remaining concentration to the resulting SWAC. The RALs were selected to represent a range of acres remediated and the resulting SWACs. Figures 6-3a through 6-3d present the hilltopping curves for the four risk drivers. The RALs (point values) are identified on the curves relative to the estimated SWACs they achieve based only on active remediation and no natural recovery.

- **SWAC Reduction for PRGs Set at Natural Background.** Certain PRGs, such as those for total PCBs and dioxins/furans for RAO 1 and for arsenic for RAO 2, cannot be used directly as RALs because they are set to natural background (Table 4-7). It is not technically possible to implement a RAL set at natural background because although sediments continually entering the LDW from upstream have COC concentrations considerably lower than those in LDW sediments, these concentrations are still above natural background concentrations. For PRGs set at natural background, a range of RALs was selected to achieve the long-term model-predicted concentrations over time and immediately after construction.

  As incrementally lower RALs were considered and more acres were identified for active remediation, a point of minimal change in SWAC was predicted. The estimated curves, shown in Figures 6-3a through 6-3d,[8]

8 Section 9 contains SWAC-over-time curves based on future site-wide SWACs predicted using the BCM.

approach a value (the asymptote) driven by continual upstream inputs from the Green/Duwamish River as well as urban inputs from lateral drainage to the LDW. The estimated rate of change (SWAC reduction per acre) is predicted to be so small that, immediately after construction, the site would be considered to have reached the lowest model-predicted post-construction SWAC. Through continued natural recovery over time, the site would reach the long-term model-predicted concentrations (shown as the asymptote on the curve). It is worth noting that predicted changes in the post-remedy SWACs (shown in Figures 6-3a through 6-3d) are largely driven by the post-remedy bed sediment replacement values, while the long-term model-predicted concentrations are largely dependent on concentrations associated with upstream sources and to a lesser extent, lateral sources (see Tables 5-1a through 5-1c).

6.2.2 Range of Selected RALs

The array of RALs and how they relate to each RAO are summarized in the following subsections and in Table 6-2.

6.2.2.1 RAO 1 (Human Health Seafood Consumption) RALs

For this FS, progress toward achievement of RAO 1 (reduction of human health risks from seafood consumption) is assessed based on estimated reductions in the site-wide SWAC of total PCBs, arsenic, cPAHs, and dioxins/furans. The RALs for each risk driver are described below.

The total PCB PRG for RAO 1 is not expected to be achieved because it is set at natural background. Therefore, the goal is to set an array of RALs that result in incrementally lower site-wide SWACs after construction and shorter model-predicted natural recovery periods to reach cleanup objectives. (However, at very low RALs, time to achieve cleanup objectives increases due to longer construction times.) A total PCB RAL of 2,200 µg/kg dw was selected to address hot spots. The remaining RALs of 1,300, 700, 240, and 100 µg/kg dw comprise a range resulting in incrementally larger areas of active remediation and corresponding reductions in the site-wide SWAC immediately after construction (Table 6-2). The SWAC reduction is in turn predicted to result in a commensurate incremental reduction in human health risks. A RAL of 1,300 µg/kg dw is based on the CSL.[9] A RAL of 700 µg/kg dw is based on providing a well-spaced range of RALs for evaluation. A RAL of 240 µg/kg dw is based on the SQS.[10] The lowest total PCB RAL (100 µg/kg dw) is predicted to yield minimal change in the average

[9] Assuming a TOC content of 2% (the site-wide average), the total PCB dry weight equivalent of the CSL (65 mg/kg oc) is 1,300 µg/kg dw. If selected, actual implementation of this RAL would be based on the organic carbon-normalized CSL.

[10] Assuming a TOC content of 2%, the total PCB dry weight equivalent of the SQS (12 mg/kg oc) is 240 µg/kg dw. If selected, actual implementation of this RAL would be based on the organic carbon-normalized SQS.

concentration immediately after construction, and to achieve the long-term model-predicted concentration range. As discussed in Section 6.1.2, further active remediation is not predicted to appreciably lower the site-wide SWAC for total PCBs.

For arsenic and cPAHs, 95% or more of the risk associated with seafood consumption is attributable to the consumption of clams. A relationship between the concentrations of arsenic and cPAHs in clam tissue and sediment would be required to estimate sediment risk-based threshold concentrations (RBTCs) for RAO 1. However, RI data showed a poor relationship between clam arsenic and cPAH concentrations and associated sediment concentrations (i.e., clam tissue-to-sediment relationships for both arsenic and cPAHs were too uncertain to develop quantitative sediment RBTCs). Because of this, neither arsenic nor cPAHs have seafood consumption PRGs. RALs were selected for each to provide for overall reductions in sediment concentrations of these two risk drivers. Co-occurrence with the other risk drivers will also reduce site-wide sediment concentrations. For arsenic, a RAL of 93 mg/kg dw (the CSL) is used to address hot spots, and two other RALs, 57 (the SQS) and 15 mg/kg dw, are used to provide a range. For cPAHs, a RAL of 5,500 µg TEQ/kg dw is used to address hot spots, and two other RALs, 3,800 and 1,000 µg TEQ/kg dw are used to provide a range.

The dioxin/furan PRG for RAO 1 is not expected to be achieved because it is set at natural background. Therefore, the goal is to set a range of RALs that result in incrementally lower site-wide SWACs following active remediation. A RAL of 50 ng TEQ/kg dw was selected to address hot spots. Other dioxin/furan RALs of 35, 25, and 15 ng TEQ/kg dw comprise the range resulting in incrementally larger areas of active remediation and corresponding reductions in the site-wide SWAC immediately after construction (Table 6-2). The lowest dioxin/furan RAL (15 ng TEQ/kg dw) is predicted to result in minimal change in the site-wide SWAC and to achieve the long-term model-predicted concentration immediately after construction is complete. Further active remediation is not predicted to appreciably lower the site-wide SWAC for dioxins/furans.

6.2.2.2 RAO 2 (Human Health Direct Contact) RALs

Achievement of RAO 2 is assessed on three spatial scales, based on the three direct contact exposure scenarios: site-wide for netfishing, area-wide within potential clamming areas, and area-wide within beach play areas. In addition, future-use scenarios for beach play are evaluated in all intertidal areas (see Figure 3-1).

Netfishing

The netfishing exposure area is site-wide (441 acres) and the point of compliance is surface sediment (0 to 10 cm). For total PCBs, cPAHs, and dioxins/furans, the netfishing site-wide PRGs are predicted to be achieved immediately following remediation of the EAAs. All arsenic direct contact PRGs are set to natural background; therefore, they are unlikely to be achieved. The goal is to achieve the long-term model-predicted concentration. An arsenic RAL of 93 mg/kg dw is used to address hot spots.

The remaining RALs (57 and 15 mg/kg dw) provide a range, with the lowest RAL set to achieve long-term model-predicted concentrations at the end of construction. Further active remediation is not predicted to appreciably lower the site-wide SWAC for arsenic.

Beach Play Areas

As described in Section 3, the LDW has eight beach play areas; note that these are not all necessarily areas where beach play currently occurs but they were identified as such because public access is possible. The beach play scenario is evaluated on an average basis at individual beaches and across all beaches combined (exposure areas). The point of compliance for the beach play scenario is 0 to 45 cm. Intertidal RALs were developed for arsenic, cPAHs, and dioxins/furans. For total PCBs, an intertidal RAL was not needed in these areas because the tribal clamming and beach play direct contact PRGs for total PCBs are predicted to be achieved following remediation of the EAAs and hot-spot areas.[11]

The PRGs for the beach play areas are the 10^{-6} RBTCs for the individual risk drivers (with the exception of arsenic where the PRG is set at natural background). Total PCB beach play PRGs are predicted to be achieved at all of the individual beach play areas using the highest RAL of 2,200 µg/kg dw. The PRG of natural background for arsenic is unlikely to be achieved. For cPAHs, the PRG falls within the range of upstream inputs and post-remedy bed sediment replacement values, and therefore may not be achieved at all beach play areas, although some of the individual beaches are predicted to achieve the PRG. A dioxin/furan intertidal RAL was set to the 10^{-6} RBTC for beach play.

The beach play RALs for both arsenic and cPAHs are set to the 10^{-5} RBTCs as points to ensure that, at a minimum, 1) the total 10^{-5} risk goals required by MTCA are achieved, and 2) progress is made toward achieving 10^{-6} RBTCs (or natural background for arsenic) on an average basis over the beaches. For arsenic, cPAHs, and dioxins/furans, RALs of 28 mg/kg dw (10^{-5} RBTC), 900 µg TEQ/kg dw (10^{-5} RBTC), and 28 ng TEQ/kg dw (10^{-6} RBTC), respectively, are applied in all intertidal areas, and hence, all potential current and future beach play areas.

Clamming Areas

The tribal clamming scenario is evaluated on an area-wide basis across the potential clamming exposure areas. The same point of compliance considerations that applied to beach play, as described above, also applied to clamming areas. The direct contact tribal clamming PRG for total PCBs is predicted to be achieved after the EAAs have been actively remediated (Figures 6-2a through 6-2d). An arsenic RAL of 93 mg/kg dw, applied on a point basis, is expected to achieve the tribal clamming 10^{-5} RBTC; the 10^{-6}

11 In intertidal areas, compliance for total PCBs was evaluated based on surface sediment and limited to the 10 cm depth (the biologically active zone). The site-wide RAL for total PCBs (in the top 10 cm) achieved the cleanup objectives for direct contact clamming and beach play areas.

RBTC is below natural background. The lower arsenic RALs (57, 28, 15 mg/kg dw) are designed to achieve incrementally lower SWACs and the long-term model-predicted concentrations in potential clamming areas. The RALs discussed above for cPAHs and dioxins/furans in beach play areas are also predicted to result in SWACs that achieve the PRGs in clamming areas, so no RALs based on tribal clamming were set for these two risk drivers.

6.2.2.3 RAO 3 (Protection of Benthic Invertebrates) RALs

The RALs for any risk-driver SMS contaminant for RAO 3 are:

- **CSL10 –** achieves the CSL within 10 years after construction is complete. The locations exceeding the CSL within 10 years were predicted using the recommended BCM input parameters. The BCM methods are described in Section 5, and predicted outcomes are shown in Section 9 and Appendix F.
- **CSL –** achieves the CSL by the time construction is complete.
- **SQS10 –** achieves the SQS within 10 years after construction is complete. The locations exceeding the SQS within 10 years were predicted using the recommended BCM input parameters. The BCM methods are described in Section 5, and predicted outcomes are shown in Section 9 and Appendix F.
- **SQS –** achieves the SQS by the time construction is complete.

SMS criteria for total PCBs and the other non-polar organic compounds are on an oc-normalized basis. Total PCB RALs for RAO 3 are 12 and 65 mg/kg oc for the SQS and CSL, respectively, but may be expressed as dry weight values in the FS for mapping purposes and ease of discussion (240 and 1,300 µg/kg dw for SQS and CSL, respectively, assuming 2% TOC). The SMS criteria for metals are expressed on a dry weight basis. For arsenic they are 57 and 93 mg/kg dw, for the SQS and CSL, respectively.

Implementation of the time-dependent RALs (SQS10 and CSL10) requires prediction of location-specific future concentrations using the BCM (methods are described in Section 5, and predicted outcomes are presented in Section 9 and Appendix F).

6.2.2.4 RAO 4 (Ecological Receptor Seafood Consumption) RALs

For RAO 4, total PCBs is the only risk driver. Achievement of the PRG (hazard quotient less than 1.0) is assessed on a site-wide basis. Separate RALs were not defined for RAO 4 because the total PCB range of RALs described above for RAO 1 (2,200, 1,300, 700, 240, and 100 µg/kg dw) is predicted to achieve RAO 4 immediately after construction or through a combination of active remediation and natural recovery.

6.3 Evaluating Recovery Potential of Sediments within the AOPCs

This section presents an evaluation of recovery potential intended to guide the final assembly of remedial alternatives (Section 8) within the AOPCs (outside of EAAs) and to prioritize areas that will likely require active remediation. This evaluation considers several factors, including proximity to potential contaminant sources, net sedimentation rates, scour potential, and empirical trends, that affect the ability of areas to recover through natural processes.[12]

The entire LDW was grouped into three categories with regard to recovery potential (Figures 6-4a and 6-4b). A recovery category represents areas of the LDW that share similar characteristics that could affect how well different remedial technologies would achieve the RAOs and how feasible they would be to implement. The recovery categories are:

- **Category 1** includes areas where recovery is presumed to be limited. It includes areas with observed and predicted scour, net scour, and empirical data demonstrating increasing concentrations over time.
- **Category 2** includes areas where recovery is less certain. It includes areas with net sedimentation and mixed empirical contaminant trends.
- **Category 3** includes areas where recovery is predicted. It includes areas with minimal to no scour potential, net sedimentation, and empirical trends of decreasing concentrations.

6.3.1 Mapping the Lines of Evidence for Evaluating Recovery Potential

To delineate the areas in each of these recovery categories, the following physical and chemical lines of evidence were considered (Table 6-3):

- Scour and deposition patterns:
  - Annual net sedimentation rates estimated by the STM and averaged over the 30-year STM period
  - 100-year high-flow event scour areas predicted in the STM (maximum scour depth observed over the 30-year model period)
  - Areas with empirical evidence of vessel scour, as interpreted from 2003 bathymetric survey sun-illumination maps.
- Land and water use functions:

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[12] When reviewing empirical trends, proximity to contaminant sources, depth of contamination, and type of contaminant exceedance were considered. When source control is complete, recovery may be viable but not yet observed empirically.

  - Berthing areas, former dredging events, and potential for disturbance by future dredging
  - Proximity to the toe of the slope along the navigation channel
  - Shoreline land use, public access, and outfall locations
  - Overwater structures
  - Vessel traffic patterns, based on knowledge of navigational operations, operator interviews, and bridge opening logs
  - Habitat restoration areas, recreational shoreline access areas, and historical cleanup areas.
- Empirical evidence of recovery through total PCB and other risk-driver concentration trends (excluding dioxins/furans) in:
  - Surface sediment from resampled stations
  - Subsurface sediment from the top two intervals (the shallowest 2 ft) of cores.

Table 6-3 lists the key lines of evidence and the specific criteria used to delineate each recovery category, which are discussed below. The GIS maps showing the extent of these features are presented in Section 2 and Appendix F. Other bulleted items (not listed in Table 6-3) were secondary considerations used as lines of evidence to help interpret and evaluate empirical trends and to delineate the layers in Table 6-3. For example, overwater structures and former dredging events were used to define active berthing areas. The following subsections describe how these features were overlaid to map recovery category areas. Recovery categories are defined only for the purposes of developing site-wide remedial alternatives and assigning remedial technologies (Section 8). Location-specific design considerations and new empirical data for these areas will be evaluated during remedial design.

Figure 6-4a presents the three recovery categories. Figure 6-4b includes the empirical contaminant trends with the recovery categories. A detailed analysis of this process by subarea is provided in Appendix D.

6.3.1.1 Net Sedimentation

Natural recovery processes in the LDW include the natural deposition of cleaner sediment from upstream that is expected to reduce surface sediment COC concentrations.[13] Recovery is not considered viable if the STM estimates a potential for net scour (no sedimentation under average flow conditions); such areas are considered Category 1. Any positive rate of sedimentation indicates that an area may potentially be

[13] Important mechanisms that reduce surface sediment contaminant concentrations are deposition of sediment sourced from upstream, followed by mixing and burial (see Section 2, Figure 2-11). These processes are described in greater detail in Section 5.

amenable to natural recovery, and thus this criterion places an area in Category 2 or 3 unless other lines of evidence suggest recovery is not occurring.

Additionally, changes in bathymetric data between 2003 and 2008 in the navigation channel were reviewed (Figure 6-5) as a qualitative check on STM-estimated net sedimentation rates. Pre-dredge bathymetric data collected in 2008 in the navigation channel by the USACE were paired with bathymetric data collected in August 2003 by LDWG.[14] Figure 6-5 displays the differences in elevation at points along the 2008 transects in the navigation channel. Where data from both surveys were available, differences observed over this 5-year period suggest that sedimentation had occurred in much of the navigation channel. While not used as a primary line of evidence for assigning recovery categories, many areas of empirically-estimated deposition roughly match the model predictions. However, differences in survey methods and limited documentation of the bathymetric surveys have produced some uncertainties in the data, which may inaccurately show some areas as having scour (e.g., RM 1.7 to RM 1.9 near Slip 2).

6.3.1.2 High-flow Events

High-flow events increase the rate of erosion in certain areas of the LDW, which could reduce recovery potential. Scour deeper than 10 cm, as estimated by the STM to occur any time during a 100-year high-flow event, is evidence that recovery may not be occurring (see Figure 2-9). A depth of 10 cm was selected because it is the depth of the biologically active zone and the depth of most of the surface sediment samples in the FS baseline dataset.

6.3.1.3 Vessel Scour Areas

Vessel scour areas were identified based on observed ridges and furrows (as determined using the sun-illuminated image of the 2003 bathymetric data) assumed to be caused by vessel traffic along established vessel traffic routes. These bed form areas are assigned to Category 1 because deposited sediment may be eroding or sedimentation may be restricted. The mapping of this layer was restricted to areas where active berthing (vessels and overwater structures) was observed because vessels maneuvering into these areas may be causing scour or because spud placement during vessel mooring may be disturbing the sediments. Bed forms identified outside of berthing areas could represent spud mounds (from vessels moored outside of mapped berthing areas), depressions from vessels resting on the bottom in shallow water, debris, or shallow track lines from transiting vessels. However, these bed forms outside of known vessel use areas are relatively shallow and localized and are not expected to expose buried contamination or impede recovery. Therefore, the mapping of vessel

[14] The August 2003 data collection effort predated the January 2004 maintenance dredging in the navigation channel from RM 4.3 to 4.65 (the last navigation channel dredging event prior to the 2003 data collection was in January 2002; Table 2-9).

scour areas was restricted to higher-traffic areas based on the presence of a pier/wharf face, documented maintenance dredging events, and/or operator interviews indicating that the area supports frequent vessel traffic (see Figures 2-10 and 6-5).

6.3.1.4 Berthing Areas

Berthing areas are locations in the LDW adjacent to existing overwater structures that are not part of marinas, such as piers, wharves, pile groups, and dolphins (Figure 2-28 displays both overwater structures and berthing areas). These areas are assumed not to be viable for natural recovery if evidence of vessel scour was observed or empirical trends show increasing concentrations of risk drivers (excluding dioxins/furans). Berthing areas without evidence of vessel scour are assumed to exhibit recovery potential and thus were placed in Category 2. Berthing areas with evidence of vessel scour were placed in Category 1. Empirical contaminant trends, when available in berthing areas, were used as a final check to either confirm a recovery category designation or as an override to assign an area to another recovery category depending on the observed trend (see next subsection).

6.3.1.5 Empirical Contaminant Trends

Empirical trends in risk-driver (excluding dioxins/furans) concentrations were used as a final check to either confirm or override recovery category assignments based on physical criteria on a case-by-case basis. The identification of a sample location as belonging to an empirical trend category followed a three-step process. First, sample locations with the appropriate data (resampled surface sediment locations within 10 ft of one another or cores with two sample intervals in the top 2 ft) were identified (Table 6-4; Part 1). Second, each detected risk driver exceeding the SQS was assigned to one of three categories (Table 6-4; Part 2):

- Increase: contaminant concentration increasing more than 50% over previous or deeper concentration
- Equilibrium: a small (less than 50%) change in concentration
- Decrease: contaminant concentration decreasing more than 50% from previous or deeper concentration.

Third, the trend assignments for the risk drivers exceeding the SQS were grouped into a summary designation for each location (Table 6-4; Part 3 and Figure 6-4b). Dioxins/furans were not evaluated because of a lack of temporal data. Figure 6-4b shows two symbols per location, one for total PCBs alone and another for all other risk-driver contaminants:

- Increase (red): All contaminants evaluated increased by more than 50%. A location with two red symbols was in Category 1.

- Equilibrium or mixed (gray): A location with mixed results by contaminant (risk drivers other than total PCBs having any combination of assignments in bulleted list above) or concentration changes in equilibrium (less than 50% change) was in Category 2. If a location's trend assignment of "mixed" was based on a combination of decreasing trends and equilibrium (but no increasing trends) that location was in Category 3.
- Decrease (blue): All contaminants evaluated had concentrations decreasing by more than 50%. A location with two blue symbols was in Category 3.
- Below SQS (green): Total PCBs or all other contaminants were not detected above the SQS.

The shape of the symbol denotes whether it is a co-located surface grab sample or a sediment core. Empirical overrides of the physical criteria (Table 6-3) occurred on a case-by-case basis (described in Table D-2). The empirical data are discussed in greater detail in Appendix F.

6.4 Uncertainty Analysis of AOPCs and Recovery Potential

Uncertainties in the process of developing AOPC footprints and recovery potential categories are discussed below.

6.4.1 AOPC Uncertainty

This section examines the degree of confidence that exists with the estimate of the AOPC footprints using the criteria discussed in Section 6.1. The primary factors contributing to uncertainty in the AOPC footprints are:

- Age of the data
- Data mapping and interpolation
- Use of SWACs instead of 95% upper confidence limit (UCL95) on the SWAC.

These uncertainties are discussed below.

6.4.1.1 Age of Data

The FS baseline surface sediment dataset was used to map the AOPCs. Older data at stations that were resampled (collected within 10 ft of newer data) were excluded from the FS baseline dataset on a contaminant-by-contaminant basis. The intent was to use the most recent data available for defining the nature and extent of contamination. LDWG conducted sampling in 2005, 2006, 2009, and 2010 to expand and update the existing dataset. However, because the FS study area is large (441 acres), some data that are more than 10 years old remain in the dataset.

The FS baseline surface sediment dataset is comprised of over 1,400 surface sediment samples spanning 20 years of data collection (1990 through 2010). Between 1990 and 2004, approximately 1,200 surface sediment samples, 340 subsurface sediment cores, and 90 fish and shellfish tissue samples were collected from the LDW by parties other than LDWG. These samples and cores were analyzed for metals and organic compounds. Data that were deemed acceptable based on a review of analytical methods and quality assurance reports became part of the RI and FS baseline datasets. Additional data were collected from 2004 to 2006 by LDWG for the RI to characterize contamination and physical properties of the LDW. These data included approximately 900 samples of the following media: fish, clam, crab, and benthic invertebrate tissue; seep water (water seeping from banks along the LDW); surface sediment (the top 10 cm); subsurface sediment (below the top 10 cm); and porewater (water in spaces between sediment particles). In 2009 and 2010, LDWG collected an additional 41 surface sediment samples and 6 composite sediment samples for the FS to characterize beach play areas and to expand the dioxin/furan dataset.

Many of the sediment samples are now over 10 years old, and surface conditions may have changed in these sampled areas. In mapping the AOPCs, however, this level of uncertainty is considered to be acceptable for the FS by assuming all data points represent baseline conditions. Remedial alternatives are assembled around these predictions along with other lines of evidence described in Section 8. Sampling conducted during remedial design will be conducted to help reduce any outstanding uncertainties. To account for uncertainties associated with older data being used to evaluate RAL exceedances, areas of AOPC 1 meeting all or most of the following characteristics are assumed to be candidates for verification monitoring during remedial design:

- Relatively old data (i.e., sampled prior to 1998)[15]
- Risk-driver concentrations exceeding but close to the AOPC 1 RALs, specifically SQS exceedances less than 1.5 times the SQS or total PCB concentrations slightly over 240 µg/kg dw
- Isolated points (i.e., only 1 point with an SQS exceedance in a 0.5-acre or larger area or where a point is surrounded by passes)
- Not in Recovery Category 1
- BCM predictions of recovery within 10 to 20 years from baseline.

Verification monitoring during remedial design should confirm whether the sediments in these areas exceed the RALs. Areas designated as candidates for verification

[15] The AOPC footprint was first delineated in 2008 for the draft FS. Samples collected prior to 1998 were more than 10 years old at that time (2008).

monitoring are shown in Appendix D and are mapped separately in the remedial alternatives (Section 8). No empirical time trend data were available for these 23 acres.

6.4.1.2 Data Mapping and Interpolation

The FS baseline dataset contains data from numerous site investigations conducted over the past 20 years. These investigations have been used to determine the nature and extent of sediment contamination associated with past hazardous substance releases. This extensive dataset was used to build the conceptual site model, map the nature and extent of contamination, and understand site processes for evaluating remedial alternatives. However, as with every environmental investigation, some uncertainty remains associated with the horizontal and vertical extent of sediment contamination, as discussed in the following points:

- **Laboratory Reporting Limits:** A portion of the uncertainty is related to reporting limits that exceed the screening criteria, especially in older data. Therefore, only detected SQS exceedances (expressed spatially as Thiessen polygons) were used to delineate the AOPCs for RAO 3. Samples with only undetected data (i.e., reporting limits) exceeding the SQS criteria were not considered exceedances. In the ERA (Windward 2007a), an evaluation of the reporting limits that exceeded the SQS concluded that there was a low probability that these exceedances would be of concern.
- **Sampling Design**: Another portion of the AOPC uncertainty is related to the uneven distribution of sampling in historical datasets. Good spatial coverage exists throughout the LDW, but the sampling density is not evenly distributed. For example, some investigations targeted specific areas (e.g., Boeing Plant 2) and these areas have much denser sampling coverage than other areas of the LDW. For this reason, the spatial extent of contamination remains somewhat uncertain, which is common in the feasibility study phase of any large site. Sampling coverage and density will be refined through the addition of new data collected during remedial design.
- **Interpolation Methods:** Two interpolation methods were used to map surface sediment data (IDW and Thiessen polygons; see Appendix A). Each of these methods has inherent uncertainties, including the sampling density, influence of geomorphology on the distribution of contaminants, and influence of surrounding data. The uncertainty in these methods was minimized by conducting an extensive exploratory analysis and by optimizing the IDW parameters used for interpolating total PCBs, arsenic, and cPAHs. This parameterization simulates a "best-fit" estimate of the true concentration gradients (Appendix A). The selected mapping techniques (i.e., IDW interpolation and Thiessen polygons) are well documented and widely used in managing contaminated sediments. The spatial extent of

COC concentrations is expected to be refined during the remedial design phase when additional samples are collected.

- **Vertical Compositing**: The subsurface sediment dataset includes many sediment cores that extended down to "native sediments," where most contaminant concentrations were below the SQS. This was documented in the logs for the cores collected in 2006 for the RI. However, many cores collected for other sampling events did not have logs, were composited over broad depth intervals (e.g., 4 ft), or were too shallow to reach the native sediments and/or the bottom of contamination. For these shallower cores, the interpreted bottom of contamination may not be the true bottom. Some of the vertical core samples were composited over 2-ft or longer intervals, such that either the bottom of contamination is not completely understood within the sample interval or the depth within the core for the highest contaminant concentrations is not completely understood.

- **Vertical Extent of Contamination:** On a site-wide scale, the vertical extent of contamination (greater than SQS) has been interpolated into an isopach layer representing the bottom of this contamination (described in Appendix E). The native alluvium contact, which has also been interpolated into an isopach layer, can be used as a surrogate for the uncertainty in the extent of the bottom of contamination for this FS (see Appendix E). The top of the native alluvium isopach layer is also assumed to be the maximum depth of any subsurface sediments with total PCB concentrations greater than 100 µg/kg dw (below this contact, sediments are assumed to exhibit native, pre-industrialized conditions). Because cores are much less numerous than surface sediment samples, the interpolation of the subsurface contamination may not represent actual conditions as effectively as it does for surface sediments. These estimates will need to be refined during remedial design.

  Additionally, the cores were collected by many different parties using various sampling methods and compositing schemes. The data were also not always accompanied by field and core processing logs that could be used to adjust recovered depths to *in situ* depths or to provide other useful information. Finally, not all intervals within each core were sampled, and within those intervals sampled, not all COCs were analyzed. If a sampling interval was not analyzed and the interval immediately above was contaminated, then the bottom of the contamination is assumed to be the bottom of the skipped interval. For cores that did not reach the bottom of contamination (detected SQS exceedances), 1 ft was added to the depth of the bottom of the core, and this depth was assumed to be the bottom of contamination.

6.4.1.3 95% Upper Confidence Limits (UCL95) on SWACs

The UCL95 on the mean is a statistically derived quantity associated with a representative sample from a population (e.g., sediment or tissue chemistry results) such that 95% of the time, the true average of the population from which the sample was taken will be less than the quantity statistically derived from the sample dataset (e.g., 95% of the time, the true average sediment contaminant concentration will be less than the UCL95 based on sediment chemistry sample results). The UCL95 is used to account for uncertainty in contaminant concentration measurements and to ensure that contaminant concentrations are not underestimated.

The AOPCs were delineated in part by estimating when a post-remediation site-wide SWAC achieves a target concentration. Therefore, mean values, not UCL95s, were used to delineate the AOPCs and evaluate predicted results in Section 9. However, in accordance with EPA and Ecology policy for evaluating compliance and estimating exposure concentrations, an upper confidence limit of the true mean (UCL95 on the SWAC) will be developed for each compliance monitoring dataset and compared to the target goal to account for sampling variability. The UCL95 from a well-designed post-remediation sampling program is expected to exceed the true SWAC by some increment.

Because the delineation of the AOPCs and the evaluation of the remedial alternatives are based on SWACs instead of UCL95 values, the footprints could potentially be larger. However, remediation of incrementally larger footprints manages contaminated sediment to incrementally lower concentrations, decreasing variability in the dataset. Footprints based on achieving the long-term model-predicted concentrations (SWACs) are likely not much different than those based on UCL95 values because, over time, natural recovery, coupled with remediation of hot spots, will reduce variability such that SWACs and UCL95 values become similar.

Appendix H discusses methods for calculating the UCL95 on the SWAC using the total PCB RI baseline dataset.

Overall, the nature and extent of sediment contamination is sufficiently understood to characterize risks, and develop reasonable estimates of the AOPCs and LDW-wide remedial alternatives for the FS. Uncertainty in the horizontal and vertical extent of sediment contamination above selected RALs will be refined during remedial design.

6.4.2 Recovery Potential Uncertainty

The recovery categories synthesize a large amount of information into a simple construct that can be used for managing uncertainty in technology assignments for this FS-level analysis. However, each criterion used in this analysis contains both uncertainties and assumptions. Remedial design-level analysis will provide additional information that will supersede many of the assumptions in this analysis. A few of the major assumptions that may affect an FS and remedial design-level analysis include:

- Berthing areas, navigation channel operations, and elevations necessary for berthing and navigation may change.
- Further observations and analysis of location-specific vessel scour and its effect on recovery may change. Location-specific analysis of impacts may result in different conclusions on scour potential and may change technology selection.
- STM estimates may be combined with location-specific empirical data to refine sedimentation rates and scour potential.
- Additional data could refine location-specific contaminant trends over time.
- Source control changes could affect the rate of observed natural recovery.

A point to be considered in decision-making for source control implementation, remedy design, and remedy implementation is whether areas of AOPC 1 located near certain outfalls may be subject to recontamination. A premise of EPA's sediment remediation guidance is that active remediation should generally not be implemented until sources have been controlled to the extent necessary to reduce the risk of recontaminating the remediated area (EPA 2005b). Whether active or passive, the success of any remediation may be affected by source control. This FS analysis is consistent with these principles. The FS accounts for recontamination potential in the technology assignments (Section 8) and in the predicted outcomes (Section 9) using the range of BCM input parameters (Section 5).

Estimates of recovery potential should also include: 1) physical conditions that may preclude recovery; 2) predictive modeling that assumes lateral sources will be controlled, at least to some extent, in the future; 3) empirical trends demonstrating that recovery is underway, but that "final" recovery will require additional source control measures and time; and 4) recontamination potential from external sources (see Appendix J). All of these factors have been considered in this FS. However, remedial design-level sampling and further evaluation of source control effectiveness will be necessary in certain areas before any remedial action is initiated. These data and model predictions will be essential in reassessing future recovery or recontamination of surface sediments after source controls are in place.

Table 6-1 Lowest Point Concentrations Used to Delineate AOPCs and Associated SWACs

Risk Driver	Lowest Point Concentrations Used to Delineate AOPC[a]	Preliminary Remediation Goals (PRGs)				Long-term model-predicted concentrations (SWAC)	Estimated SWACs after Active Remediation of AOPC[b]			Are Cleanup Objectives Achieved?			
		RAO 1 (site-wide SWAC)	RAO 2[c] (site-wide netfishing; beach play; clamming SWACs)	RAO 3 (point)	RAO 4 (site-wide SWAC)		Site-wide	Beach Play	Clamming	RAO 1	RAO 2	RAO 3	RAO 4
AOPC 1 (180 acres). Active remediation of AOPC 1 would achieve PRGs for RAOs 2, 3, 4 immediately after construction (with the exception of RAO 2 for arsenic)													
Total PCBs (µg/kg dw)	240 (site-wide)	bg: 2	**1,300; 1,700; 500**	**12 mg/kg oc**	**128-159**	n/a	92	62	69	**T**[e]	✓	✓	✓
Arsenic (mg/kg dw)	57 (site-wide) 28 (intertidal)	n/c	bg: 7	**57**	n/a	n/a	11	9	9	n/a	**T**[c]	✓	n/a
cPAHs (µg TEQ/kg dw)	1,000 (site-wide) 900 (intertidal)	n/c	**380;** 90; **150**	n/a	n/a	n/a	210	150	150	n/a	✓[d]	n/a	n/a
Dioxins/furans (ng TEQ/kg dw)	25 (site-wide) 28 (intertidal)	bg: 2	**37; 28; 13**	n/a	n/a	n/a	6	4	5	**T**[e]	✓	n/a	n/a
SMS contaminants	SQS (site-wide)	n/a	n/a	**SQS**	n/a	n/a	n/a			n/a	n/a	✓	n/a
AOPCs 1& 2 (302 acres). Active remediation AOPCs 1 and 2 would achieve long-term model predicted concentrations (the lowest technically achievable SWACs) immediately after construction.													
Total PCBs (µg/kg dw)	100 (site-wide)	bg: 2	**1,300; 1,700; 500**	**12 mg/kg oc**	**128 to 159**	40-50	46	46	48	✓[e]	✓	✓	✓
Arsenic (mg/kg dw)	15 (site-wide) 28 (intertidal)	n/c	bg: 7	**57**	n/a	9-10	10	9	9	n/a	✓[c]	✓	n/a
cPAHs (µg TEQ/kg dw)	same as AOPC 1	n/c	**380;** 90; **150**	n/a	n/a	100 - 150	140	140	140	n/a	✓	n/a	n/a
Dioxins/furans (ng TEQ/kg dw)	15 (site-wide) 28 (intertidal)	bg: 2	**37; 28; 13**	n/a	n/a	4-6	4	4	4	✓[e]	✓	n/a	n/a
SMS contaminants	same as AOPC 1	n/a	n/a	**SQS**	n/a	n/a	n/a			n/a	n/a	✓	n/a

Table 6-1 Lowest Point Concentrations Used to Delineate AOPCs and Associated SWACs (continued)

Notes:

1. AOPC 1 is also delineated where cores having SQS exceedances in the top 2 ft occur in scour areas. AOPC 2 is also delineated where any core exceeds the SQS at any depth.
2. Site-wide point concentrations used to delineate AOPCs are applied to concentrations in the upper 10 cm of sediment and intertidal point concentrations used to delineate AOPCs are applied to concentrations in the upper 45 cm of sediment.

a. Site-wide point concentrations used to delineate AOPCs are applied in the upper 10 cm of sediment throughout the LDW, and in the upper 60 cm of potential scour areas (i.e., Recovery Category 1 areas; see Section 6.3). Intertidal point concentrations used to delineate AOPCs are applied in the upper 45 cm of sediment in intertidal areas (above -4 ft MLLW).

b. SWACs are estimated by replacing grid cells in AOPCs 1 and 2, respectively, with the following post-remedy bed sediment replacement values: total PCBs = 60 and 20 µg/kg dw; arsenic = 10 and 9 mg/kg dw; cPAHs = 140 and 100 µg TEQ/kg dw; and dioxin/s/furans = 4 ng TEQ/kg dw. AOPC 2 SWACs are based on replacing grid cells in both AOPCs 1 and 2. SWACs are based on the cumulative effect of removing all points/areas above the site-wide and intertidal point concentration shown for each risk driver (the entire AOPC footprint).

c. Because natural background PRG is unlikely to be achieved, this RAO is being evaluated by surface sediment reaching the long-term model-predicted arsenic concentrations. These concentrations are achieved with time after remediation of AOPC 1 and are achieved immediately after remediation of AOPCs 1 and 2.

d. Although the combined beach play area cPAH SWAC is not below 90 µg TEQ/kg dw, this PRG is considered to be achieved because most of the individual beaches achieve this PRG or a 1×10^{-6} excess cancer risk threshold.

e. Because natural background PRGs are unlikely to be achieved for total PCBs and dioxins/furans, RAO 1 is being evaluated by surface sediment reaching the long-term model-predicted concentrations for these two risk drivers. These concentrations are achieved with time after remediation of AOPC 1 and are achieved immediately after remediation of AOPCs 1 and 2.

✓ = Achieves cleanup objective (PRG or long-term model-predicted concentration) immediately following construction.

T = Achieves cleanup objective over time. Institutional controls will be required to further reduce RAO 1 risks regardless of the selected RAL. For RAOs 1 and 2 (arsenic) the goal is to reduce sediment concentrations to as close as practicable to the PRG, estimated in this FS as long-term model-predicted concentrations.

Bold = PRG achieved

AOPC = area of potential concern; bg = background; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; kg = kilograms; µg = micrograms; mg = milligrams; n/a = not applicable; n/c = not calculated; ng = nanograms; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAL = remedial action level; RAO = remedial action objective; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent.

Table 6-2 Array of Remedial Action Levels

Risk-Driver Remedial Action Level[a]	Rationale	Cleanup Objective Achieved[b] (✓ = achieved immediately after construction; T = achieved with time)			
		RAO 1[c]	RAO 2	RAO 3	RAO 4
Total PCBs (µg/kg dw)					
2,200 (site-wide)	• Manage hot spots	**T**	Total PCB direct contact PRGs are achieved following remediation of EAAs and hot spots.[e]	**T** (achieves CSL with time)	**T**
1,300 (site-wide)	• Dry weight equivalent of CSL[d]; achieved immediately after construction	**T**		**T**	**T**
700 (site-wide)	• Provides a well-spaced range of RALs for evaluation	**T**		**T**	✓
240 (site-wide)	• Dry weight equivalent of SQS[d;] achieved immediately after construction	**T**		✓	✓
100 (site-wide)	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations • Point of minimal change in SWAC	✓		✓	✓
Arsenic (mg/kg dw)					
93 (site-wide)	• Achieve CSL immediately after construction / Manage hot spots	n/a	**T**	**T**	n/a
57 (site-wide)	• Achieve SQS immediately after construction and part of a well-spaced range of RALs	n/a	**T**	✓	n/a
28 (intertidal)	• 10^{-5} beach play RBTC (applied as point basis; 45 cm point of compliance) and part of a well-spaced range of RALs	n/a	**T**	✓	n/a
15 (site-wide)	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations • Point of minimal change in SWAC	n/a	✓	✓	n/a
cPAHs (µg TEQ/kg dw)					
5,500 (site-wide)	• Manage hot spots	n/a	**T**	n/a	n/a
3,800 (site-wide)	• 10^{-5} netfishing RBTC (applied as a point basis) and part of a well-spaced range of RALs	n/a	✓	n/a	n/a
1,000 (site-wide)	• Site-wide SWAC within range of upstream values	n/a	✓	n/a	n/a
900 (intertidal)	• Beach play 10^{-5} RBTC (applied as point basis; 45 cm point of compliance)	n/a	✓	n/a	n/a

Table 6-2 Array of Remedial Action Levels (continued)

Risk-Driver Remedial Action Level[a]	Rationale	Cleanup Objective Achieved[b] (✓ = achieved immediately after construction; T = achieved with time)			
		RAO 1[c]	RAO 2	RAO 3	RAO 4
Dioxins/Furans (ng TEQ/kg dw)					
50 (site-wide)	• Manage hot spots	**T**	**T**	n/a	n/a
35 (site-wide)	• Provides a well-spaced range of RALs for evaluation	**T**	✓	n/a	n/a
28 (intertidal)	• 10^{-6} beach play RBTC (applied as point basis; 45 cm point of compliance)	**T**	✓	n/a	n/a
25 (site-wide)	• Provides a well-spaced range of RALs for evaluation	**T**	✓	n/a	n/a
15 (site-wide)	• Site-wide SWAC within range of upstream values and long-term model-predicted concentrations • Point of minimal change in SWAC	✓	✓	n/a	n/a
SMS Contaminants (apply throughout the LDW)					
CSL at Year 10 (site-wide)	• Achieve CSL within 10 years after completion of construction	n/a	n/a	**T**	n/a
CSL at Year 0 (site-wide)	• Achieve CSL immediately after completion of construction	n/a	n/a	**T**	n/a
SQS at Year 10 (site-wide)	• Achieve SQS within 10 years after completion of construction	n/a	n/a	**T**	n/a
SQS at Year 0 (site-wide)	• Achieve SQS immediately after completion of construction	n/a	n/a	✓	n/a

Notes:

a. A remedial action level is a contaminant-specific sediment concentration that triggers the need for active remediation (i.e., dredging, capping, or ENR with or without *in situ* treatment). It is a point-based concentration that can be targeted to achieve an area-based goal (SWAC). Site-wide remedial action levels are applied to concentrations in the upper 10 cm of sediment throughout the LDW and in the upper 60 cm in Recovery Category 1 areas. Intertidal remedial action levels are applied to concentrations in the upper 45 cm of sediment in intertidal areas (above -4 ft MLLW).

b. See Section 9 for predicted outcomes and RALs by remedial alternative.

c. Risks associated with RAO 1 are reduced through a combination of active remediation, natural recovery, and institutional controls. The goal is to reach the long-term model-predicted concentration, which is as close to natural background as technically practicable (equilibrium).

d. Dry weight equivalents of the SQS and CSL SMS criteria of 12 and 65 mg/kg oc, assuming 2% TOC (average site-wide TOC value). If selected, actual implementation of this RAL would be based on organic carbon-normalized criteria defined by the SMS.

e. An intertidal RAL for PCBs in the upper 45 cm of sediment was not developed because the PRGs for direct contact scenarios are achieved after remediation of the EAAs and other hotspot areas (using the highest RAL sets shown above).

Year 0 = the point in time immediately following completion of construction.

Year 10 = the point in time 10 years after completion of construction.

✓ = Achieves cleanup objective immediately following construction. For RAO 1, institutional controls are also needed.

T = Achieves cleanup objective over time. Institutional controls will be required for RAO 1 regardless of the selected RAL. For RAOs 1 and 2 (arsenic) the goal is to reduce sediment concentrations to achieve the long-term model-predicted concentrations.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; kg = kilograms; µg = micrograms; mg = milligrams; n/a = not applicable to the RAO; ng = nanograms; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAL = remedial action level; RAO = remedial action objective; RBTC = risk-based threshold concentration; SMS = sediment management standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; TOC = total organic carbon.

Table 6-3 Criteria for Assigning Recovery Categories

Criteria		Recovery Categories: Category 1 Recovery Presumed to be Limited	Category 2 Recovery Less Certain	Category 3 Predicted to Recover
Physical Criteria				
Physical Conditions	Vessel scour[a]	Observed vessel scour	No observed vessel scour	
	Berthing areas[b]	Berthing areas with vessel scour	Berthing areas without vessel scour	Not in a berthing area
Sediment Transport Model	STM-predicted 100-year high-flow scour (depth in cm)[c]	> 10 cm	< 10 cm	
	STM-derived net sedimentation rate[b] (cm/yr) using average flow conditions	Net scour	Net sedimentation	
	Rules for applying criteria	*Any one criterion in Category 1 results in the area achieving a Category 1 designation.*	*Conditions achieve a mixture of Category 2 and 3 criteria*	*All conditions must achieve the Category 3 criteria.*
Empirical Contaminant Trend Criteria – used on a case-by-case basis to adjust recovery categories from the criteria above				
Empirical Contaminant Trend Criteria[d]	Resampled surface sediment locations	Increasing total PCBs or increasing concentrations of other detected risk drivers exceeding the SQS (> 50% increase)[e]	Equilibrium and mixed (increases and decreases) results (for risk drivers exceeding the SQS)	Decreasing concentrations (> 50% decrease) or mixed[f] results (decreases and equilibrium)[e]
	Sediment cores (top 2 sample intervals in upper 2 ft)			

Notes:

1. Empirical trends were evaluated for two contaminant groups: total PCBs and other risk drivers exceeding the SQS. Dioxins/furans were not evaluated because the small dioxin/furan dataset does not include resampled surface sediment locations and has very few subsurface sediment samples.

a. Observed vessel scour areas are shown on Figure 2-10.
b. Berthing areas are shown on Figure 2-28 and modeled net sedimentation rates are shown on Figure 2-11.
c. High-flow scour areas are shown on Figure 2-9.
d. Empirical trend data are described in Appendix F and summarized in Figure 6-4b. See Table 6-4 for description of empirical trend methodology.
e. ±50% decrease is reasonable considering that analytical variability alone is 25%, and the difference in co-located field replicates ranged from 8% (arsenic) to 48% (cPAHs).
f. A location with mixed results in which risk drivers exceeding the SQS have decreasing trends and concentration changes in equilibrium (but no increasing trends) can be in Recovery Category 3.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyl; SQS = sediment quality standard; STM = sediment transport model

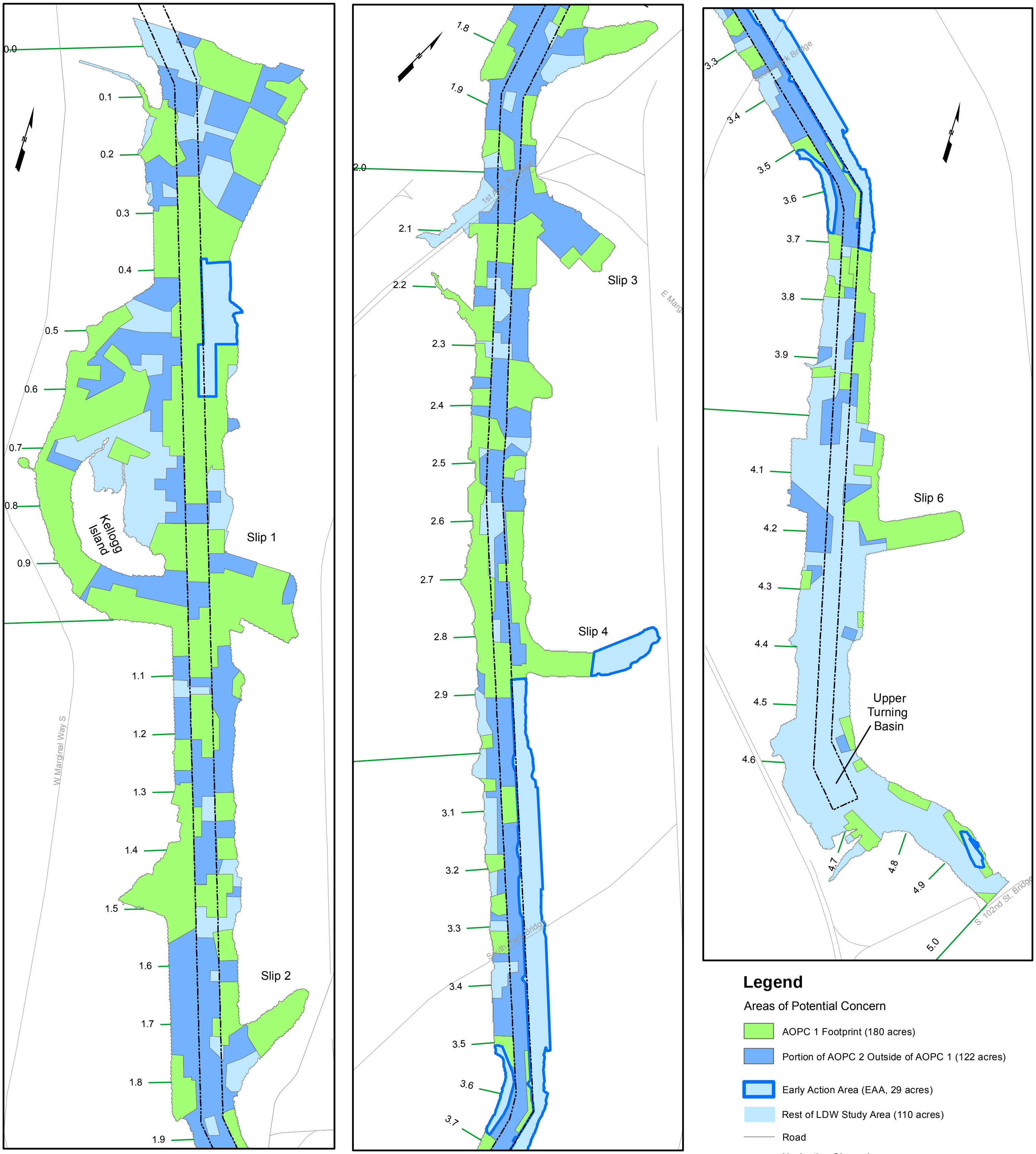
Table 6-4 Empirical Data Methodology Used in Natural Recovery Trend Evaluation

Part 1: Selection of Locations and Data	**Part 2: Trend Criteria Evaluated by Risk Driver**	**Part 3: Natural Recovery Classification by Station** (Figure 6-4b symbol colors; 1 symbol for total PCBs; 1 symbol for other risk drivers)
Resampled surface stations (not more than 10 ft apart)	Increase (> 50% change in concentration)	Increase – all evaluated risk drivers increase (**red**); all red symbols = Category 1
Top 2 sample intervals of cores within top 2 ft of core[a]	Equilibrium (less than 50% change in concentration in either direction)	Equilibrium – all evaluated risk-driver concentrations change by less than 50% (**gray**); Category 2.
Detected risk drivers exceeding the SQS evaluated for concentration changes	Decrease (>50% change in concentration)	Mixed – Risk drivers other than total PCBs have some mixture of any of 3 classifications (**gray**); Category 2 if mixture includes increases; Category 3 if mixture is decreases and equilibrium.
		Decrease – all evaluated risk drivers decrease (**blue**); Category 3.
		Detected total PCBs or other risk drivers do not exceed the SQS[b] (**green**); not specifically used for recovery assignments; area is likely below RALs.

Notes:

1. Two groups of contaminants evaluated: (a) total PCBs detected above the SQS, and (b) risk drivers other than total PCBs detected above the SQS. Figure 6-4b has one symbol for total PCBs and one symbol for other risk drivers.
2. Empirical data evaluation included: 53 to 67 resampled surface sediment locations and 165 cores with appropriate depth intervals (118 samples with an SQS exceedance for total PCBs, 58 samples with an SQS exceedance for other risk drivers). Evaluated the top two intervals of cores if both intervals were within the top 2 ft (can use co-located surface samples).

a. Core trends were also evaluated by comparing the data from the uppermost core interval to that from a co-located surface sediment location, if available.



Notes:
1. AOPC 1 was delineated using beaches with total excess cancer risk (all risk-driver contaminants combined) greater than 10^{-5}, subsurface SQS exceedances in scour areas, and surface sediments exceeding the following RALs: SQS for any contaminant, total PCBs 240 µg/kg dw, arsenic 28 mg/kg dw in intertidal areas, cPAHs 1,000 µg TEQ/kg dw sitewide and 900 in intertidal areas, and dioxins/furans 25 ng TEQ/kg dw.
2. AOPC 2 was delineated using subsurface SQS exceedances at any depth and surface sediments exceeding the following RALs: total PCBs 100 µg/kg dw, arsenic 15 mg/kg dw, and dioxins/furans 15 ng TEQ/kg dw.
3. Verification monitoring areas (23 acres) are included in AOPC 1, but are presumed to be below the RAO 3 PRGs at the time of construction.

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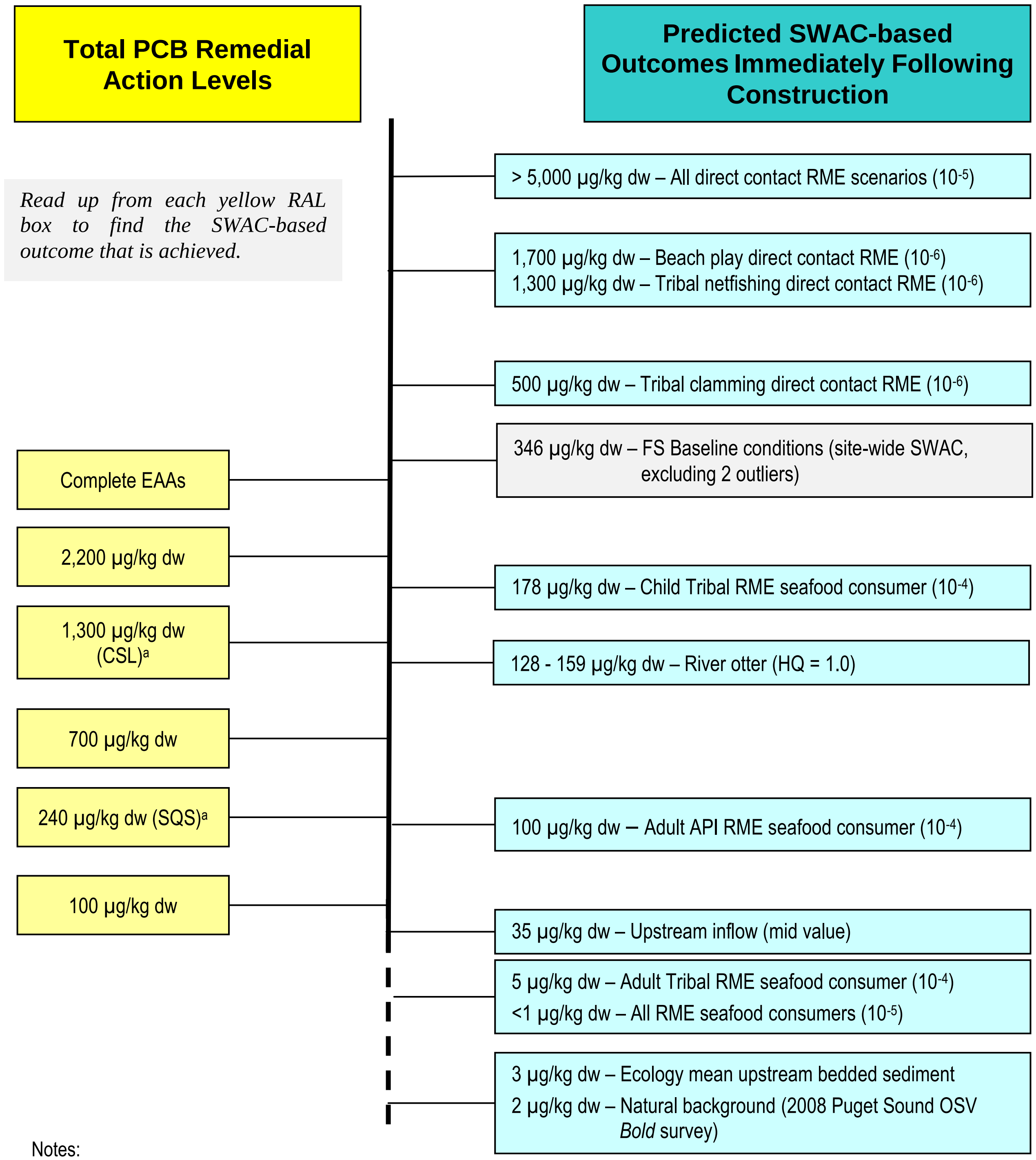
Lower Duwamish Waterway Final Feasibility Study 60150279-14.38	The AOPC Footprints
DATE: 10/31/12 DWRN:mvi/sea Revision: 0	FIGURE 6-1

Figure 6-2a Total PCB Remedial Action Levels for Human and Ecological Health



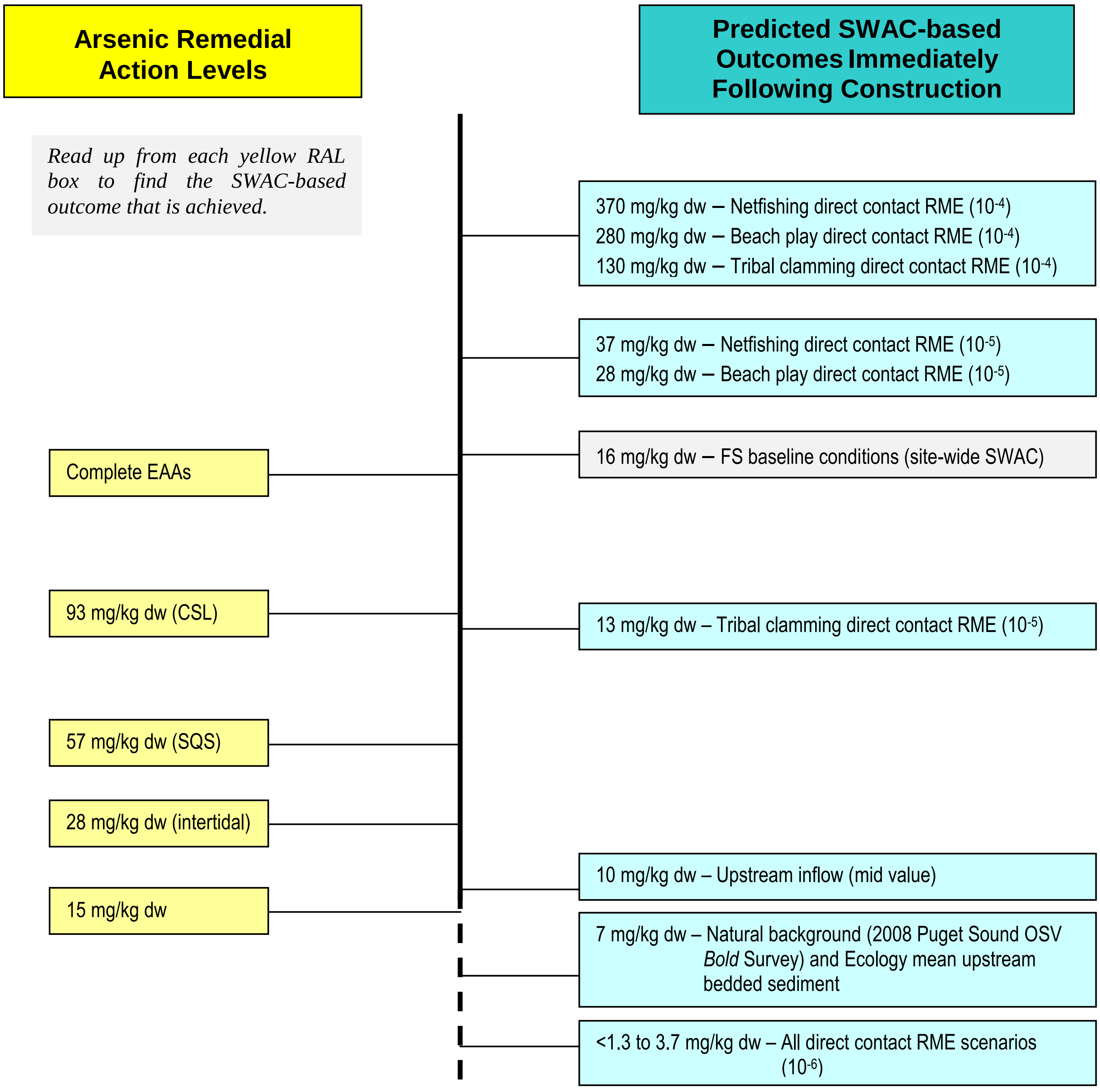
Notes:

a Dry weight equivalents of the SQS and CSL SMS criteria of 12 and 65 mg/kg oc, assuming 2% total organic carbon (average LDW-wide TOC value).

10^{-5} = Risk of 1 additional cancer in 100,000 people over a lifetime; CSL = cleanup screening level; EAA = Early Action Area; HQ = hazard quotient; PCB = poly-chlorinated biphenyl; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; SQS = sediment quality standard; TOC = total organic carbon; UCL = upper confidence limit.

— — — — = not achievable

Figure 6-2b Arsenic Remedial Action Levels for Human and Ecological Health

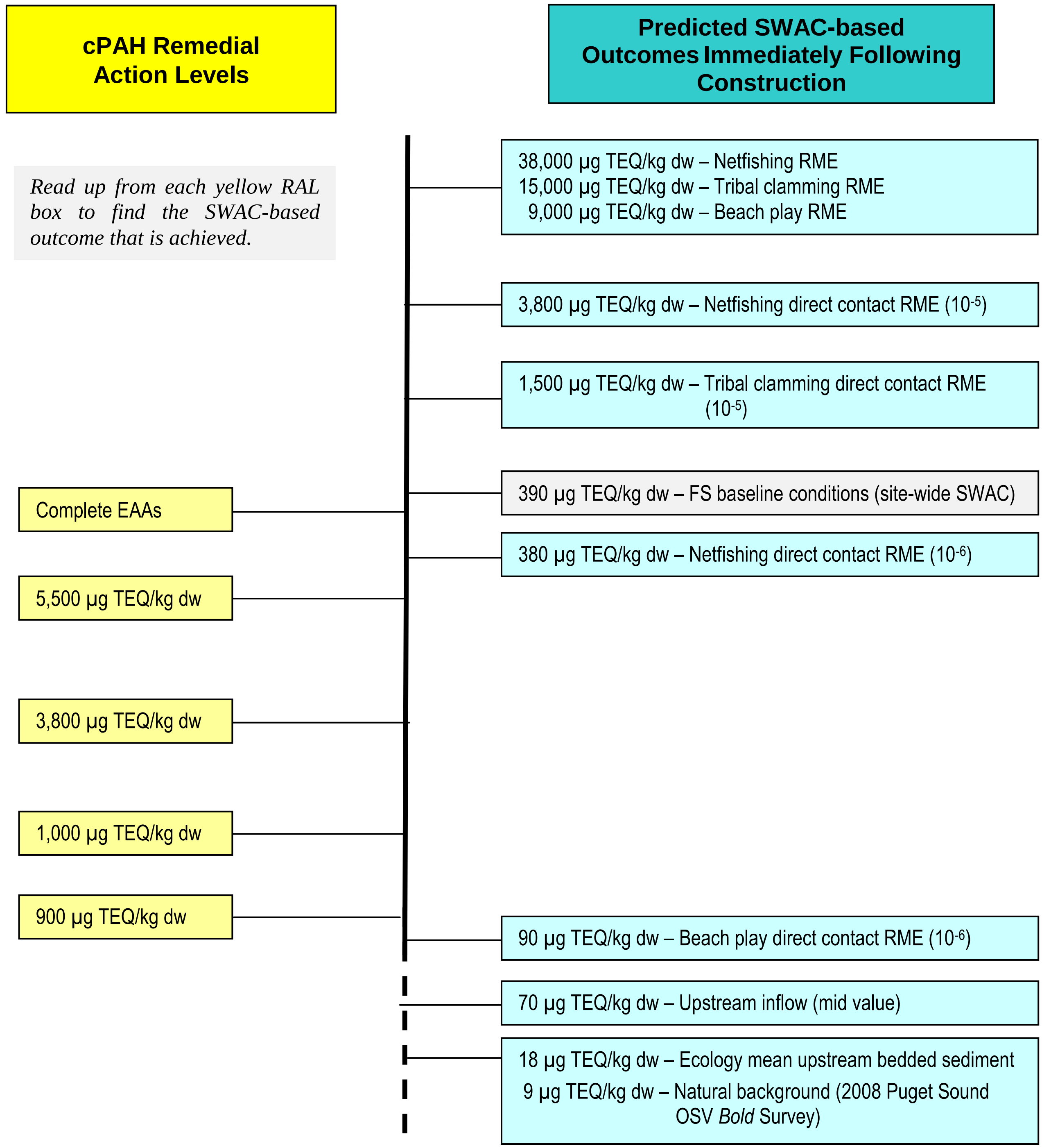


Notes:

10^{-5} = Risk of 1 additional cancer in 100,000 people over a lifetime; CSL = cleanup screening level; EAA = Early Action Area; HQ = hazard quotient; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; SQS = sediment quality standard; UCL = upper confidence limit.

▬ ▬ ▬ ▬ = not achievable

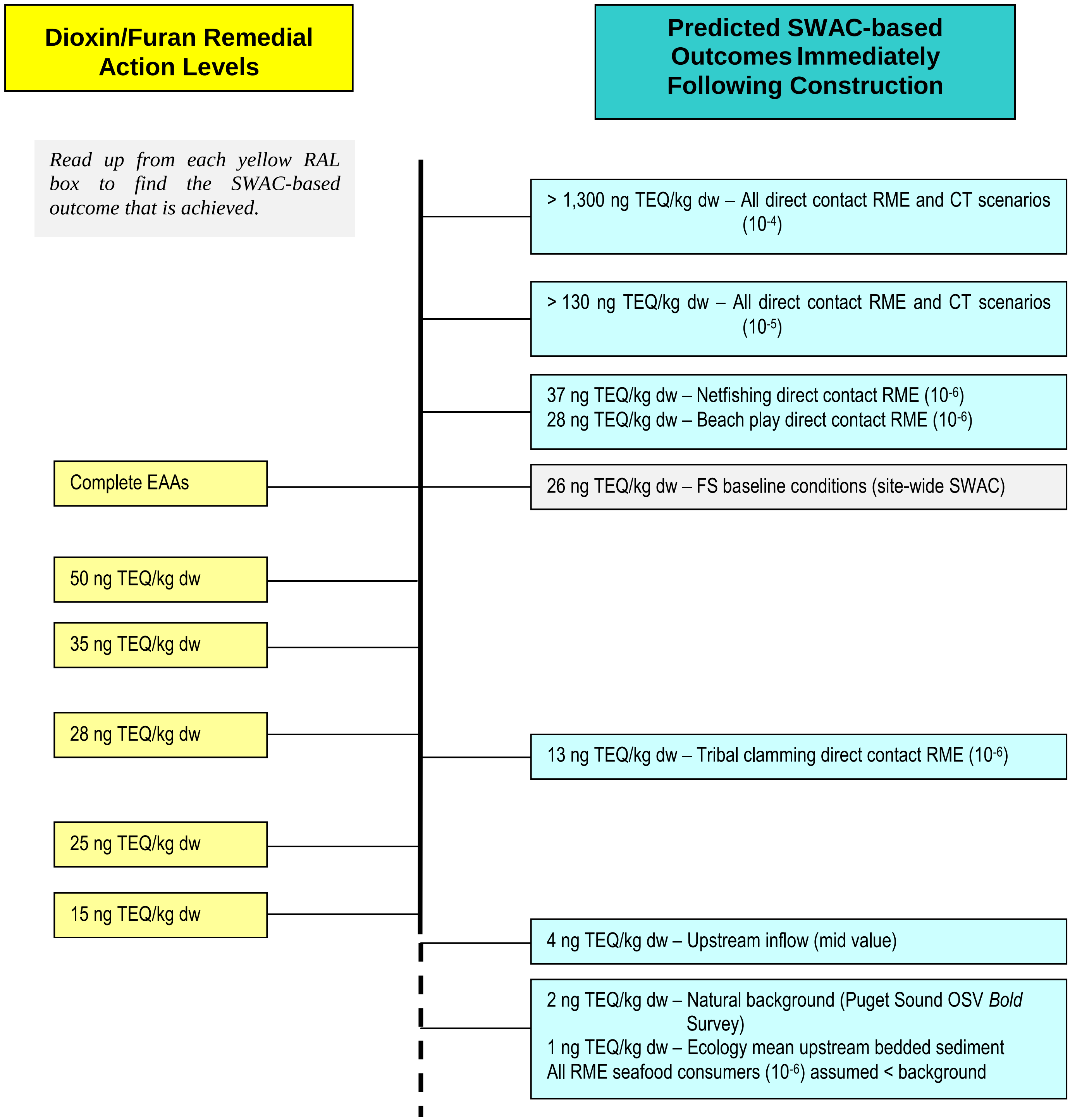
Figure 6-2c cPAH Remedial Action Levels for Human Health



Notes:
10^{-5} = Risk of 1 additional cancer in 100,000 people over a lifetime; cPAH = carcinogenic polycyclic aromatic hydrocarbon; EAA = Early Action Area; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL = upper confidence limit.

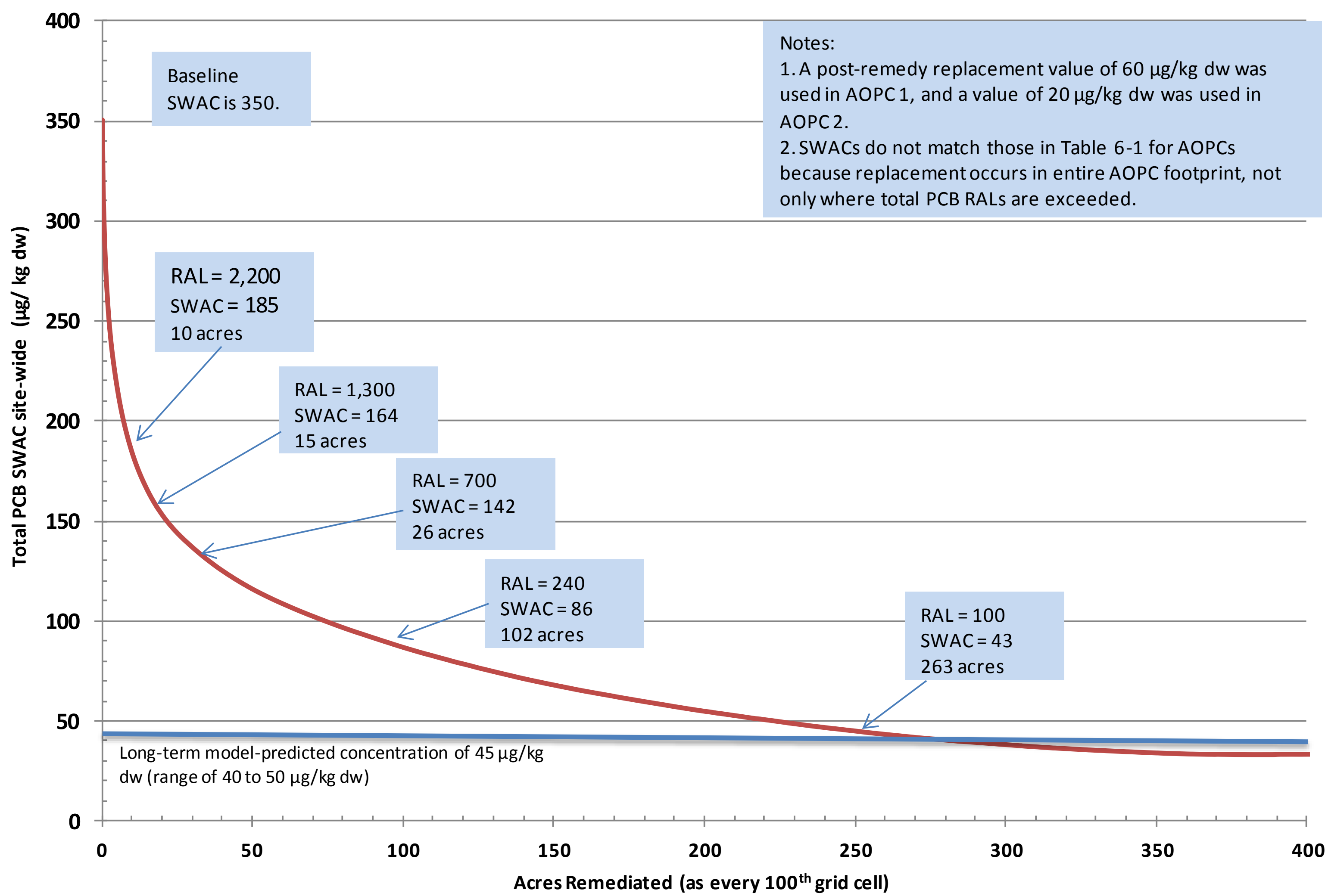
▬ ▬ ▬ ▬ = not achievable

Figure 6-2d Dioxin/Furan Remedial Action Levels for Human Health



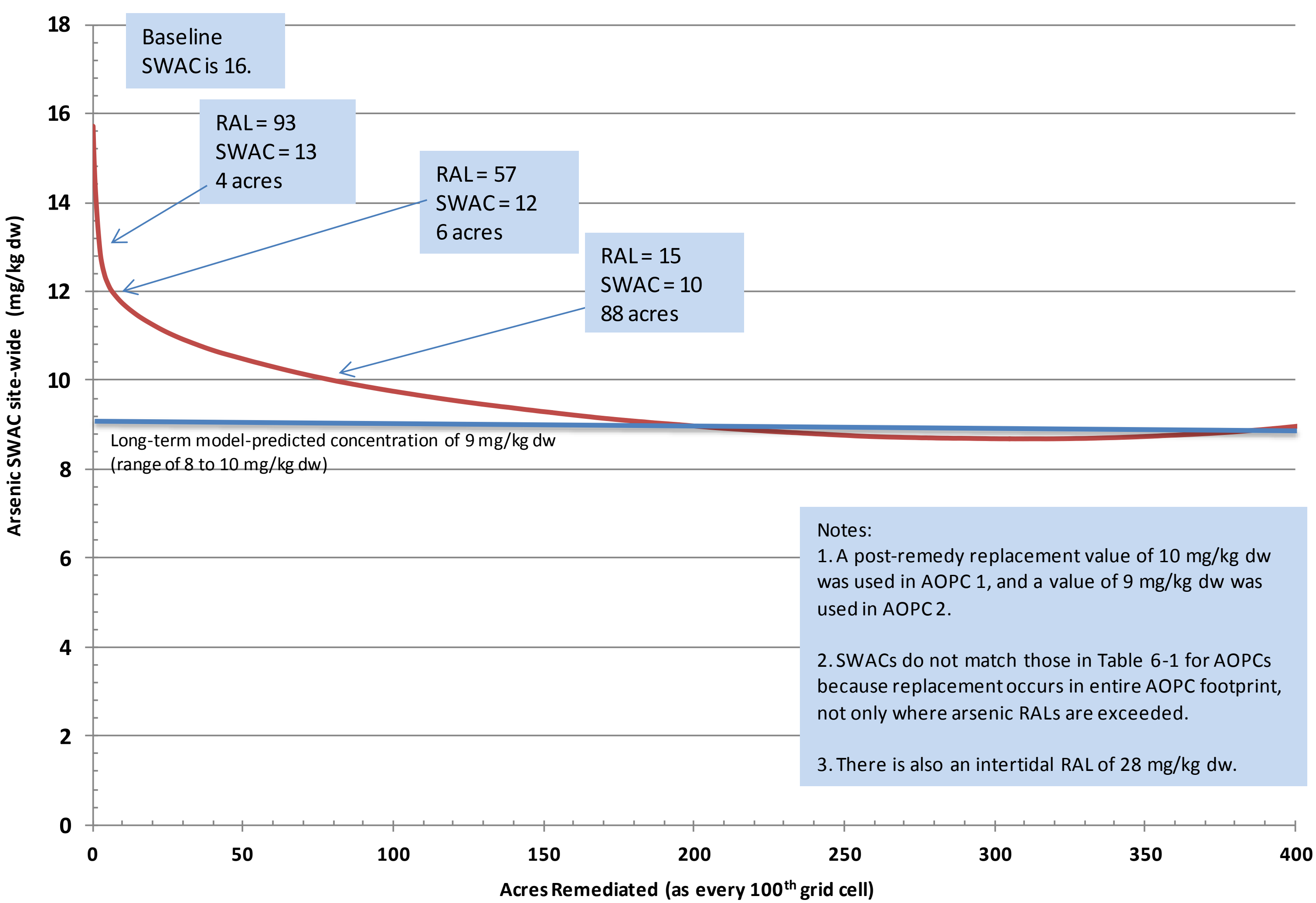
Notes:
10^{-5} = Risk of 1 additional cancer in 100,000 people over a lifetime; CT = central tendency; EAA = Early Action Area; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent.
— — — — = not achievable

Figure 6-3a Site-wide SWACs vs. Remediated Acres – Total PCBs



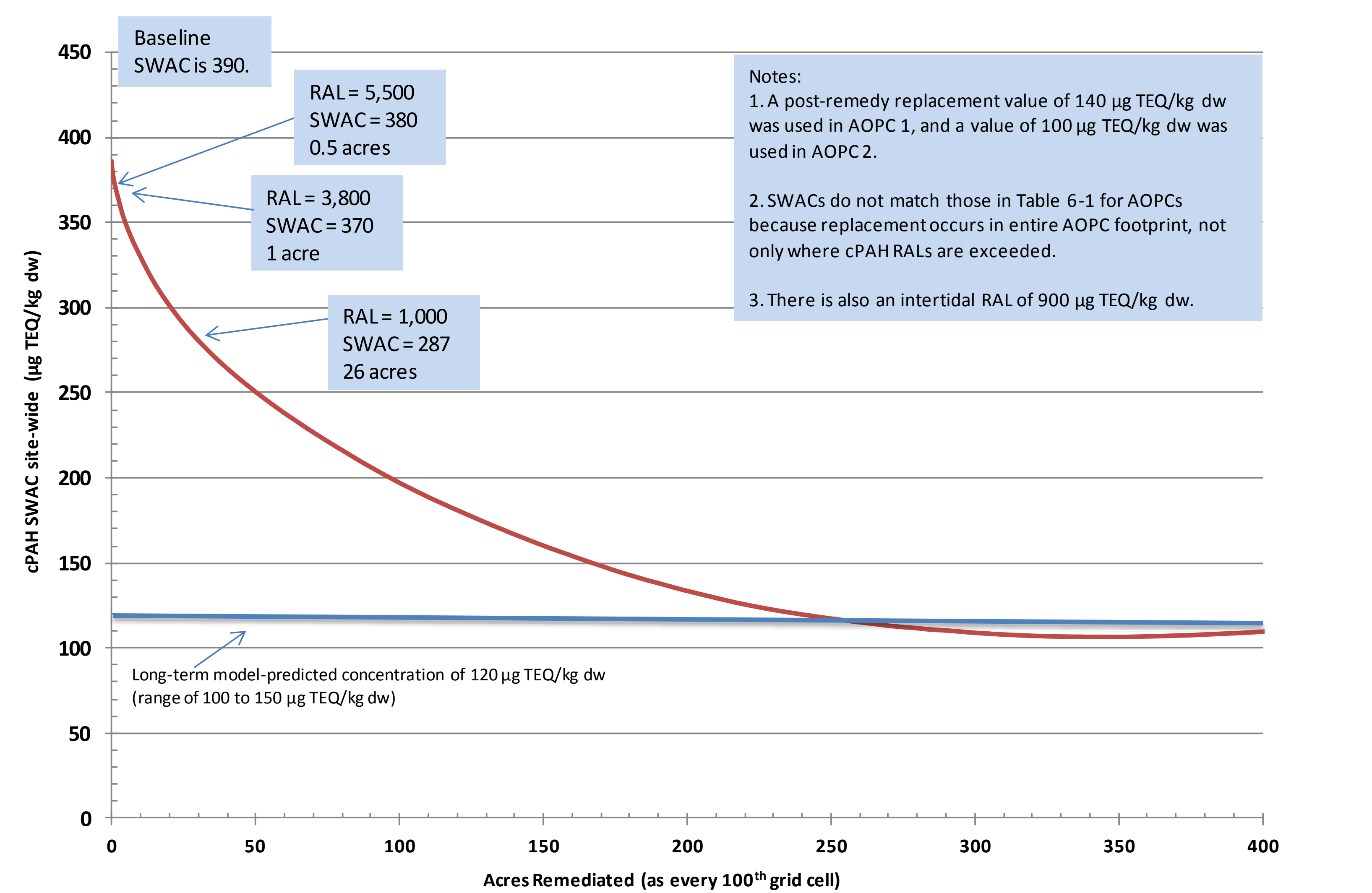
All units are µg/kg dw; RAL = remedial action level; SWAC = spatially-weighted average concentration.

Figure 6-3b Site-wide SWACs vs. Remediated Acres – Arsenic



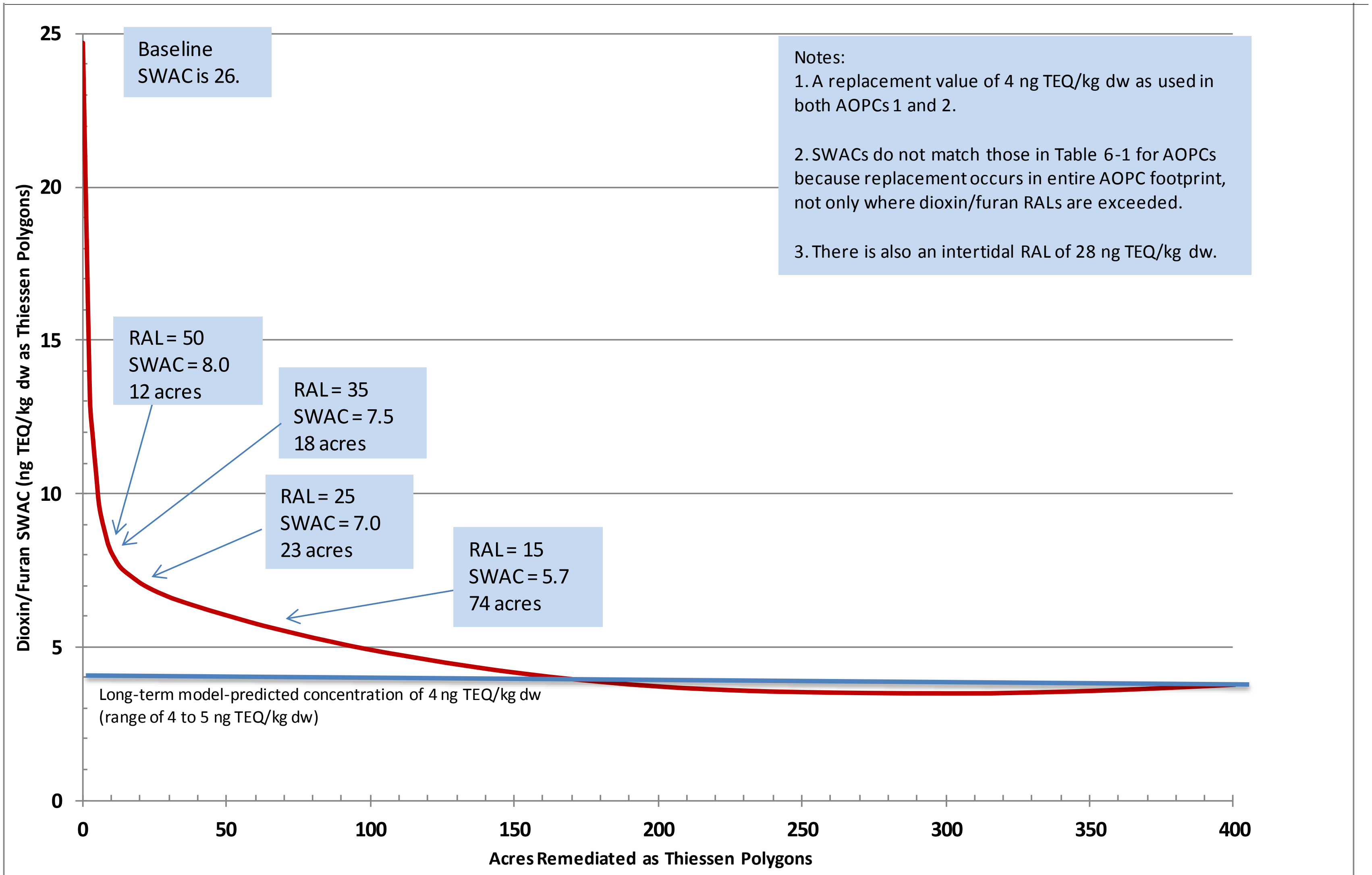
All units are mg/kg dw; RAL = remedial action level; SWAC = spatially-weighted average concentration.

Figure 6-3c Site-wide SWACs vs. Remediated Acres – cPAHs



All units are µg TEQ/kg dw; RAL = remedial action level; SWAC = spatially-weighted average concentration.

Figure 6-3d Site-wide SWACs vs. Remediated Acres – Dioxins/Furans



All units are ng TEQ/kg dw; RAL = remedial action level; SWAC = spatially-weighted average concentration.

Legend

Recovery Category

- Category 1: Recovery Presumed to be Limited (77 acres)
- Category 2: Recovery Less Certain (44 acres)
- Category 3: Predicted to Recover (281 acres)
- Early Action Area (29 acres)
- Outfall Location
- River Mile Marker
- Navigation Channel

Feet: 0 200 400 800

Notes:
1. See Table 6-3 for recovery category criteria.
2. The entire FS study area downstream of RM 4.75, except the EAAs, is grouped into recovery categories (402 acres).
3. Surface sediment concentrations are evaluated separately (during technology assignments).
An area may be remediated because of elevated COCs regardless of the recovery category.

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Lower Duwamish Waterway Final Feasibility Study 60150279-14.38			**Recovery Categories**
DATE: 10/31/12	DWRN:de/SEA	Revision: 0	**FIGURE 6-4a**

Legend

Recovery Category

- Category 1: Recovery Presumed to be Limited (77 acres)
- Category 2: Recovery Less Certain (44 acres)
- Category 3: Predicted to Recover (281 acres)
- Early Action Area (29 acres)
- Outfall Location
- River Mile Marker
- Navigation Channel

Feet
0 200 400 800

Natural Recovery Empirical Data

- Resampled Surface Sediment Location Total PCBs
- Resampled Surface Sediment Location Other Risk Drivers
- Top Two Intervals in Cores Total PCBs
- Top Two Intervals in Cores Other Risk Drivers
- Below SQS
- Data that do not Support Recovery (≥50% Concentration Increase)
- Data that Support Recovery (≥50% Concentration Decrease)
- Station in Equilibrium or Mixed Result

Notes:
1. Resampled surface sample locations include data trumped from both the RI and FS datasets.
2. See Table 6-3 for recovery category criteria and Table 6-4 for the methodology used to evaluate the empirical contaminant trends.
3. Only detected risk drivers exceeding the SQS were evaluated for concentration trends.
4. Mixed results can occur at a location when the risk drivers other than total PCBs do not all have the same trend (mixture of increase, decrease, and/or equilibrium).

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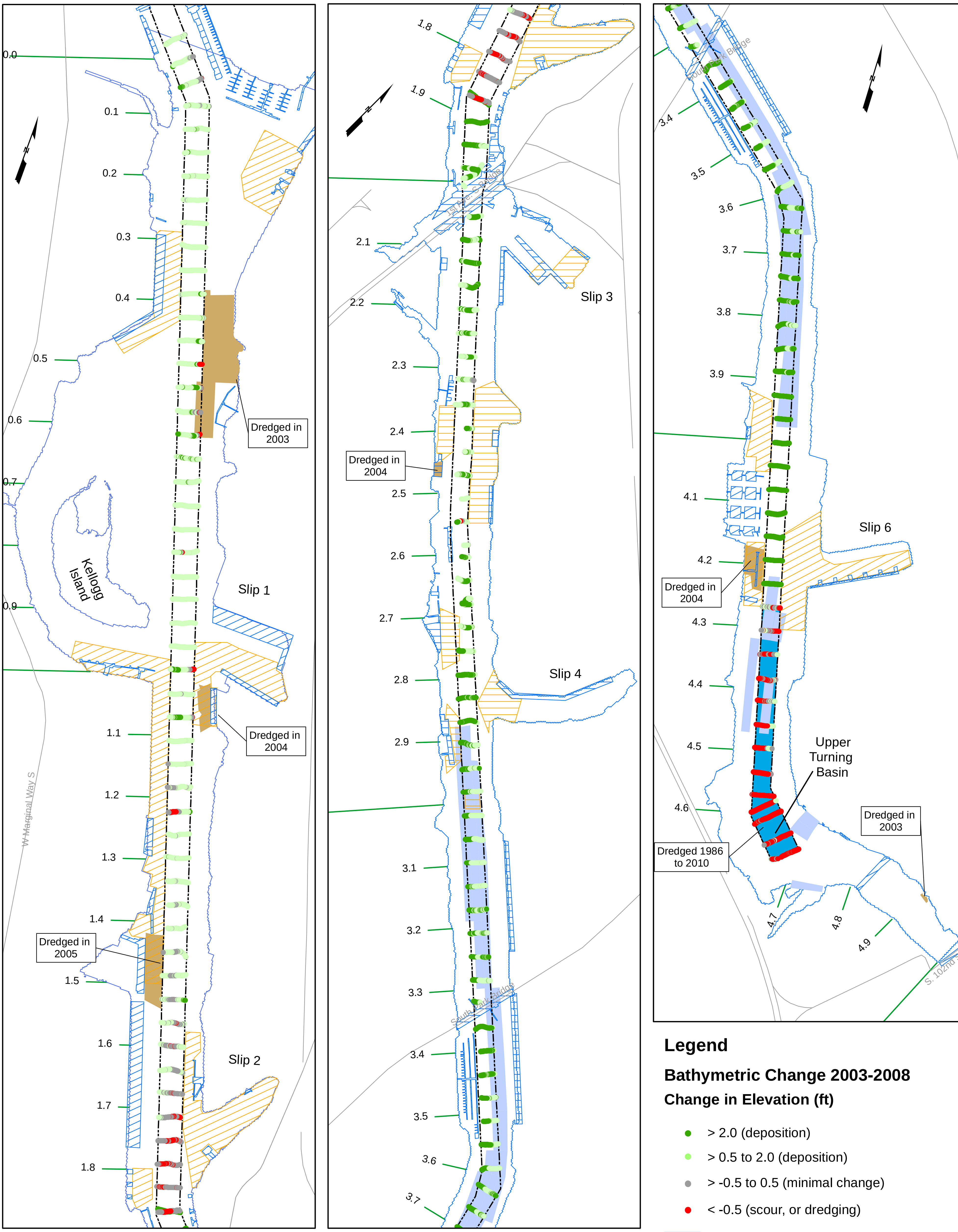
60150279-14.38

DATE: 10/31/12 | DWRN:de/SEA | Revision: 1

Recovery Categories and Empirical Contaminant Trends

FIGURE 6-4b



Dredge Event Post 2002

- USACE Dredge Event
- Private Dredge Event

Legend

Bathymetric Change 2003-2008

Change in Elevation (ft)

- > 2.0 (deposition)
- > 0.5 to 2.0 (deposition)
- > -0.5 to 0.5 (minimal change)
- < -0.5 (scour, or dredging)

- STM Predicted High-flow Scour > 10 cm
- Overwater Structure
- Evidence of Propeller Wash Scour
- Road
- Navigation Channel
- River Mile Marker

Notes:
1. 2008 bathymetric data from USACE in point format sounding. The survey was completed in 09/25/08.
2. Site-wide October 2003 bathymetric data in grid format from David Evans and Associates.
3. 2003 grid data were extracted into the 2008 points and the difference in elevation calculated.
4. Maximum scour depths from 100-year high-flow data dated June 2008 (QEA 2008).

Feet
0 200 400 800

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Lower Duwamish Waterway Final Feasibility Study 60150279-14.38			**Bathymetric Change in Navigation Channel between 2003 and 2008**
DATE: 10/31/12	DWRN:de/Sea	Revision: 1	**FIGURE 6-5**

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7 Identification and Screening of Remedial Technologies

This section identifies and screens remedial technologies consistent with the U.S. Environmental Protection Agency's (EPA) *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988). This step toward development of the remedial alternatives parallels and is consistent with Washington State's remedial investigation and feasibility study requirements, Washington Administrative Code (WAC) 173-340-350.

The technology screening for the Lower Duwamish Waterway (LDW) was originally completed and issued as the *Candidate Technologies Memorandum* (CTM; RETEC 2005). The CTM identified and screened a comprehensive set of general response actions, technology types, and process options that are potentially applicable to cleanup of contaminated sediments in the LDW. These three categories or tiers provide a systematic structure and method to identify and evaluate various physical, chemical, and administrative "tools" available for implementing remedial actions. General response actions describe in very broad terms the types of actions potentially applicable to cleanup of contaminated media. Each general response action may contain one or more technology type. For example, one general response action is physical removal of contaminated materials from the site, and two common technologies that can accomplish sediment removal are dredging and excavation. Process options are a further subdivision or tier in the technology screening procedure, and define the specific type of equipment used within a technology. For example, dredging may use a clamshell dredge, hydraulic dredge, or upland-based excavation equipment, such as backhoes.

The CTM evaluated remedial technologies and process options that could be carried forward for additional consideration in the FS. The screening evaluation was conducted using the effectiveness, implementability, and cost criteria consistent with EPA guidance (EPA 1988). Effectiveness refers to whether or not a technology can contain, reduce, or eliminate contaminants of concern (COCs). Implementability refers to whether a technology can be operated under the physical and chemical conditions of the LDW, is commercially available, and has been used on sites similar in scale and scope to the LDW. The CTM contains complete descriptions of remedial technologies and process options and the supporting literature considered for alternative development in the FS.

In this section, technology recommendations from the CTM (RETEC 2005) are reviewed and updated to account for any recent technology developments or relevant experience at other cleanup sites. The Superfund Innovative Technology Evaluation (SITE) Program, the EPA Hazardous Waste Clean-up Information (CLU-IN) website, and the Federal Remediation Technologies Roundtable (FRTR) were reviewed for recent and relevant information about innovative treatment technologies, including their cost and performance, results of technology development and demonstration, and technology optimization and evaluation. The complete screening process is summarized in tables as follows:

- Table 7-1 lists all of the candidate remedial technologies and process options that were evaluated in the FS process, along with an initial screening for potential applicability. Remedial technologies retained as initially feasible are shaded.
- Tables 7-2a through 7-2e provide the detailed screening of process options shown as "retained as initially feasible" in Table 7-1, which were presented previously in the CTM and were updated to account for any recent technology developments. These tables were also updated to include new technologies reviewed for the FS (e.g., spray cap).
- Table 7-3 summarizes the assessment of the effectiveness, implementability, and relative costs of the retained remedial technologies and process options.
- Table 7-4 provides the technologies and process options carried forward into alternative development as representative technologies and process options.

Finally, this section selects representative, effective, and implementable process options to carry forward for developing remedial alternatives. The selections consider information on past and current sediment remediation projects in the Puget Sound region, elsewhere in EPA Region 10, and nationally where appropriate. Selecting representative process options for the FS is consistent with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) (EPA 1988) and Model Toxics Control Act (MTCA) (Ecology 2001) guidance. Reducing the number of process options does not preclude reexamination of other options during the remedial design/remedial action (RD/RA) phase of the cleanup project. Rather, it is a means to streamline the development and evaluation of the remedial alternatives (as described in Section 8) without sacrificing engineering flexibility. Representative technologies and process options used in the development of alternatives are shaded in Table 7-4.

Section 8 of this FS provides detailed descriptions of the technology types and process options that are assumed for cost estimating purposes under each remedial alternative.

7.1 Review and Selection of Representative Process Options

7.1.1 Dredging and Excavation

Removal is a common and frequently implemented general response action for sediment remediation nationwide and in the Puget Sound region. Mechanical dredging, mechanical excavator dredging, hydraulic dredging, and excavation using upland-based equipment (dry excavation) are the four representative process options available for removing contaminated sediments.

7.1.1.1 Removal Process Options

Mechanical Dredging

A mechanical dredge typically consists of a suspended or manipulated bucket that bites the sediment and raises it to the surface via a cable, boom, or ladder. The sediment is deposited on a haul barge or other vessel for transport to a disposal site. Under suitable conditions, mechanical dredges are capable of removing sediment at near *in situ* densities, with almost no additional water entrainment in the dredged mass and little free water in the filled bucket. Low water content is important if dewatering is required for sediment treatment or upland disposal.

Clamshell buckets (open, closed, hydraulic-actuated), backhoe buckets, dragline buckets, dipper (scoop) buckets, and bucket ladders are all examples of mechanical dredges. Clamshell dredges work best in water depths less than 100 feet (ft) to maintain production efficiency. Nominal bucket capacities (i.e., when full) for environmental applications typically range from less than 1 cubic yard (cy) to 10 cy. Clamshell buckets are most effective in consolidated sediments and are the devices of choice for sediments containing debris.

Environmental buckets, or specialty level-cut buckets, offer the advantages of a large footprint, a level cut, and the capability to remove even layers of sediment. A level-cut bucket reduces the occurrence of ridges and winnows that are typically associated with conventional clamshell buckets. Environmental buckets are effective in unconsolidated sediments. They are not effective when digging in heavier sand or where a significant amount of debris may be present.

Mechanical dredging results in sediment excavation with near *in situ* density (water content), thereby reducing the need for substantial ancillary facilities and equipment to process wet dredged material. Mechanical dredging tends to minimize water entrainment by maintaining much of the *in situ* sediment structure (water entrainment ratio of approximately two parts water to one part dredged sediment). Material tends to be dewatered on the barge and then can be transloaded, transported, and managed at permitted off-site facilities that are authorized to handle wet sediments (these facilities are available to projects in this region). As a result, upland sediment processing and water treatment facilities require less acreage to handle mechanically dredged sediments.

Hydraulic Dredging

Hydraulic dredges remove and transport dredged material as a pumped sediment-water slurry. Large debris is typically removed by clamshell buckets prior to hydraulic dredging of sediments. Then, sediment is dislodged into the water column by mechanical agitation, cutterheads, augers, or high-pressure water or air jets. In very soft sediment, it may be possible to remove surface sediment by straight suction or by forcing the intake into the sediment without first mechanically dislodging the sediment. The majority of the loosened slurry is then captured by suction from pumps into an intake pipe and transported through a dredge discharge pipeline to a handling/dewatering facility.

Hydraulic dredging requires substantial ancillary facility acreage (e.g., approximately 26 acres were utilized for Fox River Operable Unit 1 remediation) and equipment to process dredged sediments (dewatering) and to treat the wastewater before discharge. Hydraulic dredging entrains tremendous volumes of water, typically at 8 to 10 parts water to 1 part dredged sediment. As a result, the upland area requirements to support sediment and water handling for hydraulic dredging are significantly greater than for mechanical dredging to handle the same volume of dredged sediment. In addition, the facilities handling the slurry need to be placed as close as possible to the dredging operations to enable pumping from the site to occur effectively.

Land available to site sediment processing equipment adjacent to the LDW is limited and consists mostly of small parcels (i.e., less than 5 to 10 acres). Areas large enough to site a facility capable of dewatering hydraulically dredged sediment with meaningful dredging production rates are not available. Hydraulic dredging may be viable for location-specific circumstances where the total volume of water generated is relatively small and controllable.

A prime example is using a diver-operated, hand-held, hydraulic dredge to remove materials under or around piers, pilings, or in other under-structure places where conventional dredging equipment is unable to reach. Using this technology, an otherwise unreachable location may be feasible to dredge, depending on circumstances. However, one must consider the diver’s limited visibility, the overall safety of the diver potentially exposed to physical hazards and resuspended contaminants, and the reduced production rate compared to overall project volume requiring removal. As with other hydraulic dredges, the presence of debris limits the effectiveness of a diver-operated hydraulic dredge. Because under-pier areas typically include riprap and debris, incomplete removal of contaminated sediments can be expected even with a diver-operated hydraulic dredge, and thus capping would likely still be required following dredging.

Dry Excavation

Dry excavation using barge-mounted or upland-based precision excavators refers to the removal of sediments in the absence or limited presence (e.g., a few feet) of overlying water. This involves removing intertidal sediment under naturally-occurring low-tide (exposed) or shallow-water conditions. The fixed-arm, articulated arrangement of the precision excavators pushes the bucket into the sediment to the desired cut level without relying on the weight of the bucket for penetration. Engineered dewatering of an excavation area can also be undertaken to enable dry excavation. Dewatering methods include the use of earthen dams or sheet piling, often in combination with dewatering pump operations.

Upland-based removal of sediment using precision excavators can be employed on exposed shoreline and intertidal areas during low-tide conditions where access is feasible. To avoid the need for extensive upland dewatering treatment facilities, this FS assumes that upland-based excavation is limited to elevations above –2 ft mean lower low water (MLLW) during low-tide conditions, and where access is practicable.

7.1.1.2 Dredge Residuals

All in-water removal operations result in the release of a portion of the contaminants in the material being dredged and will leave behind some level of residual contamination in the sediment after dredging is complete (USACE 2008a). Resuspension of sediments occurs when a dredge and associated operations dislodge bedded sediment particles and disperse them into the water column. These resuspended sediments either settle back near the point of dredging (known as "residual" contamination), or are transported by currents farther afield (known as "release"). Releases also occur as a result of dissolution of contaminants into the water column and, in some cases, through volatilization. Resuspension during dredging is affected by factors such as the type and size of dredging equipment, level of operator skill, positioning of equipment used during dredging, dredge sequencing, depth of dredge cut, type and volume of debris encountered, and the substrate type and bottom topography. Resuspension, residuals, and releases can be estimated and monitored.

Resuspension, releases, and residual contamination can result from various causes that can be grouped into two categories:

- Undisturbed residuals are contaminated sediments found at the post-dredging surface that were not fully removed. The causes of undisturbed residuals include:
  - Incomplete characterization of depth-of-contamination in the remedial design, resulting in previously undocumented contaminated sediment being left in place.
  - Inaccuracies in meeting target dredge design elevation, resulting in contaminated sediment being left in place.
  - Furrows or ridges created by incomplete horizontal removal also leaving contaminated sediment in place.
- Generated residuals are contaminated post-dredging surface sediments that are dislodged or suspended by the dredging operation and subsequently redeposited on the bottom of the water body. Causes include:
  - Material resuspended by the bucket (mechanical dredging) during its bite or by the dredge cutterheads (hydraulic dredging) during its pass.
  - Material resuspended outward by the auger or cutterhead beyond the influence of the pump suction and left behind.

- Vertical positioning of the auger or cutterhead at too great of a cut depth, resulting in material riding over the dredge head.
- Material adhering to the outside of the bucket and washed off on its upward travel through the water column, then settling back down to the bottom.
- Material dripping from a partially closed or overfilled bucket on its upward travel through the water column, then settling back down to the bottom.
- Turbid flow or sloughing of material from steep cut banks spreading sediment from adjacent areas on top of areas where dredging was completed.
- Release of sediment contaminants dissolved in porewater when sediment is disturbed during dredging.

The nature and extent of dredging residuals dislodged or suspended by a dredging operation are not easily predicted. Most projects have based their post-dredging residual concentration by monitoring a specified surficial sediment thickness (e.g., 0 to 10 centimeters [cm] below mudline). By comparing the monitored thickness to the average concentration in the final production cut profile, it is possible to estimate the amount of residuals that will be generated by the project (USACE 2008a). Palermo and Patmont (2007) performed mass balance calculations for 11 project sites, estimating that generated residuals represented approximately 2 to 9% of the mass of contaminant dredged during the last production cut. The available data suggest that multiple sources contribute to generated residuals, including resuspension, sloughing, fall back, and other factors. However, on a mass basis, sediment resuspension from the dredge operations appears to explain only a portion of the observed generated residuals, suggesting that other sources such as cut slope failure and sloughing could be quantitatively more important.

The study also indicated that the presence of hardpan/bedrock, debris, and relatively low dry density sediment results in higher generated residuals.

Numerous case studies have shown that the spatial extent of dredge residuals can extend beyond the footprint of the dredge prism. For this reason, residuals monitoring and management provisions will be included in the remedial design phase that address adjacent areas as well as the dredge prism.

Dredge monitoring studies conducted over the last 13 years have estimated the rate of resuspension at 2 to 5% of polychlorinated biphenyls (PCBs) by mass downstream (or as residuals) compared to the mass of material contained in a dredge prism. Most of the release is in the bioavailable dissolved form (USACE 2008a; TetraTech 2010a, Fox River; Connolly 2010, Hudson River; Steuer 2000; Anchor QEA and ARCADIS 2010). Some loss of material is expected at all dredging sites regardless of the specific dredging process options, engineering controls (e.g., silt curtains, barriers), and best management practices used during dredging. Estimates of sediment export downstream of the LDW from resuspension during dredging are presented in Section 9.1.2.3 and Appendix M, Part 2.

7.1.1.3 Recent Developments in Dredge Positioning Technology

Recent introduction and widespread use of real-time kinematic differential global positioning systems (RTK–DGPS), coupled with radio telemetry and data logging technology, have greatly improved the accuracy and operational flexibility of mechanical dredging. The latest generation of precision dredge and bucket guidance systems integrate RTK-DGPS, excavator and bucket inclinometer sensors, vessel motion sensors, electronic heading, and tide data to enable dredging accuracy generally to within less than 6 inches. Dredge operators are now able to visualize the location of the bucket cutting edge in relation to the target elevation, the bucket open/close status, and the horizontal position of the bucket through use of these advanced positioning and monitoring systems.

7.1.1.4 Dredging and Excavation Technology Summary

Mechanical dredging and excavation, the most commonly practiced forms of sediment removal in the Puget Sound region, are adopted in this FS as the representative primary removal process options for in-water work. Dry excavation using conventional earth-moving equipment is also retained for use in intertidal and embankment areas, but it is expected to be implementable only for a low percentage of the removal volume because of access limitations.[1] Representative dredging projects in the Puget Sound region are identified in Table 7-5. As shown in Table 7-5, approximately 90% of the projects completed in the Puget Sound region adopted mechanical dredging during implementation.

Mechanical dredging and excavation were selected as the primary in-water removal technologies because several factors within the LDW favor these over hydraulic dredging:

- The LDW is a working industrial waterway and significant amounts of debris may be present in the sediments, the result of approximately 100 years of commercial and industrial activity. The presence of debris is a significant problem for hydraulic dredging. Although mechanical dredging is also adversely affected by debris, it is better suited to manage and accommodate debris removal.

[1] Details regarding the range and type of dredge equipment available within the local/regional construction community are presented in Section 8 and Appendix I. Cost estimates prepared and presented in Appendix I are based on mechanical dredging, and barge-mounted excavators.

- Two Subtitle D landfills in the region are permitted to accept wet sediment generated from mechanical dredging (see Section 7.1.3), thereby avoiding the need to dewater mechanically dredged solids.
- The environmental dredging literature contains no documented quantitative evaluations that distinguish between the resuspension and recontamination characteristics of mechanical and hydraulic dredging under other than ideal debris-free site conditions (USACE 2008a).

The assumption of mechanical dredging and excavation for development of remedial alternatives does not preclude other options from being considered during remedial design.

For the FS, partial dredging (diver-operated hydraulic dredging) and capping are assumed as the representative primary process option for under-pier work (see Section 7.1.4) because full removal of contaminated sediment is often difficult in these areas. Under-pier areas have limited access, limited maneuverability, accumulated debris, and riprap structures. This assumption does not preclude other process options from being considered during remedial design. For example, a design decision could be made to remove a pier deck to allow access for mechanical excavation or capping, or to adopt diver-operated hydraulic dredging, or to apply a spray cap.

7.1.2 Treatment Technologies

Treatment technologies can potentially be applied to in-place sediment (*in situ* treatment) or to sediment after it has been physically removed from the aquatic system (*ex situ* treatment). The CTM (RETEC 2005) presented a detailed evaluation of treatment technologies and their applicability for sediment cleanup in the LDW. This section provides updated information about innovative technology developments and relevant experience at other cleanup sites. The CTM also reviewed the extensive regulatory and industry efforts in Washington State and elsewhere to determine the viability of treatment in the context of centralized sediment management facilities. The following discussion reviews viable *in situ* and *ex situ* treatment approaches and their applicability to the LDW.

In situ treatment options with potential applicability to the LDW are physical immobilization by amendment of materials to enhance sorption capacity of the natural sediments. To date, *in situ* treatment of sediments has been mostly by amendment of activated carbon or organoclays in pilot and full-scale sediment remediation projects.

In situ treatment techniques are less energy-intensive, less expensive, and less disruptive to the environment than conventional treatment technologies, and they can reduce ecosystem exposure by binding contaminants to organic or inorganic sediment matrices. The contaminant sorption capacity of natural sediments may be modified and enhanced by adding such amendments as activated carbon for adsorption of non-polar organics and certain metals such as mercury (various activated carbon products are available as powder, granules, or pellets, each with different sediment application characteristics); natural minerals such as apatite, zeolites, or bauxite and refined minerals such as alumina/activated alumina for sequestration of metals/metalloids; ion exchange resins (organoclays) for replacement of metals/ inorganic contaminants with amines or other functional groups; zero-valent iron for dechlorination of PCBs; and lime for pH control or degradation of nitroaromatic compounds. Multifunctional amendment blends may also be used to address complex contaminant mixtures in sediments, and subsequently may enhance overall sorption capacity. Usually activated carbon serves as the backbone (for hydrophobic partitioning) and either is impregnated with the target amendment or blended in a briquette-like composite using an appropriate and non-toxic binder (e.g., clays or other binder materials; Ghosh et al. 2011). Amendments can be engineered to facilitate placement in aquatic environments, by using an aggregate core (e.g., gravel) that acts as a weighting component and resists resuspension, so that the mixture is reliably delivered to the sediment bed, where it breaks down slowly and mixes into sediment by bioturbation.

One of the most advanced *in situ* treatment technologies in terms of its state of development is amending sediment with activated carbon. This treatment has the effect of adsorbing hydrophobic contaminants, reducing porewater contaminant concentrations, and reducing their bioavailability for uptake by benthic organisms. Direct placement of activated carbon to sediments has now been demonstrated in a wide range of bench-scale and pilot studies, and successfully deployed in large field efforts with promising documented monitoring results (Ghosh et al. 2011). Activated carbon has proven effective in reducing the bioavailability of a range of sediment contaminants, including PCBs, polycyclic aromatic hydrocarbons (PAHs), dioxins, DDT, and mercury. However, while the pilot studies are starting to provide valuable information, further research is needed to understand both transient and long-term changes that take place naturally in the environment, and also demonstrate the application of activated carbon at full-scale contaminated sediment areas. Further discussion of this technology is presented in Section 7.1.2.1.

Ex situ treatment options with potential applicability to the LDW are conventional soil washing/particle separation, advanced soil washing (Biogenesis™), solidification, and thermal treatment. To date, *ex situ* treatment of sediments, while a subject of considerable interest nationwide, has been mostly limited to soil washing and air (steam injection) stripping in full-scale sediment remediation projects.

Technologies that destroy or detoxify contaminants have been accepted at very few projects (e.g., Bayou Bonfouca) for cleanup at contaminated sediment sites for two reasons. First, it is difficult to balance treatment costs with a beneficial reuse outlet for the material; and second, upland and in-water disposal alternatives are much less expensive, particularly in this region. With the exception of the addition of cement-type materials to reduce free water content and mobility prior to upland disposal, only one contaminated sediment remediation project in this region (Area 5106 at Hylebos

Waterway in Commencement Bay) has utilized treatment (see Section 7.1.2.2) or incorporated beneficial reuse of treated sediments.[2]

7.1.2.1 Direct Amendment with Activated Carbon or Organoclays

The goal of *in situ* treatment, by amending or thin capping the bioactive surface layer of sediment, is to reduce the bioavailability of hydrophobic organic contaminants. The two most common material classes for amendment are activated carbon and organoclays. The transfer of organic contaminants such as PCBs from the sediment to the strongly binding activated carbon particles not only reduces contaminant concentration and the bioavailability to benthic organisms but also reduces contaminant flux into the water column, and thus accumulation of contaminants in the aquatic food-chain (Ghosh et al. 2011). Of the two amendments, activated carbon has received more testing and evaluation than organoclays, particularly with respect to sediment remediation, because the sorption capacities for PCBs and PAHs in activated carbon are at least an order of magnitude higher than in the other sorbents (Ghosh et al. 2011). Organoclays have received attention largely in the context of addressing localized deposits of dense non-aqueous phase liquids (DNAPLs; Bullock 2007, Reible and Lampert 2008).

Extensive bench-scale studies have confirmed the effectiveness of activated carbon for *in situ* treatment. For example, average doses of 2 to 4% (by dry sediment weight) of activated carbon applied to surface sediments have resulted in reductions greater than 95% in PCB bioavailability and sorption capacities of the activated carbon have been retained for as long as the bench-scale studies were continued (up to 10 years in some studies). Based on promising laboratory results, beginning in 2006, several pilot-scale field demonstrations of activated carbon placement were implemented in the United States and Norway (see Figure 7-1). These projects show how various engineering challenges were met for applying activated carbon and monitoring of its long-term effectiveness:

- Hunter's Point Naval Shipyard (San Francisco, CA), conducted in 2006, in estuarine application to address PCBs and PAHs
- Lower Grasse River (Massena, NY), conducted in 2006, in freshwater application to address PCBs
- Trondheim/Grenlandsfjords Harbors (Norway), conducted in 2006, in estuarine application to address PCBs, PAHs, and dioxins
- Grenlandsfjords Harbors (Norway), conducted in 2009, in estuarine application to address dioxins and furans

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[2] Treatment to eliminate free liquids from dredged sediment is no longer required by two regional landfills servicing the Puget Sound area (see Section 7.1.3.2).

- ♦ Bailey Creek, U.S. Army Installation (VA), conducted in 2009, in freshwater wetland application to address PCBs
- ♦ Canal Creek (Aberdeen Proving Grounds, MD), conducted in 2010, in freshwater application to address mercury, PCBs, and DDT.

The primary objective of these demonstration projects was to verify that the bioavailability of PCBs, PAHs, DDT, dioxins/furans, and/or mercury can be effectively reduced at the field scale by placing activated carbon into surface sediments. While the specific approaches varied for each pilot project listed above, most of the projects focused on the following:

1) Evaluate efficient, low-impact delivery systems of activated carbon for amendments into in-place sediments (using large-scale equipment and a range of application methods).

2) Determine the extent of sediment resuspension and contaminant release during application.

3) Assess persistence, binding potential, and small-scale spatial variations of the activated carbon after application to sediments in the natural environment, and also assess mixing of activated carbon over time as a result of bioturbation processes.

4) Evaluate short- and longer-term changes in contaminant porewater concentrations, sediment-to-water fluxes, desorption kinetics, and/or equilibrium partitioning from sediments that result from activated carbon amendment.

5) Measure short- and long-term changes in contaminant bioavailability by biomonitoring deposit-feeding benthic organisms after applying the activated carbon amendment.

6) Evaluate activated carbon-sediment stability and erosion potential over time.

7) Evaluate contaminant bioavailability for uptake, transfer, or any changes to the benthic and/or submerged aquatic plant communities, as a result of activated carbon amendment.

Several types of activated carbon applications were evaluated at these sites, including slurry amendment (water and/or native clay mixtures) on top of the sediment surface, mixing or injection of slurry amendments into surface sediments, and pelletized applications (e.g., SediMite®, AquaBlok®).

The period over which ENR/*in situ* treatment remains effective will be an important consideration during remedial design. Design life will need to be evaluated at the location-specific level and will likely influence decisions on the type (e.g., source and type of carbon), amount of amendment used (i.e., design safety factor), and the potential need for replenishment. Physical stability and chemical activity (e.g., adsorption capacity) over the long term are the most important design life factors. Activated carbon and other charcoals created under high-temperature conditions are known to persist for thousands of years in soils and sediments, and both laboratory studies and modeling evaluations indicate promising long-term physical stability of the amendment material and chemical permanence of the remedy (Ghosh et al. 2011). Empirically-derived contaminant concentration data and modeling simulations show that *in situ* treatment can reduce bioavailability over the long term where contaminant loading (mass transfer) from groundwater, surface water, and newly deposited sediments is low.

The FS assumes that half of the ENR footprint would warrant amendment with a material such as activated carbon for *in situ* treatment. This assumption provides a basis for estimating costs and comparing the remedial alternatives; however, during remedial design, the emphasis on ENR or *in situ* treatment will depend on location-specific factors and additional testing of the implementability of these technologies. The composition of ENR/*in situ* treatment will depend on additional evaluation during remedial design; it may include carbon amendments, habitat mix, and/or scour mitigation specifications to increase stability and enhance habitat.

The following sections provide synopses of two of the most relevant field demonstrations.

Hunter's Point Naval Shipyard (San Francisco, California) – Carbon Amendment
Beginning in January 2006, a large field demonstration of activated carbon via direct amendment was conducted in a shallow tidal flat of the South Basin adjacent to the former Naval Shipyard at Hunters Point, in San Francisco Bay (CA) (Luthy 2005, Luthy et al. 2009, Cho et al. 2009). The former Navy installation was predominantly used for ship repair and maintenance, which resulted in the release of PCBs to the environment. The activated carbon was applied to two test plots (D and F) with a surface area of 34.4 m^2 each, located within the intertidal region of the former shipyard, and away from the shoreline. Two more plots (C and E) served as control and reference plots. A barge-mounted rotovator system (for plot D) and a crawler-mounted slurry injector system (for plot F) were used to mix activated carbon directly into the surface sediments at a target mixing depth of 30 cm below the mudline, to include the biologically active zone.

Baseline and post-amendment monitoring field assessments were conducted in December 2005, July 2006, July 2007, and January 2008, respectively. These assessments were performed to characterize surficial sediment concentrations, analyze the water column, test uptake, and study bioaccumulation. Prior to treatment, the PCB concentration in sediment among the plots varied between 1,350 and 1,620 micrograms per kilogram dry weight (µg/kg dw). Mixing of activated carbon into surface sediments was assessed using black carbon measurements. The measured activated carbon dose averaged 2.0 to 3.2% by dry sediment weight and exhibited small-scale spatial variability. The uneven activated carbon distribution was possibly induced by the unidirectional mixing motion of the large mechanical mixing devices, the relatively small dimensions of the test plots, and insufficient mixing time. In terms of variability, Plot F showed higher variability than Plot D, indicating that activated carbon-mixing via the slurry injection device on Plot F was less homogeneous than the rotovator device employed at Plot D. Ineffective homogenization of the activated carbon into the sediment would influence the short- and long-term performance of the technology.

No adverse impacts, such as sediment resuspension and PCB release, were observed in the water column over the treatment plots as a result of applying the activated carbon and mechanically mixing it into the sediments. In addition, the activated carbon amendment did not impact the structure of the macro benthic community (composition, richness, or diversity) (Luthy et al. 2009, Cho et al. 2009).

Both *in situ* clam bioassay and *ex situ* bioavailability for uptake studies confirmed that PCB bioaccumulation was reduced; an approximate 78% tissue concentration reduction in bioavailability was achieved when clams were exposed to sediment treated with an average 3.4% activated carbon. Although the *in situ* bioassay results were sometimes influenced by field conditions resulting from newly deposited sediment, heat stress, and shallow burrowing depth, the reduction in bioavailability was consistent with the results of earlier laboratory studies (Millward et al. 2005; McLeod et al. 2007, 2008). Reductions in congener bioaccumulation with activated carbon were inversely related to the congener octanol-water partitioning coefficient (K_{ow}), suggesting that the efficacy of activated carbon is controlled by the mass-transfer rate of PCBs from sediment into activated carbon (Millward et al. 2005). The semi-permeable membrane devices (passive samplers) were used to show that PCB uptake in activated carbon-treated sediment was reduced by 50%, with similar results in porewater. This reduction was evident 13 months post-treatment and even after a subsequent 7 months of continuous exposure, indicating activated carbon treatment efficacy was retained for an extended period (Cho et al. 2009). Although reductions in aqueous PCB concentrations in equilibrium with the sediment following activated carbon-amendment often correlate with reduced PCB bioaccumulation, the reduced availability of contaminants from ingestion of sediments appeared to be the actual cause of lower tissue concentrations (Janssen et al. 2010, 2011).

The two activated carbon-treated plots showed decreases in the fraction of PCBs desorbed with an increasing dose of activated carbon, which supports the finding of reduced PCB availability after activated carbon application. After 18 months, the field-exposed activated carbon demonstrated a strong stabilization capability to reduce aqueous equilibrium PCB concentrations by almost 90%. These results are promising and suggest the long-term effectiveness of activated carbon in the field (Luthy et al.

2009, Cho et al. 2009). Finally, based on the absence of significant differences between the 6-month and 18-month total organic carbon (TOC) values measured in cross sections of sediment cores taken from Plots D and F for sediment stability testing and based on hydrodynamic modeling, it was concluded that mixing activated carbon into cohesive sediment at selected locations within the South Basin at Hunter's Point neither reduced surface sediment stability nor resulted in significant erosion of treated sediments (Zimmerman et al. 2008). Surficial sediment of the two activated carbon-treated plots contained less black carbon/TOC 24 months after treatment, which was explained by continued sediment deposition.

Lower Grasse River (Massena, New York) – Carbon Amendment

Similar pilot field studies were initiated in September 2006 to evaluate the ability to deliver activated carbon slurries to in-place sediments and assess the effectiveness of this approach in reducing the bioavailability of PCBs in sediments and biota in the Lower Grasse River in Massena (NY). Alcoa Inc., with oversight from EPA, implemented the pilot demonstration project, which began with laboratory studies and land-based equipment testing, continued with field-scale testing of alternative placement methods, and culminated in a field demonstration of the most promising activated carbon application and mixing methods in a 0.5-acre pilot area within the Lower Grasse River (Alcoa 2007, EPA 2007b).

Based on the results of initial laboratory studies that evaluated bioavailability reductions achieved at different activated carbon doses, a target application concentration of 2.5% activated carbon (dry-weight basis) in the top 15 cm of sediment after treatment was used in the Lower Grasse River field demonstration. Three application techniques were implemented within the pilot study area as follows:

- A 7-ft by 12-ft enclosed device first applied (sprayed) the activated carbon slurry onto the sediment surface. The material was then mixed into near-surface (0 to 15 cm) sediments using a rototiller type mechanical mixing unit (tiller).
- A 7-ft by 10-ft tine sled device (tine sled) used direct injection of activated carbon into the upper 15 cm of the sediments.
- Application of activated carbon to the sediment surface using the tiller, but with the mixing devices removed. Monitoring of this "unmixed" treatment area allowed for an evaluation of the rate and extent of incorporation of the surficial layer of placed activated carbon into near-surface sediments over time through natural processes (e.g., bioturbation).

Baseline (summer 2006), construction (fall 2006), and post-construction (2007, 2008, and 2009) monitoring were conducted (Alcoa 2010). Water quality action levels for PCBs (0.065 micrograms per liter [µg/L]) were not exceeded adjacent to or downstream of the pilot project area during activated carbon application. Similarly, turbidity levels during construction never approached the action level of 25 nephelometric turbidity units (NTUs) above background. Turbidity measured downstream of the pilot project area was only slightly higher than that measured upstream, with average turbidity and total suspended solids (TSS) increases of roughly 0.2 NTU and 0.8 milligrams (mg)/L, respectively. The water column monitoring data indicated that construction activities did not have a significant impact on water quality in the river, and further suggested that silt curtains are not needed for either the tine sled or tiller equipment.

Sediment cores were collected immediately following the fall 2006 application and in the three post-construction monitoring years (2007, 2008, and 2009) and were analyzed for black carbon to verify the applied dose. The target dose of 2.5% activated carbon (dry weight basis) in the top 15 cm of sediment was achieved in nearly all test plots. Compared with the tine sled, application of activated carbon using the tiller (with or without mixing) resulted in greater small-scale spatial variability in activated carbon levels.

A detailed 3-year post-implementation physical, chemical, and biological monitoring program (i.e., 2007 through 2009) was completed to evaluate the long-term effectiveness of the activated carbon treatment. Monitoring results are summarized below:

- Measurements of activated carbon levels in the treated sediments (i.e., based on black carbon analysis and microscopy results) confirm that the applied carbon has continued to remain in place. Levels are based on mass balance calculations of activated carbon applied in 2006.

- Most of the activated carbon in the treatment areas was applied within the upper 10 cm of the sediment, declining to background levels at approximately 20 cm below the mudline. The 2008 and 2009 monitoring revealed that the activated carbon was slightly deeper in the sediment profile than observed in 2006 post-construction and 2007 sampling, due to natural sedimentation occurring on top of the activated carbon-treated sediments since 2006.

- PCB bioaccumulation in the tissue of test organisms (whole body worms; wet weight basis) in the activated carbon treatment areas was reduced in excess of 80% for the *in situ* tests and in excess of 90% for the *ex situ* tests. Greater than 90% reductions in porewater PCB concentrations were also observed in the test plots. PCB bioavailability was reduced even further over the 3-year post-construction monitoring period due to a combination of improved mixing (bioturbation) of activated carbon in surface sediments, and site-wide natural recovery over time.

- Batch equilibrium testing to evaluate the effect of activated carbon on PCB partitioning between the sediment and water phases showed reductions in the range of 93 to 99%.

- Two trends were observed in the results from *in situ* passive samplers deployed on top of the treatment areas:
  - Ambient PCB sediment levels declined from 2006 to 2009 (as a result of site-wide natural recovery); and
  - Aqueous PCB concentrations at the sediment surface in the treatment areas decreased by 90% (similar to reductions observed from biological testing), and even in 2009, the treated sediments continued to act as a "sink" for water column PCBs in the river (i.e., net flux of PCBs from surface water to sediments).
- Results of ecological monitoring activities show a benthic community adapted to fine-grained sediments both pre- and post-carbon application. Benthic habitat and community composition measures were similar (not statistically different) between the treatment areas and upstream background locations, suggesting that activated carbon application did not affect the benthic community. Additional studies of potential impacts to submerged aquatic vegetation at high activated carbon doses are ongoing.
- Erosion potential testing indicated that treated sediments had a slightly higher erosion potential than pretreatment sediments, but nevertheless were within the range of historic data for native sediments.

In summary, the Lower Grasse River pilot project demonstrated that activated carbon can be successfully applied to river sediments with minimal impact to water quality within the river. Post-construction monitoring revealed that the activated carbon is stable in the fine sediments and has significantly reduced PCB bioavailability. Batch equilibrium experiments showed that aqueous phase PCB concentrations in surface sediments have been reduced on average by more than 95% at activated carbon doses of 2% or greater. *In situ* and *ex situ* biological uptake studies showed 80 to 90% reductions with an activated carbon dose greater than 2%.

7.1.2.2 Soil Washing with Air Stripping

Soil washing can be classified as conventional or advanced form of *ex situ* treatment. Conventional soil washing is a form of primary treatment that uses conventional and readily-available material handling unit processes to separate sediment particles, typically into coarse (sand and gravel) and fines (silt and clay) fractions (Figure 7-2). This treatment process separates the sediment particles using conventional equipment. These equipment systems have been derived largely from the mining and mineral processing industries, and include screening, gravity settling, flotation, and hydraulic classification (e.g., using hydrocyclones) (USACE-DOER 2000). Advanced soil washing, such as Biogenesis™, combines the physical separation aspects of conventional soil washing with additional treatment such as agitation, or the addition of surfactants, chemical oxidants, or chelating agents to the finer fraction of material.

Soil washing is a wet process and therefore generates wastewater that requires treatment and discharge. Depending on site conditions, the washed coarse fraction may be suitable for in-water placement (see Section 7.1.3.4 for beneficial uses of sediment) as a cap, enhanced natural recovery (ENR), or habitat creation/restoration medium. The finer fraction, which has higher concentrations of contaminants, is typically dewatered, transported, and disposed of in a permitted upland landfill. Ideally, the net outcome of soil washing is a reusable coarse fraction and a reduced volume of contaminated material requiring additional treatment or direct disposal.

Sediments in portions of the LDW may be sufficiently coarse-grained to consider soil washing as a potentially viable treatment. One vendor has indicated that soil washing has the potential to be economical where the sediment contains greater than 30% sand (Boskalis-Dolman 2006). When the sediment contains less than 30% sand, treatment performance and economics deteriorate. Other factors affecting the economics and implementability of soil washing are:

- Physical and chemical properties of the sediment.
- Availability of an upland location for transloading sediment from barges.
- Availability of an upland location for sediment containment, storage, and operation of the soil washing facility. Although this facility may or may not be located at the transloading facility, this FS assumes that it will be located within the transloading facility footprint for the purpose of cost estimating.
- Disposal costs for the fines fraction.
- Ability to commit to long-term (and continuous) high-volume sediment throughput (economies of scale).
- Ability to reuse washed coarse fraction beneficially and at low cost.

The last two factors are the most difficult to reconcile in a manner that promotes economic viability.

The following sections describe conventional and advanced soil washing techniques recently used at several sites.

Area 5106, Hylebos Waterway, Commencement Bay (Washington) – Soil Washing

Unlike other parts of the Hylebos Waterway cleanup, the sediments at Area 5106 were treated before confined disposal (EPA 2004). The non-time critical removal action was conducted by Occidental Chemical Corporation at its former chlor-alkali plant facility along the Hylebos Waterway. About 36,000 cy of contaminated sediments containing volatile organic compounds and semivolatile organic compounds were hydraulically dredged and pumped to an upland treatment system. Treatment consisted of aeration and air stripping to separate out the volatile organic compounds (VOCs), which were, in turn, adsorbed onto activated carbon. The treated slurry was dewatered and the dewatered sediments were disposed of in the Blair Slip 1 confined disposal facility, because treated materials still contained relatively high concentrations of semivolatile organic compounds and metals.

Raritan River, Arthur Kill, and Passaic River (New Jersey) – Soil Washing

Biogenesis™ is an advanced soil washing process that was used in a recently completed full-scale demonstration, which treated approximately 15,000 cy of contaminated sediments from the Raritan River, Arthur Kill, and Passaic River, New Jersey (Biogenesis 2009, Malcolm Pirnie 2007). The Biogenesis™ process combines the physical separation aspects of conventional soil washing with high-pressure agitation, surfactants, chemical oxidants (e.g., hydrogen peroxide), and chelating agents. This process uses equipment including but not limited to: truck-mounted washing units, sediment processor, sediment washing unit, hydrocyclones, shaker screens, water treatment equipment, tanks, water blasters, compressors, and earth moving equipment.

Important Biogenesis™ process steps include:

1) Dredged sediment is screened to remove oversized material and debris before transfer to the holding tanks.

2) High-pressure water, proprietary solvent, and physical agitation are combined to separate contaminants from the solids.

3) Treated sediment is then dewatered using a hydrocyclone and centrifuge. Some effluent water may be recycled through the system, but significant quantities of wastewater are generated that require treatment and disposal.

The process results in residual waste products, including sludge and organic material, which require disposal at a regulated landfill. Depending on the nature of the sediment and cleanup levels required, the sediment washing process may need to be repeated for multiple cycles.

The Biogenesis™ proprietary process is designed to separate and to destroy organic contaminants partially (through oxidation); metals are conserved but concentrated in the fines fraction. Results for treated sediment from the three different dredged material sites demonstrated reductions in dioxin concentrations (from 517 nanograms toxic equivalent (ng TEQ)/kg dw prior to treatment to 71 ng TEQ/kg dw post treatment). While this washing technology achieved some measure of contaminant reduction, this appears to have been attributable primarily to solubilization of contaminants and separation of fine solids, rather than because of contaminant destruction through the cavitation/oxidation process. The mass of fine solids lost to the wastewater stream (centrate solids) ranged from approximately 9 to 18% of the incoming sediment mass, although dissolved concentrations were not evaluated (USACE 2011). Only slight decreases in PCB concentrations were documented (450 µg/kg dw prior to treatment and 380 µg/kg dw post treatment) (Biogenesis 2009). PAHs were not effectively removed or destroyed because of adsorption to, or sequestration within, the organic material mixed with the sediment. PAH concentrations in the treated sediment were approximately 52% of concentrations in the incoming sediment for the bench tests. Total PAH mass presumed destroyed or unaccounted for in the overall process ranged from zero to 49.9% (USACE 2011). Approximately 13,000 tons of processed dredged material was loaded onto trucks and transported off site for beneficial reuse as fill material.

Fox River (Wisconsin) – Soil Washing/Sediment Processing

In 2009, approximately 540,000 cy of PCB-contaminated sediments at Fox River (Operable Unit 1) were hydraulically dredged and pumped through a pipeline to a sediment processing facility equipped with particle-size separation, dewatering, and water treatment equipment (i.e., equivalent unit operations used in conventional soil washing). The sediment slurry passed over a vibrating screen enabling <0.5-inch material to pass through. The sand fraction of the slurry was then separated from the silt and clay fractions using a 150-micrometer (µm) coarse sand separation unit. The sand was polished in an up-flow clarifier, gravity dewatered, and temporarily stored on site for potential reuse. Average PCB concentration of dredged material was approximately 1,900 µg/kg dw (EPA 2009c). Total PCB concentrations in the treated sand fraction were on the order of 300 µg/kg dw.

The remaining fine grained sediment (<60 µm) was mechanically filter-pressed to dewater it. The resulting filter cake, typically containing between 1,000 and 10,000 µg/kg dw total PCBs was then land-filled. Process wastewater was treated by sand-filtration and granular activated carbon adsorption. Treated water was returned to the Fox River. Discharge water was monitored for PCBs, mercury, lead, pH, ammonia, biochemical oxygen demand, and TSS.

It is important to note that the process used at Fox River does not destroy organic contaminants. Further, while one of the project goals was beneficial reuse of the processed sand fraction, the sole beneficial reuse to date for this material was using a portion of the sand fraction as fill material (spread in the upland portion of the project site) and as a fill behind the sheetpile bulkhead wall constructed at the site. No beneficial uses outside of the project have been identified (TetraTech 2010a).

Hudson River (New York) – Soil Washing/Sediment Processing

Phase 1 of the dredging operations was conducted at the Hudson River during 2009 (Anchor QEA and ARCADIS 2010). Mechanical dredges with environmental clamshell buckets were used to remove approximately 278,000 cy of river sediments. Dredged material was transported by barges to a shore-based processing and transportation facility. Approximately 370,000 tons of PCB-contaminated sediments were processed to separate size fractions and dewater the solids in a similar fashion to that described above for the Fox River project. As a first step in processing the dredged material, debris and rock were removed and dredged sediments were processed through trammel screens and hydrocyclones to separate the material by size.

Approximately 40% of the sorted materials were fines and 60% were coarse material and wood. After coarse material separation, the slurry of fine sediments was mixed with a polymer in a gravity thickener and filter-pressed. Segregated debris and coarse solids and filter cake removed from the filter presses were temporarily stored in staging areas prior to rail transport and disposal at a permitted facility in Texas. Residual contaminant concentration in the coarse material precluded beneficial reuse of this material. All fractions of dredged material (debris, coarse, and fine) were therefore transported to and disposed of at a permitted facility in Texas. The fine fraction was separated from the coarse fraction and processed through mechanical dewatering to decrease the water content, thereby reducing the transport and disposal costs. A water treatment plant with the capacity to handle 2 million gallons of water per day was built to treat the water collected during the dewatering process. Treated water (approximately 88 million gallons per season) was discharged to the Champlain Canal.

Potential Environmental Review and Permitting Requirements

Permitting requirements for a prospective soil washing operation are currently undetermined and are dependent on the extent of the CERCLA and MTCA LDW site jurisdictional area. If the soil-washing location was determined to be on site, all substantive permitting requirements would be overseen by EPA and complied with as applicable or relevant and appropriate requirements (ARARs), and all procedural and environmental review requirements would be waived. The LDW site includes the upland areas (beyond the scope of this FS) that contributed contamination to the waterway; such upland areas would be considered "on site" for the purposes of siting a treatment facility. All necessary permits would need to be secured if the treatment location is not on site. Permits would also be required for any off-site disposition of treated CERCLA materials and waste streams, such as placement of treated material as off-site fill or off-site discharge of wastewaters to the King County sanitary sewer system.

7.1.2.3 Solidification

Solidification is a proven and effective *ex situ* technology that reduces the moisture content of dredged sediments and reduces the leachability (mobility) of metals. The process involves mechanical blending of the contaminated medium, in this case sediment, with an agent such as cement, cement kiln dust, or super-absorbent polymers. These agents react with moisture in the contaminated media and may produce a material that is much improved structurally (i.e., compressive strength) and can effectively reduce the leachability of contaminants. However, contaminants are not destroyed by solidification.

The major regional landfills (Allied Waste of Roosevelt, Washington, and Waste Management of Columbia Ridge, Oregon) are able to receive contaminated wet sediment at their sites in truck and rail containers (without requiring material to pass a Paint Filter Test [EPA 2008a]). These containers are lined to prevent loss of material (e.g., drainage) during transport.

Solidification does not adequately treat the COCs and solidified sediment would still require transport to a landfill for disposal. For this reason, solidification is not carried forward for alternative development in this FS, but it may be reconsidered during remedial design if moisture or leachability reduction is needed to comply with landfill operating permits.

7.1.2.4 Thermal Treatment

Thermal treatment involves the *ex situ* elevation of the temperature of dredged sediment to levels that either volatilize the organic contaminants (for later destruction in an afterburner) or directly combust the contaminants (e.g., incineration). A number of different system configurations and operating principles have been developed and are available in the marketplace, as described in the CTM. Thermal treatment systems are generally effective for destroying a broad range of organic compounds. Metals are not destroyed by thermal treatment systems.

Thermal treatment facilities are not available either locally or regionally. Therefore, dredged sediment would need to be transported out of state (either to Idaho or Utah) to utilize an existing facility. Alternatively, a temporary on-site (i.e., adjacent to the LDW) facility is technically feasible to consider. Implementability considerations include general siting considerations and obtaining local permits (e.g., air).

The primary drawback to thermal treatment is that treated sediment is unlikely to achieve metal concentration limits for beneficial reuse and may thus still require upland landfill disposal. Studies (e.g., toxicity testing) would also be needed to ascertain whether treated sediment would have properties suitable for supporting benthic productivity before in-water placement of the treated material would be allowed. Thermal destruction processes also require monitoring and management of air releases of hazardous constituents, such as dioxins/furans. Dioxins/furans can be created and released in air emissions from some thermal treatment processes, and fulfilling all substantive permit requirements for managing these air emissions can be difficult and can affect implementability of on-site thermal treatment.

Cement-Lock® Technology is a thermo-chemical manufacturing process that decontaminates dredged material and converts it into Ecomelt®, a pozzolanic material, which when dried and finely ground can be used as a partial replacement for Portland cement in the production of concrete. In the Cement-Lock® process, a mixture of material and modifiers is charged to a rotary kiln at high temperatures, which yields a homogeneous melt with a manageable viscosity. All nonvolatile heavy metals originally present in the sediment are incorporated into the melt matrix via an ionic replacement mechanism. The melt then falls by gravity into water, which immediately quenches and granulates it. The resulting material, Ecomelt®, is removed from the quench granulator by a drag conveyor.

Preliminary pilot-scale results have shown that organic contaminants are partially destroyed, and inorganics (e.g., metals) are encapsulated within the Cement-Lock®

matrix (i.e., Ecomelt®). Although the thermal technology is effective at destroying organic contaminants and immobilizing metals, some metals remain leachable (USACE 2011). The Cement-Lock® cement product passed the Toxicity Characteristic Leaching Procedure test for priority metals. The technology was recently demonstrated at a pilot-scale level for sediments dredged from the Stratus Petroleum site in upper Newark Bay (NJ) in 2006 and from the Passaic River (NJ) in 2006 and 2007. However, both demonstrations experienced equipment-related problems and were terminated (GTI 2008). In these studies, the Ecomelt product samples showed an average reduction in PCB concentrations from 2,800 µg/kg dw (pretreatment) to 0.2 µg/kg dw (post-treatment), with a PCB mass found in the off-gas stream of 0.01% of the incoming sediment PCB mass, for an overall 99.9% (not including the 30% of input mass adsorbed by the carbon bed) unaccounted for and presumed destroyed. The average reduction for 2,3,7,8-tetrachlorodibenzodioxin (TCDD) was from 0.17 µg/kg dw (pretreatment) to 0.008 µg/kg dw (post-treatment) (GTI 2008), with approximately 0.1% of the incoming total dioxin/furan mass being measurable in the Cement-Lock® product (USACE 2011). The fraction of metals leachable in the Ecomelt (Toxicity Characteristic Leaching Procedure [TCLP] mass/total metals in aggregate) ranged from zero to 20%, with average and median values of 3.0 and 0.28%, respectively. The fraction of metals leachable as a fraction of the total metals in the raw feed ranged from zero to 8.8%, with average and median values of 1.1 and 0.24%, respectively (USACE 2011).

Thermal treatment is not carried forward for further consideration in the FS because the process is unlikely to achieve the total metal concentration limits for beneficial reuse although a reduction in leaching potential could perhaps be achieved through use of one of the available technologies (e.g., Cement-Lock® technology).

7.1.2.5 Treatment Technology Summary

Application of activated carbon to sediments to reduce bioavailability is retained as a viable *in situ* treatment technology for the LDW. The technology can be considered in various ways from stand-alone applications to enhancements of other technologies (e.g., amending cap materials or incorporating into media used for ENR). Activated carbon amendment could also prove to be an essential tool of adaptive management (e.g., as a contingency action for underperforming remedial action areas).

Conventional soil washing/particle separation and advanced soil washing have sufficient merit to carry these processes forward in developing the LDW remedial alternatives. Soil washing is retained as an *ex situ* treatment process option because it has been applied at other contaminated sites in the United States and Europe, results in volume reduction of treated dredged material, and may result in a sand fraction suitable for beneficial use in the LDW, or possibly reduce or eliminate the cost of disposal for the sand fraction. Significant engineering design would be required to specify soil washing site location(s), special equipment needs (e.g., cyclones, filters, water treatment systems, etc.), operational procedures, and environmental review and permitting requirements to implement soil-washing treatment.

This FS assumes that soil-washing treatment would be located entirely within the transloading/dewatering facility and would consist of the following elements:

1) Physically wash the dredged material and separate the coarser grained (clean) sediment from the fine particle (contaminated) sediment.

2) Treat the wash water and discharge it to the LDW. Assume use of the following treatment train: collect and settle wastewater, flocculate, filter, analyze, and discharge.

3) Collect and stockpile the cleaned sediment in an on-site location separated from the soil-washing and wastewater treatment operations. Chemically analyze the sediment for COCs to confirm that remnant COC concentrations are less than sediment quality standards (SQS) or other applicable criteria and thereby are determined suitable for beneficial reuse.

4) Transfer the treated sands (processed material achieving target levels established for the project) off site and stockpile for assumed reuse as capping and ENR material for the project. Stockpile requirements need to address logistics and timelines for sand reuse. Specific requirements for sand quality and use need to be defined, including regulatory approvals.

5) Chemically analyze all remaining sediment to determine if treatment has magnified COC concentrations to be greater than landfill-designated hazardous waste concentrations.

6) Based on the chemical analytical results, load railcars with remaining sediment, transfer to the landfill, treat any excess wastewater, and dispose of the remaining sediment appropriately in either a Subtitle C or D landfill.

More advanced soil-washing technologies are not carried forward into the FS as the representative process option in the FS because conventional soil-washing techniques would likely produce the most value in terms of volume reduction for the cost. The expected post-treatment concentrations may preclude the material from beneficial reuse in Puget Sound.

Solidification and treatment technologies were screened out for full-scale consideration in the FS as described above.

7.1.3 Disposal/Reuse of Contaminated Sediment

Several disposal options for dredged sediment were identified in the CTM and are reconsidered here for their applicability to cleanup of the LDW:

- On-site disposal
  - Contained aquatic disposal (CAD)

    - Confined disposal facility (CDF)
- Off-site disposal
    - Existing Subtitle C landfill (40 CFR Part 265, Subtitle C of RCRA)
    - Existing Subtitle D landfill (40 CFR Part 258, Subtitle D of RCRA)
- Open water disposal
    - Dredged Material Management Program (DMMP) site
- Beneficial reuse.

The on-site disposal options retain the contaminated material in or very near the site in new, engineered facilities. The off-site disposal options pertain to upland disposal in existing regional landfills. Open water disposal is also a process option for dredged material that meets the DMMP's criteria for open water disposal. All of these disposal alternatives have demonstrated effectiveness and have been successfully used in the Puget Sound region.

Beneficial reuse is often preferred to disposal, when feasible, although application can be limited by physical characteristics or contaminant concentrations.

7.1.3.1 On-Site Disposal

CAD and CDF are two potential on-site process options for disposal of dredged sediment. As discussed in the CTM (RETEC 2005), both disposal options confine contaminated sediment within an engineered structure. These options differ primarily in location or setting: CAD facilities are located within a water body, and CDFs are located nearshore or upland.

CAD Sites

CAD implementation, although a proven technology, is constrained in the LDW. Material is typically placed in horizontal layers, which requires locating the CAD site in a relatively flat area or depression to minimize excavation quantities during construction, and to prevent spread of contaminated sediment downslope. Potential CAD sites in the LDW are located within or near the defined navigation channel. To ensure that the authorized channel depths are maintained, the top surface of the CAD must be positioned below the authorized channel depth to allow for maintenance dredging. The federally-authorized navigation channel requires maintenance of a specified depth; remedial alternatives within the channel cannot interfere with the authorized channel depth. Two locations in the LDW best satisfy these requirements:

- The deep area at the north end of the LDW directly south of Harbor Island, where the existing depth is well below the authorized navigation channel depth

- The southernmost portion of the LDW, defined by the Upper Turning Basin and adjacent navigation channel.

An advantage of CAD over upland disposal is that the overall project dredging production rate can be significantly accelerated because dredged sediment can be placed directly into bottom-dump barges for rapid movement to and placement into the CAD. Dredging would not be subject to the production rate constraints associated with transloading and transportation to a landfill. As result, the overall period of short-term dredging impacts could be reduced through use of CAD.

Numerous implementability issues would have to be addressed to implement CAD including:

- Logistical and timing considerations need to be planned for, including: 1) CAD construction (e.g., dredging and disposal of excavated sediment), 2) sequencing and timing to dredge and place contaminated sediment in the CAD, and 3) identification and coordination to secure and place capping material. In addition, capping (either interim or final) must be completed by the end of each in-water construction window to protect fish runs from disturbance by construction during migration.

- Barge dumping of contaminated sediment into a CAD site involves some dispersion of material as it falls through the water column and lands on the mudline. Unless care is taken, the dumped sediment can cause a "mud wave" when it strikes the bottom. This can cause contaminated sediment to move out of the CAD area and migrate onto adjacent surfaces. Models are available (e.g., STFATE) to assess this factor and engineering controls would need to be incorporated into the design to minimize or mitigate this factor. These engineering controls can include designing the CAD with features to limit mud waves, monitoring adjacent areas, and capping or implementing ENR for any affected adjacent areas.

- Propeller scour in the navigation channel as well as movement by tugs and other vessels accessing adjacent berthing areas could stir up exposed contaminants and move them into other areas before the cap is installed. Modeling of propeller wash, along with appropriate navigation controls during the construction season can be used to minimize this potential.

A CAD could also potentially be located outside of the LDW (e.g., elsewhere in Puget Sound). However, this would likely be an off-site disposal action subject to permitting requirements. Because the administrative implementability of an off-site CAD is considered low, these possibilities are not explored in this FS.

CAD is being carried forward, and will be evaluated as a disposal alternative with the understanding that CAD capacity may not match the total volume of contaminated dredged sediment under some alternatives. However, regardless of which remedial alternative is selected, CAD may be considered during remedial design on a smaller-scale, location-specific basis, subject to agency approval.

CDF Sites

A nearshore or upland CDF (e.g., construction of a CDF in a slip) is a technically feasible option for the disposal of LDW dredged material, but is not carried forward as a primary in-water disposal technology for the FS. During engineering design, if a small-scale CDF potentially could be applicable, numerous hurdles would need to be overcome. Some of these hurdles include: identifying suitable available land/water sites for acquisition, providing compensatory habitat mitigation for lost aquatic habitat, and demonstrating appropriate economic development purposes for the upland facility in accordance with the Clean Water Act Section 404(b)(1) guidelines.

7.1.3.2 Off-Site Landfill Disposal

Sediments removed from the LDW are not expected to require disposal in a landfill permitted to receive Resource Conservation and Recovery Act (RCRA) hazardous waste or Toxic Substances Control Act (TSCA) waste (i.e., Subtitle C landfill). Nevertheless, a regional Subtitle C landfill (Waste Management, Inc. located at Arlington, Oregon) is available to receive material that exceeds the relevant RCRA or TSCA limits should such material be encountered during remediation.

Two regional Subtitle D landfills (Waste Management, Inc. located at Columbia Ridge, Oregon, and Allied Waste, Inc. located at Roosevelt, Washington) receive both municipal waste and solid nonhazardous contaminated media. Both facilities have been used for the majority of contaminated sediment projects in the Puget Sound region, including several projects in the LDW (Table 7-5). Further, both facilities are permitted to receive wet sediment (i.e., sediment that does not pass the paint filter test and therefore contains free liquid). These existing Subtitle D landfills are retained as representative disposal process options for remedial alternatives that call for sediment removal with disposal in an upland landfill.

7.1.3.3 Open Water Disposal

In Puget Sound, the open water disposal of sediments is managed and monitored under the DMMP, which is jointly administered by the U.S. Army Corps of Engineers (USACE), the EPA, the Washington State Department of Natural Resources (WDNR), and Ecology. The DMMP User's Manual (USACE 2008b) details the sediment evaluation, testing, and disposal procedures for open water disposal of dredged material at DMMP-designated disposal sites in Puget Sound. The DMMP non-dispersive deep water disposal site nearest to the LDW is in Elliott Bay. This facility has approximately 6.6 million cy of remaining capacity.[3]

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[3] Approximately 2.4 million cy of dredged material have been placed at the Elliott Bay disposal site between 1989 and 2007. With a capacity of 9.0 million cy, the site will be operational for about 50 more years, assuming about 130,000 cy of placement per year (USACE 2007a).

Some of the LDW sediments that have been dredged from the navigation channel between river mile (RM) 3.8 and RM 4.8 and from private berthing areas outside of the navigation channel have previously been tested and accepted for open water disposal. This suggests that at least some of the sediment removed during remediation may meet DMMP criteria. However, the FS assumes that dredged sediments requiring remediation would not be clean enough to meet DMMP requirements, although they are not necessarily precluded from DMMP open water disposal.

Open water disposal may be considered in the remedial design phase for the following material if the sediment is demonstrated to achieve the DMMP criteria for open water disposal:

- The clean sand fraction from conventional soil washing
- Suitable material dredged from areas during construction of a CAD facility
- Suitable material, if any, dredged under some alternatives in this FS.

7.1.3.4 Beneficial Use of Sediment (Clean and Treated)

Beneficial use of dredged sediment is preferred to its disposal, when feasible. However, contaminated and untreated sediment is not suitable for direct beneficial use applications. This subsection examines the potential beneficial use of:

- Clean dredged material generated by local navigation channel maintenance dredging projects
- Treated sand fraction of dredged contaminated sediments from the LDW.

Any potential in-water beneficial use application would need to meet associated material specifications to ensure an appropriate match between physical, chemical, and biological material properties and functionality in the aquatic environment.

Beneficial Use of Dredged Material from Navigation Projects

Regular USACE maintenance dredging of regional navigation channels in the LDW, Snohomish River, Swinomish Channel, and other rivers generates large volumes of sandy and silty sediments. In the Puget Sound region, this dredged material has been used beneficially for both remediation and habitat enhancement projects. Examples of projects in Elliott Bay that have used sediment from LDW Upper Turning Basin maintenance dredging activities include:

- **Denny Way Combined Sewer Overflow (CSO) Capping –** In 1990, King County and the USACE sponsored the Denny Way CSO capping project to test the feasibility of capping contaminated sediments in Elliott Bay. A 3-ft layer of sediment dredged from the LDW Upper Turning Basin was placed over a 3-acre area at the Denny Way CSO. Monitoring results over the last 15 years demonstrate that the cap is stable, is not eroding, and has successfully isolated the underlying contaminated sediments (King County 2007b).

- **Pier 53-55 Capping –** In March 1992, about 22,000 cy of sediment dredged from the LDW Upper Turning Basin was placed offshore of Piers 53, 54, and 55 in Elliott Bay, to cap approximately 2.9 acres and ENR approximately 1.6 acres of contaminated sediments. Monitoring results indicate that the 3-ft cap and ENR areas are stable, and contaminants are not migrating from the underlying sediments up into the 3-ft cap or ENR area (King County 2010b).

- **Bell Harbor Capping –** In March 1994, the Port of Seattle placed a thin-layer cap of sediment dredged from the LDW Upper Turning Basin over 3.9 acres of contaminated sediments at the former site of Pier 64/65 in Seattle. The site was also designed to incorporate habitat enhancement components, including rock corridors on top of the cap and gravel below the slope and between corridors. These substrata were specifically designed to serve as habitat for brown algae and juvenile rockfish. Subsequent monitoring has demonstrated the success of both actions (Erickson et al. 2005a, 2005b).

- **Pacific Sound Resources Superfund Site in West Seattle –** Approximately 66,000 cy of sediment dredged from the LDW Upper Turning Basin, along with over 200,000 cy of sediment dredged from the Snohomish River, was placed as a cap at the Pacific Sound Resources contaminated sediment site in West Seattle in 2004 (USACE 2007b).

This FS assumes that upland-sourced materials (sand, gravel, and rock) will be purchased for use as cap materials and for ENR. However, the design process should consider the use of navigation channel and berthing area dredged materials determined suitable for beneficial use application as an alternative to upland-sourced materials. The EPA's Contaminated Sediment Technical Advisory Group (CSTAG) has recommended that the navigation channel and berthing area dredged material be considered for these uses in the remediation of the LDW (CSTAG 2006). However, significant administrative issues (including timing, contracting, and administrative approvals) are associated with procuring USACE and private party dredged materials.

Beneficial Use of Treated Contaminated Sediments

For contaminated sediments dredged as part of a cleanup action, treatment would be required before possible beneficial use. Treatment by soil washing followed by beneficial use of the sand fraction may be more cost-effective than treatment followed by disposal. The coarser (sand) product (processed material achieving target levels established for the project) from a soil washing process could potentially be reused within the LDW for capping, habitat restoration, or grade restoration (i.e., to meet final bathymetry requirements) as part of the remedial action. However, a review of existing literature and local knowledge did not identify any examples of treated sediments being used beneficially in the Puget Sound region.

The sand produced from a soil washing process could also be reused in the uplands as construction fill or as material feedstock for other industrial or manufacturing applications (e.g., concrete or asphalt manufacture). Depending on the end use and associated exposure potential, it is not known whether the treated sand fraction would achieve appropriate chemical criteria for all LDW contaminants. Upland beneficial use would also require resolution of legal issues related to material classification, antidegradation, and potential liability.

Remedial alternatives that include soil washing assume that the disposition of the washed material could result in a range of outcomes: 1) achieve the applicable chemical and physical requirements for in-water use and hence be used as on-site cap or ENR material with potential material cost savings; 2) be suitable for upland use as fill with no associated value or disposal cost; 3) be suitable for open water disposal with a comparatively low disposal cost; or 4) require landfill disposal at significant cost.

7.1.4 Capping

In the CTM (RETEC 2005), capping was evaluated and retained as a containment technology that is considered both effective and implementable in the LDW. Capping is a well-developed and documented *in situ* remedial technology for sediment that isolates contaminants from the overlying water column and prevents direct contact with aquatic biota (Figures 7-3 and 7-4). Depending on the contaminants and sediment conditions present, a cap reduces risks through the following primary mechanisms (EPA 2005b):

- Physical isolation of the contaminated sediment sufficient to reduce exposure through direct contact and to reduce the ability of burrowing organisms to move contaminants to the cap surface
- Stabilization of contaminated sediment and erosion protection of the sediment and cap sufficient to reduce resuspension and transport of contaminants into the water column
- Chemical isolation sufficient to prevent unacceptable risks of exposure to sediment contaminants that are solubilized and transported through the cap material and into the water column (e.g., via diffusion or groundwater advection).

7.1.4.1 Conventional Sand and Armored Caps

A large number of sediment caps have been successfully implemented in the Puget Sound region: One Tree Island Marina, Olympia 1987; St. Paul Waterway, Tacoma 1988; Georgia Pacific Log Pond, Bellingham 2000; East and West Eagle Harbor/Wyckoff, Bainbridge Island, 1993-2002; Middle Waterway, Tacoma 2003; General Metals, Tacoma late 1990s; and others (RETEC 2002).

Within the LDW, a sand cap was constructed in 2005 in conjunction with the Duwamish/Diagonal early action area (EAA) sediment remediation project (Anchor and EcoChem 2005a) (Figure 7-5). Preliminary monitoring results from 2007 to 2009 show trends indicating that the cap has successfully isolated underlying contamination. Following cap construction, total PCB concentrations in surface sediment have fluctuated around the SQS. However, because the Duwamish/Diagonal cap is located near an active storm drain and a CSO outfall, and is adjacent to other contaminated sediments, some degree of increase in contaminant concentrations on the cap surface has been noted, highlighting the importance of source control.

The ability to implement capping technology is influenced greatly by physical constraints and engineering design. Capping may be suitable where navigation or other public uses would not be physically impeded, or in areas where it is impractical to remove all of the contaminated material because of slope or nearby structure stability concerns. If capping is chosen as part of the selected remedial alternative for the LDW, then bathymetric, hydrodynamic, slope stability, and biological conditions, as well as commercial/public land use would need to be considered. An engineered cap design specifies material types, gradation, thickness, armoring requirements, design elevation ranges, placement requirements, and other design parameters. For example, the cap design for deep depositional waters would be different from designs for intertidal and shallow subtidal areas of high habitat importance and areas that have the potential for appreciable episodic erosion.

7.1.4.2 Composite and Reactive Caps

A composite or reactive cap may be an appropriate design solution in situations where:

- A reduced cap thickness is needed in navigation-constrained areas to avoid dredging.
- Standard sand capping would require excessive thickness for containment of a specific COC.
- Contaminant migration necessitates reducing contaminant flux over what is achievable with native capping materials.

Reactive cap technology refers to including reactive amendments in the granular cap material or in manufactured mats. The additives are selected based on their ability to adsorb or react with contaminants migrating through the cap strata. Activated carbon, bentonite, apatite, AquaBlok™ (a commercial product designed to enhance contaminant sequestering through organic carbon amendments to the cap, and to reduce permeability at the sediment-water interface), and coke are examples of reactive amendment materials that have been investigated at the demonstration level or in full-scale applications. The need for and type of amendment will be evaluated for specific project areas during remedial design; design data requirements may be different between conventional and thin-layer caps. Section 7.1.4.4 summarizes preliminary modeling results that indicate amendments may not be necessary as a component of cap design for reducing migration of hydrophobic organics through the cap (e.g., PCBs and cPAHs).

The following paragraphs describe examples of composite or reactive cap demonstration level or full-scale application projects.

Carbon Amendment of Cap Materials (Various sites, Washington)

Sand with a carbon amendment was used in caps at the Upriver Dam PCB Sediments Site, Spokane, WA (Anchor 2006a), Olympic View Resource Area, Tacoma, WA (Hart Crowser 2003), and Slip 4 EAA, Seattle, WA (Integral 2010).

Activated Carbon – Reactive Core Mat (Tukwila, Washington)

After sediment dredging and capping was conducted in 1999 by King County offshore of the Norfolk combined sewer overflow (CSO) outfall within what later became the LDW study area, surface sediment monitoring showed that additional sediment removal was needed in the vicinity of the nearby south storm drain outfall of the Boeing Developmental Center to prevent recontamination (PPC 2003). Approximately 60 cy of contaminated sediment were removed and backfilled in September 2003 by Boeing to eliminate the potential source of recontamination to the adjacent cap. The sediment removal was completed during low tide cycles over a one-week period; all work was completed above the water level (at low tide). Following each day’s excavation work, a geotextile fabric layer (Mirafi filter fabric) was installed as a temporary cover to contain and limit any potential migration of silts and the associated contaminants from the excavation area. Turbidity was monitored daily as well as visual monitoring throughout the construction period. Based on turbidity measurements and visible appearance, the daily geotextile fabric cover worked well to prevent loose silt material from mobilizing within the LDW. The geotextile fabric was removed and disposed of before the cap was placed. The excavation area was capped with a fabric containing activated carbon, a layer of sand, and a cover consisting of quarry spoils in the channel segment (where higher velocities from the outfall discharge were expected). The activated carbon fabric was included in the cap permanently to adsorb and contain any residual PCBs in the channel area and prevent upward migration of PCBs in this area. Continued annual monitoring and sediment sampling have verified that no recontamination has occurred within the engineered cap and have demonstrated that the remaining contaminated area is limited to a small segment of the drainage channel located just below the south storm drain outfall (PPC 2003).

Activated Carbon – Reactive Core Mat (Stryker Bay, Duluth, Minnesota)

Stryker Bay in Duluth (MN) was heavily contaminated with tar and coke (Bell and Tracy 2007). Coal tar thicknesses under the water reached as much as 13 ft in some areas. Remediation involved placing six inches of sand cap and a reactive core mat (RCM), followed by six inches of sand cap over the contaminated sediments. The activated carbon-based geotextile fabric, a reactive cap, allowed the cap thickness to be less than a traditional sand cap, and provided stability and physical isolation. According to the *First Five-Year Review Report* (USACE 2003b), the remedial action was complete and was found to be protective of human health and the environment as intended by the 2000 Record of Decision (ROD) because soils above the direct exposure cleanup levels identified in the ROD for industrial use were removed.

Activated Clay Cap (Willamette River, Portland, Oregon)

In 2004, as part of the cleanup of the McCormick and Baxter Superfund site, the east bank and bed of the Willamette River in Portland (OR) were capped with an organoclay sediment layer to contain high concentrations of COCs, including pentachlorophenol (PCP), creosote, chromium, and arsenic (Aquatechnologies.com, Oregon Department of Environmental Quality [ODEQ] 2005). Over most of the site, the cap consists of a 2-ft-thick layer of sand. In more highly contaminated areas, a 1-ft organoclay layer was placed beneath a 5-ft-thick layer of sand. The organoclay consists of bentonite or hectorite clay modified to be hydrophobic, to have an affinity for non-soluble organics, and especially to prevent breakthrough of non-aqueous phase liquid through the cap. The design of the sediment cap incorporated different types of armoring to prevent erosion of the sand and organoclay layers. In the *Third Five-Year Review Report* (ODEQ 2011), the remedy for the sediment OU was determined to be protective of human health and the environment because the remedy required by the ROD is working as intended.

Granular Bentonite, Sand/Soil/Bentonite Slurry, and AquaBlok™ (Lower Grasse River, Massena, New York)

Pilot studies conducted in 2001 in the Lower Grasse River, Massena, (NY) evaluated capping with various materials as a cleanup alternative for remediating PCB-contaminated sediments (Quadrini et al. 2003). Materials such as a 1:1 sand/top soil mixture, granulated bentonite (clay), and AquaBlok™ were tested as single components or mixtures. Optimal results were achieved with a 1:1 sand/top soil cap applied via a clamshell attached to a barge-mounted crane. Few apparent short-term impacts were noted during the pilot project, as well as negligible water quality impacts. However, in 2003, cap monitoring data indicated significant loss of cap material, and in some cases, significant but localized scouring of underlying sediment (up to 2 ft), that translated into redistribution of the PCBs buried in the river sediments in the upper approximately 1.8 miles of the Lower Grasse River (Quadrini et al. 2003). The possible cause was an ice jam that formed on the river during the spring ice breakup. Consequently, an ice breaking demonstration project was conducted in 2007, the results of which were incorporated into the analysis of alternatives report to evaluate remedial options for the river (Alcoa 2007).

AquaBlok™/Sand (Anacostia River, Washington, D.C.)

A major demonstration of several active-addition reactive cap designs has been conducted on the Anacostia River in Washington, D.C. (EPA 2007c). The objective of this demonstration project was to provide information on the design, construction, placement, and effectiveness of these augmented caps. Various cap technologies were evaluated, including sand (as a demonstration control), AquaBlok™, coke breeze (with potential to sequester and retard the migration of organic contaminants through sorption), and apatite (which encourages precipitation and sorption of metals). The performances of these caps were evaluated in terms of physical stability, hydraulic seepage, and impacts on benthic habitat and ecology. Monitoring of the caps over an approximately three-year period using a multitude of invasive and non-invasive sampling and monitoring tools was used in assessing performance. Results indicate that the AquaBlok™ was highly stable, and likely more stable than traditional sand capping material even under very high bottom shear stresses. The AquaBlok™ material was also characteristically more impermeable, and it is potentially more effective at controlling contaminant flux, than traditional sand capping material. However, the low permeability AquaBlok™ cap showed evidence of heaving because of methane accumulation and release. AquaBlok™ also appeared to be characterized by impacts (lack of colonization) to benthos and benthic habitat similar to traditional sand capping material (EPA 2007c). Apatite results were not available for review in the EPA (2007c) report.

In another demonstration in the Anacostia River in 2004, a RCM was designed to accurately place a 1.25-cm thick sorbent (coke) layer in an engineered sediment cap (McDonough et al. 2006; Figure 7-4). Twelve 3.1-meter (m) x 31-m sections of RCM were placed in the river and overlain with a 15-cm layer of sand to secure it and provide a habitat for benthic organisms to colonize without compromising the integrity of the cap. Placement of the RCM did not cause significant sediment resuspension or impact site hydrology. The RCM was shown to be an inexpensive and effective method to accurately deliver thin layers of difficult to place, high value, sorptive media into sediment caps. It can also be used to place granular reactive media that can degrade or mineralize contaminants.

7.1.4.3 Capping and Overwater Structures

Overwater or floating structures (e.g., docks, piers, marina floats) preclude conventional means of installing a cap using a material barge and excavator or clamshell-based equipment. Various alternative methods are available and have been successfully implemented under these circumstances:

- A belt-conveyor system that can be controlled for angle and speed spray-deposits sand under piers and between pile bents (Figure 7-6).
- Small construction equipment (e.g., skid loader) that fits between pile bents can directly apply cap materials during low tide and where surface conditions are sufficiently stable and access is adequate for maneuvering. This approach was used successfully at the Wyckoff/Eagle Harbor West Operable Unit remediation site in 1997.
- A discharge pipeline can hydraulically deposit a sand-slurry underneath or through the overwater structure. The latter may require removing some of the pier decking. This approach was used successfully at the Wyckoff/Eagle Harbor West Operable Unit remediation site in 1997.

- Pier decks can be removed temporarily to improve access for mechanical placement, as employed at the Martinac Shipyard in the Thea Foss Waterway circa 2003.
- Grout-filled mats can be installed around pile bents, as employed in the Thea Foss Waterway circa 2003.

At intertidal locations where it is difficult to effectively place a sand cap by conventional means (e.g., where the slope is too steep or overhead obstructions exist), a shotcrete cap is an option. Shotcrete is typically composed of concrete or mortar and is pneumatically jettisoned from a nozzle at high velocity onto the surface to be coated at low tide. A shotcrete cap was installed during the Todd Shipyards sediment cleanup (McCarthy, Floyd|Snider 2005). The shotcrete application at Todd Shipyards effectively encapsulated existing debris (slag) mounds (Figure 7-7). Shotcrete can be applied to various material types and surface orientations, including steep embankments. However, shotcrete is not appropriate for use in habitat areas.

7.1.4.4 Modeling of Cap Recontamination

The potential for a conventional *in situ* isolation sand cap to be recontaminated over time by the movement of contaminants through the cap from underlying sediments was analyzed using a one-dimensional groundwater flux model (Lampert and Reible 2009) that also includes net sedimentation on top of the cap. The modeling approach and the results of the analysis are presented in Appendix C, Part 8 (Modeling Contaminant Transport through a Sediment Cap).

The analysis showed that PCB breakthrough above the assumed performance goals is not expected to occur.[4] This is true even where the assumed conditions are unfavorable (high groundwater flow, low sedimentation, and low organic carbon coefficient [K_{oc}]), because the sedimentation rate is always greater than the rate at which the contaminant front migrates through both the cap and the new sediment layer that is continually added over time. The analysis showed that cPAHs behave similarly to PCBs and therefore would also not exceed similar performance goals.

In the complete absence of sedimentation, the results show that capping is still feasible, but that minimum organic carbon requirements for cap materials may need to be specified to achieve a cap design life of more than 100 years. ENR is predicted to achieve assumed performance goals under average conditions, but may not be applicable in adverse conditions (high groundwater flow, no sedimentation, low K_{oc}).[5]

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[4] The assumed performance goals for cap modeling are: 1) sediment concentrations not exceeding 100 µg/kg dw total PCBs in the top 10 cm within 100 years, and 2) porewater concentrations below 0.03 µg/L at the sediment/water interface within 100 years.

[5] Analysis of ENR generally assumes that placed ENR sand mixes with underlying sediment. This analysis assumed that a thin ENR sand layer (15 cm) did not mix with underlying sediment. Therefore, the analysis is exploratory.

Cap or ENR material specification and applicability of ENR would be evaluated during remedial design.

For the 45-cm clamming point of compliance direct contact scenario, the results show that capping with a 3-ft sand cap is feasible, even in the absence of sedimentation. However, minimum organic carbon requirements for cap materials may need to be specified to achieve a cap design life of more than 100 years.

Specific locations within the LDW, such as Ash Grove Cement (RM 0.1E) and the Duwamish Shipyard (RM 1.35W), have historical high concentrations of metals (e.g., arsenic) in the subsurface. For this reason, remedial design should address the potential for dissolved metals (such as inorganic arsenic) to migrate through a proposed cap to surface sediment and surface water (Palermo et al. 1998). The potential for bioturbation and/or diffusion should also be considered during remedial design of caps.

Although cap modeling results presented in Appendix C (Part 8) indicate amendments may not be necessary as a component of cap design to reduce transport of hydrophobic organics (e.g., PCBs and PAHs), remedial design should identify whether the mobility and bioavailability of metals (such as arsenic) need to be reduced and incorporate any special needs into the design. Several studies (Pattanayak et al. 2000, Mohan and Pittman 2007) report the extensive research conducted on effective removal of arsenic through activated carbon adsorption mechanisms. Many other candidates appear interesting for arsenic adsorption, such as activated alumina, clay, silica sand, and organic polymers, which are known to be good adsorbents that can be regenerated *in situ*. Absorptive capacity should be considered in the design phase.

7.1.4.5 Capping Technology Summary

For developing and evaluating remedial alternatives in the FS, conventional sand cap and armored cap process options have been selected to represent the technology as a whole. Sand caps may be applied to net depositional areas, and armored caps may be applied to areas within the LDW subject to episodic erosion. Reactive caps, although not evaluated in this FS for LDW-wide application, may be appropriate and cost-effective depending on location-specific circumstances.

Section 8 of the FS identifies areas suitable for capping based on evaluating the potential for propeller scour, outfall scour, ship wakes, water depths required for vessel navigation and berthing, slopes, habitat requirements, and erosion associated with high-flow conditions in the LDW. Locations requiring armoring are also considered.

7.1.5 Monitored Natural Recovery (MNR)

Natural recovery of sediments refers to the ability of natural processes such as chemical and biological degradation as well as physical burial by incoming sediments to reduce contaminant concentrations over time (Figure 7-8). Where conditions support natural recovery and natural recovery is included in the remedial alternative, a monitoring program will be instituted as a key component of MNR to assess if, and at what rate, risks are being reduced and whether progress is being made toward achieving the cleanup objectives. The monitoring program associated with an MNR remedy generally combines physical, chemical, and possibly biological testing to track progress toward achieving the cleanup objectives. As with any risk-reduction approach that takes time to reach remediation goals, remedies that include MNR frequently rely upon institutional controls, such as seafood consumption advisories, to control human exposure during the recovery period (EPA 2005b). In the event that MNR does not achieve or progress sufficiently toward achieving performance objectives, contingency actions such as capping, ENR/*in situ* treatment, or dredging may be required. Establishing decision rules with targets and time frames for the performance of MNR is an essential component of an adaptive site management framework (Magar et al. 2009).

As discussed in Section 5, new material transported into the LDW from upstream will tend to settle and bury some of the contaminated sediments. This burial, combined with surficial mixing (both from bioturbation by benthic organisms and resuspension caused by physical processes), is the principal ongoing natural recovery process within the LDW. The majority of COCs in LDW sediments are resistant to chemical and biological degradation and dissolution. These mechanisms are not likely to make important contributions to natural recovery in the LDW. Thus, it is reasonable to expect that the primary factor in determining how quickly natural recovery will occur (assuming sources are adequately controlled) is the burial or sediment deposition rate. Recovery is expected to be more rapid in areas with intermediate to high net sedimentation rates and slow where net sedimentation rates are low or where the potential exists for either significant scour or episodic erosion. The bed composition model (BCM) (see Section 5) was developed as a tool to predict recovery as a function of both location within the LDW and of the concentrations of contaminants coming into the LDW from upstream and lateral (e.g., stormwater) sources.

7.1.5.1 Sediment Remediation Projects with an MNR Component

Examples of sediment remediation projects where MNR is a component of a combined remedy or where natural recovery trends have been observed are provided below.

Duwamish/Diagonal EAA (Seattle, Washington)

Data collected during the Duwamish/Diagonal EAA project (Anchor 2007) lend some empirical support to natural recovery potential in the LDW. This project involved a combination of removal (dredging), capping, and thin-layer sand placement. Surface sediment contaminant concentrations are being monitored on and adjacent to the actively remediated areas of the project site (Figure 7-5). Monitoring data associated with the cap and thin-layer sand placement are discussed below in Section 7.1.6. The data collected from stations peripheral to the actively remediated areas are plotted versus time in Figure 7-5 (center chart). The trends suggest that contamination from resuspension and dispersal during the dredging operation may have been responsible for total PCB concentrations remaining high and are consistent with data generated during the investigative phase of the project in the mid-1990s. Since that time, total PCB concentrations have declined by 50% or more in five of the eight perimeter locations, presumably as a result of natural recovery processes (see Appendix F). Net sedimentation rates ranging from 0.7 to 3.1 cm/yr were estimated from radioisotope core data in the Duwamish/Diagonal area, consistent with the STM model predictions (see Appendix F, Figure F-2). The average concentration of the perimeter stations (Figure 7-5) have already decreased (after 5 years) to below modeled predictions of recovery 10 years following remediation (Stern et al. 2009). However, dispersion of some of the newly placed capping material appeared to have initially influenced some immediately adjacent noncapped areas, thereby contributing to the decrease in PCB concentrations seen in the first post-capping year. Unpublished PCB data from 2010 sampling indicate that the total PCB concentration has decreased by approximately 67% from that observed in 2009 (Williston, personal communication, 2010) indicating the area is continuing to recover.

Slip 4 EAA (Seattle, Washington)

Additional empirical support for natural recovery in the LDW can be discerned from the Slip 4 surface sediment dataset, as shown in Figure 7-9, although the conditions in the slip are somewhat different than those in the LDW outside of the slip. This figure shows where surface sediment samples were collected and analyzed for total PCBs within the Slip 4 EAA. These data were divided into two groups representing conditions observed before 1999, and conditions observed in 2004 (see Figure 7-9). The two datasets were analyzed statistically and determined to be significantly different ($p<0.05$; Mann-Whitney two-sample test). The mean total PCB concentration in the 2004 dataset (830 µg/kg dw) is 24% of the mean concentration in the pre-1999 dataset (3,200 µg/kg dw). However, sampling of Slip 4 surface sediments in 2010 revealed increasing PCB concentrations within the EAA, which highlighted the need for additional source control actions (Ecology 2011a). Net sedimentation rates ranging from 1.6 to 3.2 cm/yr have been estimated from radioisotope core data in the Slip 4 area, contributing to the process of natural recovery; these estimated rates are consistent with the STM model predictions (see Appendix F, Figure F-2).

Sangamo Weston/Twelve-Mile Creek/Lake Hartwell (Pickens, South Carolina)

Lake Hartwell and its tributary Twelve-Mile Creek are heavily contaminated with PCBs, which were discharged by the Sangamo Weston Inc. facility between 1955 and 1977. MNR, in combination with institutional controls (fish consumption advisories), was selected by EPA as the main remedy for Operable Unit 2. Net sedimentation rates of 5 to 15 cm/yr, confirmed by radioisotope geochronology, and burial by progressively cleaner sediment over time is the dominant physical process for recovery. Field measurements show a gradual recovery of surface sediments from peak concentrations of approximately 40 mg/kg dw to around 1 mg/kg dw in more recent samples (Magar et al. 2003). In addition, sedimentation for the Twelve-Mile Creek arm of Lake Hartwell has been accelerated by the release of accumulated sediment from three upstream dams. Chemical transformation (i.e., PCB dechlorination) has also been observed via PCB congener analysis of sediment cores with depth and age. This natural process has been found to be slow and limited as a result of anaerobic subsurface sediment, but it has reduced the long-term risks associated with potential sediment resuspension (Magar et al. 2009).

Annual monitoring has been conducted through sediment sampling (at 21 locations within the tributary and lake), fish tissue sampling (at 6 lake locations), and bioaccumulation studies (in caged *Corbicula* clams) to track the progress toward achievement of cleanup objectives. Despite the substantial historical decrease in PCB sediment concentrations (below the 1 mg/kg dw cleanup level), fish tissue concentrations have not decreased accordingly (Magar et al. 2004, Magar et al. 2009). PCB concentrations in catfish fell below the Food and Drug Administration (FDA) tolerance level of 2 mg/kg wet weight (ww) for several years, but this trend has not been sustained since 2005. The other five fish species monitored show no clear trend of decreasing PCB concentrations. Fish consumption advisories remain in effect for Twelve-Mile Creek and Lake Hartwell, because PCB concentrations in fish continue to exceed the FDA tolerance level of 2.0 mg/kg ww.

James River (Hopewell, Virginia)

The chlorinated pesticide Kepone (chlordecone, a carcinogenic chlorinated hydrocarbon) was made and discharged between 1974 and 1975 through the municipal sewage system, surface runoff, and solid waste dumping into the James River estuary in Hopewell (Virginia). Average Kepone concentrations in the channel sediments ranged from 20 to 193 µg/kg dw.

MNR was selected as the main remedy for all areas of the site, and the dominant natural recovery processes were dispersion (in high-energy areas) and physical isolation through natural sedimentation (in low-energy areas). Radioisotope geochronology showed evidence of natural sedimentation within the estuary, ranging from less than 1 cm/yr to greater than 19 cm/yr, with an average of at least 8 cm/yr at 8 of the 21 sediment sampling locations (Magar et al. 2009).

Although Kepone tissue concentrations in James River fish reached as high as 5 mg/kg ww in 1975, the average tissue concentrations had fallen below the FDA action level of 0.3 mg/kg ww by 1986 (Luellen et al. 2006). The last exceedance of the action level in striped bass was measured in 1995, according to the Virginia Department of Environmental Quality (VA-DEQ 2011). However, Kepone continues to be detected in about 94% of fish tissue samples above reporting limits. Continued detections of Kepone are believed to be related to coastal disturbances related to severe weather (Luellen et al. 2006, Magar et al. 2009). The observed decline in fish contamination over the years is thought to be the result of the Kepone being sequestered in the tidal basin sediments of the James River and thus becoming less available to contaminate fish (Lawson 2004).

A fish consumption advisory is still in effect for Kepone, and the VA-DEQ continues to monitor Kepone levels in fish tissue and sediment to address concerns about contaminated sediment resuspension after high-energy events (Magar et al. 2009).

Bremerton Naval Complex (Puget Sound, Washington)

The cleanup of Puget Sound Bremerton Naval Shipyard Complex (PSNS), located on the Sinclair Inlet of Puget Sound at Bremerton (WA), included extensive dredging, capping, ENR, and long-term monitoring of surface sediments to assess natural recovery (EPA 2000c). The marine area of concern (Operable Unit B) in the PSNS is a subtidal section of the inlet, with water depths generally less than 15 m. Baseline total PCB concentrations in sediments within the area of concern were around 13 mg/kg organic carbon (oc) (with a maximum measured concentration of 61 mg/kg oc) (Merritt et al. 2010).

Three rounds of post-remedy monitoring (2003, 2005, and 2007) have been completed, including measures to verify the integrity of remedy components and assess progress toward cleanup goals. In addition, bathymetric surveys, sub-bottom profiling, and collection and analysis of sediment cores were performed. These activities have confirmed that dredging, capping and ENR remedy components are functioning as planned, and that ongoing sediment deposition and mixing (MNR) are occurring naturally (URS 2009).

Sampling of marine sediments throughout Operable Unit B and Sinclair Inlet were also conducted. In 2007, the geometric mean for Operable Unit B Marine sediment total PCB concentrations, estimated on an area-weighted average basis, was 4.5 mg/kg oc (URS 2009); this value exceeded the cleanup goal of 3 mg/kg oc, but it was less than the 2003 and 2005 area-weighted geometric mean values (6.7 and 6.1 mg/kg oc, respectively).

Total PCB concentrations in English sole tissue samples were also analyzed. The 2007 arithmetic mean English sole total PCB concentration was 0.033 mg/kg ww, above the remedial goal of 0.023 mg/kg ww (URS 2009) and well below the concentration of 0.085 mg/kg ww obtained in 2003.

Trend analyses for Operable Unit B Marine performed on the 2003, 2005, and 2007 sediment samples predicted a decreasing trend and indicated that the cleanup goals established in the ROD may be achieved within 10 years after remediation (<3 mg/kg oc for PCBs) and the long-term goal of <1.2 mg/kg oc for PCBs may be achieved by 2017 (EPA 2000, URS 2009, Leisle and Ginn 2009).

7.1.5.2 MNR Summary

NRC (2007) projected that MNR is likely to be a component of many large-scale sediment remediation projects with temporal goals. In the LDW, natural recovery is predicted to occur at varying rates at specific locations within the LDW, as supported by the LDW examples above, modeling, and comparison of co-located sediment samples collected over time (see Appendix F). For these reasons, MNR is retained as a remedial process option for developing the remedial alternatives in this FS. LDW-wide reductions in average concentrations of COCs such as PCBs are necessary to reduce resident fish and shellfish tissue concentrations. Hence, MNR is also evaluated as an LDW-wide "polishing step" for all of the remedial alternatives considered in this FS.

7.1.6 Enhanced Natural Recovery (ENR)

ENR refers to the application of thin layers of clean granular material, typically sand, to a sediment area targeted for remediation. Application thicknesses of approximately 6 inches are common, producing an immediate reduction in surface contaminant concentrations (Figure 7-7). Essentially, ENR reduces the time for sediment concentration reductions over what is possible by relying solely on natural sediment deposition where burial is the principal recovery mechanism (EPA 2005b). Thus, areas that are stable (not expected to erode) and are recovering naturally (albeit slowly) are candidates for ENR. Although ENR is best employed in areas not subject to scour, it may be appropriate in some cases to employ engineered aggregate mixes or engineered synthetic products to ensure stability (Palermo et al. 1998, Agrawal et al. 2007).

Unlike capping, which typically has a much greater application thickness, surface sediment contaminant concentrations in areas that undergo remediation by ENR are expected to be influenced by benthic recolonization and associated bioturbation. These processes result in the mixing of underlying contaminated sediment with the cleaner near-surface material. This is important for remedial design where a surface sediment concentration threshold is typically established below which MNR is appropriate (i.e., cannot be achieved in an acceptable time scale) and above which other active technologies (e.g., dredging or capping) should be considered.

The FS assumes that half of the ENR footprint would warrant amendment with a material such as activated carbon for *in situ* treatment. This assumption provides a basis for estimating costs and comparing the remedial alternatives; however, during remedial design, the emphasis on ENR or *in situ* treatment will depend on location-specific factors and additional testing of the implementability of these technologies. The composition of ENR/*in situ* treatment will depend on additional evaluation during remedial design; it may include carbon amendments, habitat mix, and/or scour mitigation specifications to increase stability and enhance habitat.

7.1.6.1 ENR Sediment Remediation Projects

Examples of ENR sediment remediation projects are provided below.

Ketchikan Pulp Company (Ketchikan, Alaska)

A thin-layer placement was successfully applied in 2001 over the sediments offshore of a former sulfite pulp mill (Ketchikan Pulp Company-KPC) in Ward Cove, Alaska (Merritt et al. 2009, Becker et al. 2009). The primary COCs were ammonia and 4-methylphenol. These COCs are not bioaccumulative. Diffusion of contaminants from underlying sediment was identified as the dominant mode of chemical transport responsible for toxicity to organisms in surface sediment.

The thin-layer cap of fine-grained to medium-grained sand was placed over 28 acres of native sediments to a thickness ranging from 15 to 30 cm (Merritt et al. 2009). In 2004 and 2007, the first and second monitoring events were conducted, and included evaluations of sediment chemistry, sediment toxicity, and benthic macroinvertebrate communities. Concentrations of both COCs in the thin-layer strata were low in 2004, indicating ENR effectiveness. The clean sand placement material was not being noticeably affected by upward migration of the COCs from underlying native sediment; the concentrations of COCs remained low in 2007. For sediment toxicity, amphipod survival was about 93 to 96% in 2004 and remained high in 2007 (92 to 95%). Benthic communities had begun recolonization by 2004 and total abundance increased substantially in 2007 (Becker et al. 2009).

Duwamish/Diagonal EAA Project (Seattle, Washington)

In response to observed increases in surface sediment concentrations of total PCBs adjacent to a portion of the primary dredging and cap area at the Duwamish/Diagonal EAA, a thin layer of sand (9 inches, to ensure a minimum 6-inch coverage everywhere) was placed in February 2005 over 4 acres of sediment, providing immediate reduction in exposures, and reducing total PCB concentrations to between 1 and 32 µg/kg dw (Figure 7-5; Anchor 2006b). Prior to dredging and capping, this adjacent area had an average total PCB concentration of 46 mg/kg oc. Immediately following cap placement, that average tripled to 136 mg/kg oc. This increase in total PCB concentrations was attributed to resuspension and dispersal of contaminated sediment (i.e., dredging residuals) during the removal action. Within the ENR area, total PCB concentrations immediately following thin layer placement were well below the SQS (at a mean of 7 µg/kg dw[6]) because of the clean material placed, achieving its goal of immediately reducing PCBs to below predredge surface sediment concentrations. Subsequent years have shown a slight increase in the PCBs concentrations (Stern et al. 2009). The slight increase is likely due to resuspension of the surrounding sediments and by deposition of upstream and lateral load contributions according to the inputs to the area used in the STM. Modeling, supported by monitoring data and physical measurements of the sediment surface layer, has also shown that the thin sand layer is not significantly mixing with the underlying sediment, consistent with measured bioturbation depths (Stern et al. 2009).

A comparison of the 2008 and 2009 total PCB averages of 8 and 5 mg/kg oc, respectively, to the 2003 predredging/capping average of 46 mg/kg oc (almost a six-fold decrease) demonstrates that ENR continues to maintain exposures below the SQS.

Based on diver probing surveys conducted in April 2009, the thickness of the ENR sand layer exhibited a minor decrease from 2006 to 2009. The estimated thickness of the ENR sand layer ranged between 5 and 10 inches at 11 different sampling locations, while 1 to 8 inches of silt were observed to have accumulated on the surface of the ENR layer.

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6 Total organic carbon content in the March 2005 sampling event was too low to calculate oc-normalized data.

When silt and sand are considered together, the average thickness was 12.8 inches (Anchor QEA 2009). These results are consistent with deposition and bioturbation processes as originally anticipated in the ENR area, but also indicate the presence of a stable surface over a period of time. Post-placement bathymetric monitoring was also conducted and nearly all of the Duwamish/Diagonal cleanup area exhibited accretion over the 5-year period following completion of the ENR remedy.

7.1.6.2 ENR Technology Summary

ENR has sufficient merit and has been sufficiently demonstrated in sediment remediation projects elsewhere to carry this technology forward in developing LDW remedial alternatives. ENR may be applied to broad areas of the LDW with lower levels of contamination, net sedimentation, and where significant erosion is not a concern.

7.2 Institutional Controls

Institutional controls are non-engineered measures that may be selected as remedial or response actions either by themselves or in combination with engineered remedies, such as administrative and legal controls that minimize the potential for human exposure to contamination by limiting land or resource use (EPA 2000e). The National Contingency Plan (NCP) sets forth environmentally beneficial preferences for permanent solutions, complete elimination rather than control of risks, and treatment of principal threats to the extent practicable. Where permanent and/or complete elimination are not practicable, the NCP creates the expectation that EPA will use institutional controls to supplement engineering controls as appropriate for short- and long-term management to prevent or limit exposure to hazardous substances, pollutants, or contaminants. It states that institutional controls may not be used as a sole remedy unless active measures are determined not to be practicable, based on balancing trade-offs among alternatives (40 CFR 300.430 [a][1][iii]).

EPA recommends that where it may provide greater protection, multiple institutional controls should be used in combination, referred to as “layering” by EPA. Institutional controls may be an important part of the overall cleanup at a site, whenever contamination is anticipated to remain following active remediation at concentrations that exceed cleanup levels. Institutional controls may be applied during remedy implementation to minimize the potential for human exposure (as temporary land use or exposure limitations). These controls may also extend beyond the end of construction (or be created at that time) or even after cleanup objectives are achieved to ensure the long-term protectiveness of remedial actions that leave contaminants on site above cleanup levels (as long-term or permanent limitations, e.g., protecting a contaminant barrier like a sediment cap from being accidentally breached).

Institutional controls potentially applicable to cleanup of the LDW site are identified and discussed below. This section describes specific individual controls in sufficient detail to allow for a comparison of remedial alternatives that includes various types and degrees of reliance on institutional controls. An integrated Institutional Controls

Implementation Plan is anticipated for the LDW after the ROD is issued that meets specific location, tribal treaty rights, and community needs. These considerations are discussed further in the FS as part of the development and evaluation of remedial alternatives (Sections 8 and 9).

EPA guidance broadly lists four types of institutional controls: governmental controls, proprietary controls, enforcement tools, and informational devices. However, governmental controls such as the permitting of some (point source but not non-point source) discharges to, or dredging and filling of the LDW, as well as some enforcement controls, such as consent decrees or administrative orders under which settling parties implement remedies including institutional controls, are not discussed at any depth in this FS because they do not inform the choices among alternative remedies. These governmental controls are, for remedy selection purposes, uniform across all alternatives and options (i.e., permitting requirements cannot be changed by remedy selection in the ROD), and consent decrees will be used if responsible parties implement any or all of any remedial action EPA selects in the ROD as required by Section 122(d) of CERCLA. Therefore, the most important institutional controls, or aspects of them, for the development of remedial alternatives are emphasized below. Enforcement tools, even though they are used, for example, to establish enforceable proprietary controls pursuant to consent decrees or orders, are discussed under the category of informational devices. It should be clear at this point that many categories overlap and that the agency guidance that created them was intended to be helpful in analyses rather than necessarily invent divisible categories (e.g., proprietary controls have government enforcement mechanisms to ensure their continuation, and some informational devices can be related to or enhanced by governmental enforcement programs):

- Proprietary controls
- Informational devices
  - Monitoring and notification of waterway users
  - Seafood consumption advisories, public outreach, and education
  - Enforcement tools
  - Environmental Covenants Registry.

These types of institutional controls are outlined below.

7.2.1 Proprietary Controls

Proprietary controls are recorded rights or restrictions placed in property deeds or other documents transferring property interests that restrict or affect the use of property. Covenants are a grant or transfer of contractual rights. Easements are a grant of property rights by an owner, often for a specific purpose (e.g., access, utility, and environmental, among other types of easements). Covenants and easements are essentially legally binding arrangements that allow or restrict usage of property for one or more specific objectives (e.g., habitat protection, protection of human health, etc.). They commonly survive the transfer of properties through real estate transactions and are binding on successors in interest who have not participated in their negotiation. This distinguishes covenants and easements from ordinary contracts or transactions between or among parties. At cleanup sites, covenants and easements commonly control or prevent current and future owners from conducting or allowing activity that could result in the release or exposure of buried contamination as long as necessary. Potential activities controlled or prohibited may include in-water activities (e.g., anchoring, spudding, vessel or tug maneuvering) and construction activities (e.g., pile driving and pulling, dredging, and filling) where buried contamination may become exposed as a result of the activity, as long as it is an activity the owner may legally control. Selecting a less expensive remedy in the form of a proprietary control that limits future property uses in ways a more expensive remedy would not, involves a complex balancing of interests by EPA and Ecology. For example, a proprietary control can lower remedial costs for a former owner at the expense of the redevelopment options of a current owner, who acquired the property after it was contaminated. For this reason, among others, EPA policy and guidance stress assessing reasonably anticipated future land use as an important part of remedy selection generally, and specifically stress limiting use of institutional controls.

Traditionally, covenants or easements were only enforceable by whomever they were granted to, and their successors, depending on how they were crafted. In Washington State, MTCA gave Ecology the right to enforce covenants created under MTCA. More recently, Washington passed its Uniform Environmental Covenants Act (UECA), which allows EPA, as well as the state (in addition to the parties to an UECA covenant), to enforce environmental covenants. For this reason, UECA covenants are anticipated to be the primary proprietary control used in LDW environmental cleanup actions.

Parties with sufficient ownership interests in shorelines and aquatic land could grant UECA covenants that would help ensure that remedial measures (such as sediment caps) are not disturbed. However, UECA covenants may not be implementable or practicable for the publicly-owned, working industrial waterway portions of the LDW where the balancing of interests is especially complex, where access and use are in any case difficult to control, and where the extent of the authority of public entities with ownership or management rights to grant covenants with the full range of controls commonly included in UECA covenants, is uncertain. Another uniquely important interest to consider is the extent to which public entity granted covenants may interfere with tribal treaty-protected seafood harvesting, in particular.

7.2.2 Informational Devices

7.2.2.1 Monitoring and Notification of Waterway Users

The LDW ROD could include an enhanced notification, monitoring, and reporting program for areas of the LDW where contamination remains following cleanup activities. Under such a program, the protection of areas where contamination remains above levels needed to meet cleanup objectives, including areas where capping or CAD containment technology have been utilized, could be enhanced. Such areas could be periodically monitored (by vessels and/or surveillance technology), with vessels performing the dual role of educating potential violators of the existence of activity restrictions, and promptly reporting violations of use restrictions to EPA or Ecology, or the U.S. Coast Guard (USCG) if the area were formally designated as a Restricted Navigation Area (RNA) by formal USCG rulemaking as described in Section 7.2.2.3, Enforcement Tools. Notification to waterway users could further be provided through enhanced signage and other forms of public notice, education, and outreach. A mechanism for the review of any USACE navigation dredging plans and other Joint Aquatic Resource Permit Application (JARPA) construction permitting activity could be established. The review would identify any projects that may compromise containment remedies (cap or CAD) or potentially disturb contamination remaining after remediation, which would include a requirement to promptly notify EPA and Ecology during the permitting phase of any project that could affect cleanup remedies. This mechanism would serve as a backup to an existing Memorandum of Agreement between EPA and USACE for coordinating such permitting, especially if that agreement were to lapse or be discontinued for any reason by either agency in the future.

Additional measures could include: establishing a LDW cleanup protection hotline private citizens could call or email to report potential violations, with a requirement that reports be investigated and conveyed to EPA and Ecology (and the USCG for any RNAs) under specified protocols; and developing and implementing periodic seafood consumption surveys to identify, by population group and geographical location, which seafood species are consumed, where they are consumed, and in what quantities they are consumed. This information would be used to update the Institutional Control Implementation Plan as appropriate and improve seafood consumption advisories and associated public outreach and education. Additional monitoring of the effectiveness of these tools can be used to adapt this approach, as discussed in the next section. The effectiveness of all these measures could be re-evaluated periodically to assess which ones should be continued or be modified.

7.2.2.2 Seafood Consumption Advisories, Public Outreach, and Education

The Washington State Department of Health (WDOH) publishes seafood consumption advisories in Washington. The WDOH currently recommends no consumption of resident seafood from the LDW. Salmon are not resident in the LDW; they are anadromous species that spend most of their lives outside of estuaries like the LDW. WDOH recommendations for Duwamish salmon are the same as for Puget Sound as a whole (e.g., no more than one meal per week of Chinook salmon). The WDOH maintains a web site that includes its advisories and provides publications and other educational forums that cover healthy eating and seafood consumption. In addition, WDOH seafood consumption advisories are posted on signs at public access locations around the LDW. Following these advisories is wholly voluntary, which makes advisories, as a necessity, a last resort. Advisories would also be fundamentally inconsistent with tribal fishing rights secured under treaties of the United States if they were relied on in lieu of cleanup measures intended to provide seafood suitable for consumption. More information can be found at http://www.doh.wa.gov/ehp/oehas/fish/rma10.htm.

The Washington State Department of Fish and Wildlife (WDFW) develops and enforces seasonal restrictions on recreational fishing and seasonal and daily catch limits per individual for various seafood species. WDFW licensing and LDW enforcement activities presumably limit resident LDW seafood consumption to some unknown degree. All recreational fishers over 15 years of age must have a fishing license and comply with specific size, species, and seasonal restrictions on fishing for fish and shellfish throughout the Puget Sound region. In the LDW, all resident fish and shellfish should not be consumed according to WDOH advisories. While WDFW regulations summarize the WDOH seafood consumption advisories, which may enhance their reach and effectiveness, they do not prohibit fishing or shellfishing within the LDW. It is lawful to seasonally collect and consume certain fish and shellfish from the LDW.

Some level of seafood consumption advisories will likely be necessary into the foreseeable future to reduce human health risks from seafood consumption. This is because of the technical impracticability of achieving the seafood consumption cleanup levels under any of the remedial alternatives. Concerns associated with the use of these ICs include the burden placed on tribes exercising their treaty rights and other fishers who use the LDW. Relying on seafood consumption advisories to further reduce human health risks may require fishers to change behavior or make cultural adjustments. This burden is difficult to value precisely given the broad range of needs different fishers may have. Given the diversity of the community that can access the LDW, including tribal members, recreational users, low-income, and non-English-speaking people, additional measures to enhance the effectiveness of seafood consumption advisories and thereby enhance confidence in relying upon them, should be fully and aggressively explored.

An enhanced approach called community-based social marketing was adopted at the Palos Verdes Superfund site in California to reduce the limitations of seafood consumption advisories (EPA 2009a, 2009b). This approach, pioneered by Doug McKenzie-Mohr of St. Thomas University in Canada in 1999, as cited in EPA (2009a), can be summarized broadly as:

- Researching to establish and quantify baseline behaviors and size/demography of different populations and to identify culturally-specific barriers and benefits.
- Defining desired behaviors and understanding barriers to achieving those behaviors; definition of incentives for overcoming barriers and achieving behavior change.
- Creating effective messages/incentives and effective delivery and monitoring mechanisms.
- Implementing culturally-appropriate outreach to all target populations using brief, clear, tested messages and incentives.
- Following up on research after a time period to monitor and evaluate levels of behavior change and to modify the approach as needed.

Application of community-based social marketing concepts in the LDW, modeled after the program and experience-base developed for the Palos Verdes site, could improve the effectiveness of existing seafood consumption advisories for protecting human health.

A collaborative advisory group could be convened to develop an LDW-specific framework and technical approach. Likely participants would include EPA, Ecology, WDOH, WDFW, and other interested federal, state, and local government agencies such as the National Oceanic and Atmospheric Administration, the Seattle Department of Neighborhoods, and ethnically-specific community group leaders, as well as non-governmental organizations and settling parties. A key mandate of the advisory group would be the founding of a small, credible, and knowledgeable core team to facilitate the effort (e.g., develop and complete surveys to better understand affected populations [demographics], and potential incentives for and barriers to improving the effectiveness of seafood consumption advisories).

The overarching goal of this effort would be to develop and implement a public outreach and education program that focuses on incentives and activities that research indicates have the greatest likelihood of adoption and would make the greatest substantive difference in environmental health. Ideally, the program would be coordinated with other health-based initiatives such as the City of Seattle's urban agriculture initiative.

Implementation of the outreach and education program could be accomplished in a number of ways, stressing culturally-appropriate teams, objective and credible participants, and a systematic approach to applying, documenting, and quantifying results of the approach. The advisory group would recommend program elements based on ideas generated by the group and the affected communities, and a review of approaches demonstrated to have caused positive behavior changes at other sites. It would also recommend appropriate programmatic changes as needed based on the evolution of monitoring and survey-based information. Example elements of the outreach and education program for enhancing the effectiveness of seafood consumption advisories include:

- Establish a website to provide up-to-date information on seafood contaminant concentrations and consumption advisories.
- Increase the use of signs containing advisory information at fishing locations.
- Conduct outreach efforts at fishing locations on a regular and periodic basis.
- Ensure all recreational anglers receive seafood consumption advisory information when purchasing licenses.
- Disseminate advisory-related information at community health facilities, schools, and at community-based functions such as health fairs.
- Encourage medical and other health professionals to communicate risks to the public.

A significant difference between the Palos Verdes site and the LDW is the presence in the LDW of tribal fishing rights secured by treaties of the United States. Nothing in this section or anywhere in this FS is intended to suggest that exercise of such rights, or the underlying cultural traditions, would be precluded by seafood consumption advisories and related programs to reduce contaminated seafood consumption as part of LDW remedial action. For this reason, the seafood consumption advisories, and public outreach education programs should be developed in consultation with affected tribes to develop accommodations for such tribes to the greatest extent practicable. A significant limitation of the Palos Verdes enhancement to conventional seafood consumption advisories is that individual responses remain entirely voluntary.

7.2.2.3 Enforcement Tools

As mentioned above in the context of the potential development of monitoring and notification programs as a selected component of remedial action for the LDW, RNAs are created by the promulgation of formal rules by the USCG. RNAs represent an enforceable means of protecting containment remedies and other areas where contamination remains from anchoring and other physical interference, particularly where UECA covenants or other proprietary controls may not be achievable, such as within Commercial Waterway District #1. To the extent that RNAs may potentially interfere with seafood harvest activities, particularly tribal harvests, engineered or other alternative means of accommodating fish harvest should be devised (e.g., alternative means of allowing anchoring or tying off a net within a RNA-created no-anchor zone).

Although this option has the significant potential to regulate potential impacts associated with anchorage, barge spudding, and tugboat propeller wash, it could restrict maritime commerce or preclude commercial activities generally necessary for construction, maintenance, and operation of commercial piers, depending on where the RNA was located. Like proprietary controls generally, even for sediment areas in private ownership, RNAs require a careful and often highly complex balancing of competing interests, and may only be useful in certain locations or circumstances. Whenever the government limits or adversely affects property rights, it may be subject to takings claims by affected persons based on the Fifth Amendment to the Constitution of the United States.

7.2.2.4 Environmental Covenants Registry

Placement and maintenance of LDW areas, with containment remedies (cap or CAD) or anywhere where contamination remains above levels needed to meet cleanup objectives, on Ecology's Environmental Covenants Registry in its Integrated Site Information System) would provide information regarding applicable restrictions (RNAs and proprietary controls) to anyone who uses or consults the state registry.

7.2.3 Institutional Controls Summary

In summary, it must be emphasized that all of the institutional controls described in this section are difficult to enforce. Privately owned sediments, like publicly owned sediments, in an urban commercial waterway are generally substantially more difficult to guard or restrict uses of than upland properties. Further, it is anticipated that some people, including tribal members with treaty-protected harvest rights, will choose to fish and consume what they catch regardless of seafood consumption advisories and robust public outreach and education programs. For these reasons, institutional controls will be relied on only to the extent necessary to develop practicable remedial actions for the LDW.

7.3 Monitoring

Monitoring is an important assessment and evaluation tool for collecting data and is a requirement of remedial alternatives conducted under CERCLA and MTCA. Monitoring data are collected and used to assess the completeness of remedy implementation, remedy effectiveness, and the need for contingency actions. The sampling and testing process options common to most sediment remediation projects are as follows:

- Sediment quality (e.g., chemistry, grain size distribution)
- Sediment toxicity
- Surface water quality (e.g., conventional parameters and contaminant concentrations)
- Contaminant concentrations in porewater

- Contaminant concentrations in fish and shellfish tissue
- Physical (e.g., visual inspections, bathymetry).

Typically, these sampling and testing process options are prescribed components of project monitoring plans which, in turn, focus on different aspects of the remedial action. For example, monitoring during the construction phase has different objectives than the operation and maintenance (O&M) monitoring that follows construction. Five different monitoring concepts that form the basis for individual or combined monitoring plans, depending on project-specific circumstances, are described below.

In addition, source control monitoring (addressed under Tier 4 of the source control strategy, see Section 2.4) and evaluation within upland drainage basins will be required by Ecology in parallel with in-water monitoring for remedial actions and may include parties other than those responsible for performing the remedial action. The goal of source control monitoring is to determine the potential for recontamination in areas that have already been remediated and become subsequently recontaminated above LDW cleanup levels. Type and scope of source control monitoring is not discussed in the FS since this varies on a site by site basis.

7.3.1 Baseline Monitoring

Baseline monitoring establishes a statistical basis for comparing physical and chemical site conditions prior to, during, and after completion of a cleanup action. Baseline monitoring for the LDW will likely entail the sampling and analysis of sediment, surface water, and tissue samples in accordance with a sampling design that enables such a statistical comparison of conditions.

7.3.2 Construction Monitoring

Construction monitoring during active remediation is area-specific and short-term and is used to evaluate whether the project is being constructed in accordance with plans and specifications (i.e., performance of contractor, equipment, and environmental controls). This type of monitoring evaluates water quality in the vicinity of the construction operations to determine whether contaminant resuspension and dispersion are adequately controlled.

Further, bathymetric monitoring data establish actual dredge prisms or the placement location and thickness of cap material.

7.3.3 Post-construction Performance Monitoring

Post-construction performance monitoring at the conclusion of in-water construction evaluates post-removal sediment conditions in dredging or containment areas. Both chemical and physical data are collected to determine whether the work complies with project specifications.

7.3.4 Operation and Maintenance (O&M) Monitoring

O&M monitoring refers to data collection for the purpose of tracking the technology performance, long-term effectiveness, and stability of individual sediment cleanup areas.

In capping areas, O&M monitoring typically consists of analysis including COCs, grain size, TOC, and cap thickness using sediment or porewater matrices. A combination of tools, including bathymetry soundings, surface grab samples, sediment cores, diver surveys, peepers, staking, and/or settlement plates is used to evaluate cap performance. Some of these tools are also used for ENR and MNR performance monitoring.

7.3.5 Long-term Monitoring

Long-term monitoring evaluates sediment, tissue, and water quality at the site for an extended period following the remedial action to assess risk reduction and progress toward achievement of cleanup objectives. Data collected under long-term monitoring yields information reflecting the combined actions of sediment remediation and source control.

7.3.6 Monitoring Summary

Monitoring is an essential element of remedial alternatives developed in this FS. Appendix K set forth key assumptions and an overall framework for monitoring using the process options and monitoring objectives described above. Appendix K also cross references these monitoring terms and concepts with those used in MTCA.

7.4 Ancillary Technologies

7.4.1 Barge Dewatering

Dewatering mechanically dredged sediment on transfer barges prior to additional sediment handling (e.g., off-loading and disposal) is an important interim management step. Dewatering produces a more consolidated sediment load and reduces the volume of water that would otherwise need to be managed elsewhere (e.g., at a transloading facility or at a landfill). Typically, the dewatering step occurs on a transfer barge within the dredge operations area by gravity settling and separation. In the past, the separated water was decanted directly back to the receiving water without further treatment. This confines the discharge to the area that is already seeing elevated turbidity as a result of dredge operations. Barge dewatering in this manner is typical of sediment remediation projects conducted in the Puget Sound region and this FS assumes it will be part of the remedial alternatives for costing purposes. As discussed below, more recent projects have included treatment.

Examples of Puget Sound region projects that used this technology are provided below. Each was implemented in compliance with project-specific water quality certifications.

Todd Shipyards (Seattle, Washington)

A patented (General Construction Company) sloping drain barge was used on this project. The technique involved ballasting one end of the barge with ecology blocks to create a sloping deck surface, which in turn, promotes gravity drainage to the down-slope end of the barge (Figure 7-10). The down-slope end of the barge is equipped with an overflow weir. The separated water was released directly back into the receiving water without further treatment.

Denny Way and East Waterway Phase 1 (Seattle, Washington)

For these two projects, dredged material was placed on flat-deck barges equipped with fabric-lined scuppers to allow gravity drainage of sediment. Sediment was retained in the barge, while the separated water was decanted directly back into the receiving water through the scuppers without further treatment.

Hylebos Waterway Sediment Remediation (Tacoma, Washington)

Dredged material was placed in hopper barges for gravity dewatering. Excess water from the hopper barge was decanted, treated to the water quality standards set for the project, and released back into the waterway. During the initial project phase, water treatment consisted of adding flocculants followed by routing the water through a series of weirs to enable suspended solids removal prior to discharging the water to the water body. During the final phase, a combination of flocculants and mixing tanks were used to treat the water prior to release to the water body.

Slip 4 Non-Time Critical Removal Action (Seattle, Washington)

For the recently completed Slip 4 project (one of the EAAs), a barge-based process was used that filtered the decant water through geotubes and several layers of geotextile fabric, and then drained the filtered water through granular activated carbon. While not a required element of the Slip 4 project, this step reduced turbidity in the return water. The project was completed in compliance with the water quality permit issued for the project.

7.4.2 Wastewater Treatment Associated with Sediment Remediation

Remedial alternatives that involve the removal and upland handling of contaminated sediment invariably generate wastewater that must be managed, treated, and discharged in a manner consistent with ARARs. Wastewater treatment technologies (e.g., for treatment of stormwater or industrial wastewater) are standard, myriad, and ubiquitous in their application to a wide variety of site-specific conditions. Treatment trains using conventional equipment are capable of treating water generated during sediment remediation projects to levels consistent with ARARs.

Section 8 assumes wastewater treatment would be required at a transloading facility to manage water generated from dewatering of sediments. Selection of an appropriate treatment train for this wastewater would require characterizing the wastewater properties and, potentially, conducting some treatability testing. The process options likely to be employed are expected to be standard and commercially available. For example, a common treatment train consists of gravity separation to remove suspended solids, media (e.g., sand) filtration, and adsorption on granular activated carbon for removal of dissolved organic compounds. Depending on dissolved metals concentrations, a chemical coagulation/flocculation process step might also be required. Discharge of treated water, similar to the soil-washing water treatment discharge (Section 7.1.2.2), would likely be directly back to the LDW after treatment, and would be governed by a CWA 401 water quality certification.

Discharge to the King County Metro sewer system could also be considered where the discharge meets flow (i.e., capacity) and chemical parameter limits. This approach would be an off-site disposal action, potentially requiring pretreatment to achieve discharge criteria and comply with all permit requirements (e.g., daily discharge volume, etc.), so as not to contribute to an overflow event (e.g., holding tanks for monitored flow).

7.4.3 Best Management Practices

Implementation of best management practices (BMPs) is widely considered essential to sediment cleanup projects (NRC 2007). BMPs are particularly important for environmental dredging to minimize release to the environment of contaminated material (sediment, water, debris) from the dredging footprint, and during barge transport, off-loading, and upland rehandling.

Environmental dredging to remove COCs also causes some residual sediment contamination (Palermo 2008). Contaminated sediments that are dislodged or suspended by the dredging operation are subsequently redeposited on the bottom either within or adjacent to the dredging footprint. The primary causes for this residual contamination are described in Section 7.1.1.2.

Resuspended residuals generally accumulate (settle) above the dredging cutline in thin layers, and are characterized by fine-grained sediment, being unconsolidated, having a high moisture content, and possibly existing as a fluid mud layer. The constituent COC concentrations in the residual layer can be approximated using the average dredge prism concentration (Hayes and Patmont 2004). The residual layer can be present within and adjacent to the dredge prism.

Potential BMPs to evaluate during design for dredging residuals and water quality management include:

- Remove debris prior to dredging.
- Minimize residuals generation by dredge control and design, such as carefully controlling depth, location, and cutting action to maximize sediment capture and minimize sloughing and bottom impacts. Optimize the fill efficiency of a dredge bucket to minimize both free-water capture and overfill fallback.

- Control speed of bucket through the water column to minimize loss of adhered sediment.
- Allow sediment-filled bucket to drain before fully emerging above the water surface.
- Contain drippage during the overwater swing of a filled bucket (e.g., by placing an empty barge or apron under the swing path during offloading).
- Wash bucket prior to lowering back into the water column.
- Use environmental or sealed bucket if practicable and if proper sediment conditions exist.
- Start dredging in upslope areas and move downslope to minimize sloughing.
- Plan multiple dredge cuts: limit initial cut depths to avoid sloughing of the cut bank; plan initial cut(s) to remove most of the contamination; and design a final "cleanup" cut into subsurface "clean" sediment to lower the average dredge prism COC concentrations.
- Use floating and/or absorbent booms to capture floating debris or oil sheens.
- Use conventional construction stormwater BMPs to control and reduce the silt burden in runoff from barges or rehandling areas.
- Develop and implement a post-dredging residuals monitoring and management plan.
- Monitor natural recovery of dredged area.
- Place a thin-layer sand cover (ENR) to address residuals.

The use of silt curtains around the dredging operations to reduce the transport of suspended solids is an engineering control that can be employed under certain circumstances. However, the effectiveness of a silt curtain is primarily determined by the hydrodynamic conditions at the site (usually relatively shallow, quiescent water, without significant tidal fluctuations are preferred), the quantity and type of suspended solids, the mooring method, and the characteristics of the barrier. Often, strong currents (greater than 2.5 ft/second) are problematic, and any application and deployment of silt curtains for high velocities would require special design and engineering features (USACE 2008a). In the Puget Sound region, silt curtains are not frequently used in areas where there are large tidal excursions, high-flow velocities, conflicts between dredging activities and navigation, or other technical limitations.

The specific array of BMPs or engineering controls implemented during cleanup will be location-specific and will be determined during design of the remedial alternative. Often, the remedial design specifications define certain BMPs along with performance requirements (such as water quality standards) to which the contractor must adhere. The contractor typically is required to provide additional details on specific BMPs in their work plans. Monitoring and adaptive management are common practices that will be used to refine and optimize BMPs throughout the duration of the project to ensure compliance with the project performance requirements. Representative BMPs have been identified as part of the FS remedial alternatives to develop cost estimates.

7.5 Summary of Representative Process Options for the FS

The shaded rows of Table 7-4 show the representative technology process options carried forward to Section 8 for potential development and evaluation of remedial alternatives. Consistent with CERCLA guidance, alternate process options may be considered during remedial design.

The suite of technologies and institutional controls is consistent with most of the sediment feasibility studies and cleanup projects conducted to date within the Puget Sound region and around the country. Further, it is consistent with recent deliberations and reports that have emerged from the sediment remediation community nationwide (NRC 2007). These reports conclude that a limited number of engineering approaches are available to address sediment cleanup and that some combination of dredging, disposal, capping, ENR, and MNR will invariably be at the core of almost every future major project.

Table 7-1 Initial Screening of Candidate Remedial Technologies

GRA	Technology Type	Process Option	Description
No action	None	Not applicable	No active remedy or monitoring.
Institutional controls	Proprietary controls and informational devices (EPA 2000)	Proprietary controls	Mechanisms in deeds or other instruments transferring property that restrict or affect the use of property
		Seafood Consumption Advisories, Education and Public Outreach	Public advisories that consumption of resident LDW fish and shellfish (and sediment contact) may present health risks.
		Monitoring and notification of waterway users	Regulatory constraints on uses such as vessel wakes, anchoring, and dredging. Physical constraints, such as fencing and signs, placed on property access points that limit human access to areas that pose a health risk.
		Enforcement Tools	Agency consent decrees or orders overseeing implementation of institutional controls and monitoring. Restrictive Navigation Areas, per Coast Guard formal rulemaking, could be an enforceable means of protecting containment remedies and other areas from anchoring and other physical interference, particularly where UECA covenants or other proprietary controls may not be achievable.
		Site Registry	Placement and maintenance of site information on the State Registry (Ecology's Hazardous Sites list and Site Register) would provide information regarding restrictions on the property.
Monitoring	Physical and chemical assessment	Baseline Monitoring	Establishes a statistical basis for comparing site conditions before, during, and after the cleanup action.
		Construction Monitoring	Short-term monitoring during remediation used to evaluate whether the project is being constructed in accordance with specifications (i.e., water quality monitoring, bathymetric surveys, discharge monitoring, inspection surveys, sediment monitoring).
		Post-construction Performance Monitoring	Post-construction performance monitoring evaluates post-removal surface and subsurface sediment conditions in dredging or containment areas to confirm compliance with project specifications.
		Long-term Operation and Maintenance Monitoring	Long-term operation and maintenance monitoring of dredging areas, containment, and/or disposal sites (i.e., CAD sites, ENR, and capping areas) required to ensure long-term effectiveness and continued stability of the structure.
		Long-term Monitoring	Long-term monitoring evaluates sediment, tissue, and water quality at the site for an extended period following the remedial action.
Monitored natural recovery	Chemical/physical transport and degradation	Combination	Desorption, dispersion, diffusion, dilution, volatilization, resuspension, and transport.
	Biological degradation	COC metabolism	Chlorine atoms are removed from PCB molecules by bacteria; however, toxicity reduction is not directly correlated to the degree of dechlorination. PAHs may be partially or completely degraded.
	Physical-burial processes	Sedimentation	Contaminated sediments are buried (by naturally occurring sediment deposition) to deeper intervals that are less biologically available. (Resuspension and transport are minor components of MNR.)

Table 7-1 Initial Screening of Candidate Remedial Technologies (continued)

GRA	Technology Type	Process Option	Description
Enhanced natural recovery	Thin-layer placement	Placement of thin layer to augment natural recovery	Application of a thin layer of clean sand and natural resorting, sedimentation, or bioturbation to mix the contaminated and clean sediments, resulting in acceptable contaminant concentrations.
Containment	Capping	Conventional sand cap	Placement of clean sand over existing contaminated bottom to physically isolate contaminants.
		Conventional sediment / clay cap	Use of dredged fine-grained sediments or commercially obtained clay materials to achieve contaminant isolation.
		Armored cap	Coarse granular material such as: cobbles, pebbles, or larger material are incorporated into the cap to prevent erosion in high-energy environments or to prevent cap breaching by bioturbators (example: membrane gabions).
		Composite cap	Soil, media, and geotextile cap placed over contaminated material to inhibit migration of contaminated pore water and/or inhibit bioturbators.
		Spray cap	Placement of capping materials (usually concrete) by spraying concrete or mortar from a nozzle at high velocity onto a surface via pressure hoses with either a dry or wet mix process.
		Reactive cap	Incorporation of materials such as granular activated carbon or iron filings to provide chemical binding or destruction of contaminants migrating in porewater.
Removal	Dredging	Hydraulic dredging	Hydraulic dredges use a cutter head, and suction provided by an on-board pump(s) to agitate, entrain, and hydraulically transport sediment via pipeline to a land-based sediment handling facility or slurry discharge location.
		Mechanical dredging	A barge-mounted floating crane on a derrick barge maneuvers a dredging bucket. The bucket is lowered into the sediment; when the bucket is withdrawn, the jaws of the bucket are closed, retaining the dredged material.
		Mechanical dredging (excavator)	Excavator dredges use a barge-mounted excavator with fixed arm linkages (boom and stick), instead of cables, to position the clamshell bucket at the target elevation for sediment removal.
	Excavating	Dry excavation	Sediment is removed by upland-based conventional excavation (backhoe) equipment. Removal during low tides may not require sheet-pile walls or cofferdams. This removal option may include erecting sheet-pile walls or a cofferdam around the contaminated sediments to dewater.
In Situ treatment	Biological*	*In situ* slurry biodegradation*	Anaerobic, aerobic, or sequential anaerobic/aerobic degradation of organic compounds with indigenous or exogenous microorganisms. Oxygen, nutrients, and pH are controlled to enhance degradation. Requires sheet piling around entire area and slurry treatment performed using aerators and possibly mixers.
		In situ aerobic biodegradation*	Aerobic degradation of sediment *in situ* with the injection of aerobic biphenyl enrichments or other co-metabolites. Oxygen, nutrients, and pH are controlled to enhance degradation.
		In situ anaerobic biodegradation*	Anaerobic degradation *in situ* with the injection of a methanogenic culture, anaerobic mineral medium, and routine supplements of glucose to maintain methanogenic activity. Nutrients and pH are controlled to enhance degradation.

Table 7-1 Initial Screening of Candidate Remedial Technologies (continued)

GRA	Technology Type	Process Option	Description
In Situ treatment (cont)	Biological	Imbiber Beads™*	A "cover blanket" of Imbiber Beads™ placed over contaminated sediments to enhance anaerobic microbial degradation processes and allow exchange of gases between sediments and surface water. The beads are spherical plastic particles that would adsorb PCB vapors generated.
	Chemical*	Aqua MecTool™ oxidation*	A caisson (18' by 18') is driven into the sediment and a rotary blade is used to mix sediment and add oxidizing agents such as ozone, peroxide, or Fenton's reagent. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		In situ oxidation*	Oxidation of organics using oxidizing agents such as ozone, peroxide, or Fenton's reagent.
		Electro-chemical oxidation*	Proprietary technology in which an array of single steel piles is installed and low current is applied to stimulate oxidation of organics.
	Physical-extractive processes*	Sediment flushing*	Water or other aqueous solution is circulated through contaminated sediment. An injection or infiltration process introduces the solution to the contaminated area and the solution is later extracted along with dissolved contaminants. Extraction fluid must be treated and is often recycled.
		In situ slurry oxidation*	An array of injection wells is used to introduce oxidizing agents such as ozone to degrade organics.
	Phy*sical-immo*bilization	Aqua MecTool™ stabilization*	A caisson (18' by 18') is driven into the sediment and a rotary blade is used to mix sediment and add stabilizing agents. A bladder is placed in the caisson to reduce TSS and the vapors may be collected at the surface and treated.
		Vitrification*	Uses an electric current *in situ* to melt sediment or other earthen materials at extremely high temperatures (2,900-3,650 °F). Inorganic compounds are incorporated into the vitrified glass and crystalline mass and organic pollutants are destroyed by pyrolysis. *In situ* applications use graphite electrodes to heat sediment.
		Ground freezing*	An array of pipes is placed *in situ* and brine at a temperature of -20 to -40°C is circulated to freeze soil. Recommended only for short duration applications and to assist with excavation.
		Activated Carbon Amendment **	Activated carbon (powder, granules, or pellets) serves as an amendment to the bioactive surface layer of sediment. Hydrophobic organic contaminants adsorb to activated carbon particles, reducing porewater contaminant concentrations and bioavailability for uptake by organisms.
		Organoclay Amendment **	Organoclay products for use in sediment remediation consist of mineral clay, polymer additives, and an aggregate core for densification. Organoclays bind contaminants through replacement of metal ions with amines or other functional groups, physically isolate the contaminated sediment from receptors (because of low permeability), and stabilize sediment by preventing resuspension and transport of contaminants.

Table 7-1 Initial Screening of Candidate Remedial Technologies (continued)

GRA	Technology Type	Process Option	Description
Ex Situ treatment	Biological*	Landfarming/ Composting*	Sediment is mixed with amendments and placed on a treatment area that typically includes leachate collection. The soil and amendments are mixed using conventional tilling equipment or other means to provide aeration. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation. Other organic amendments such as wood chips, potato waste, or alfalfa are added to composting systems.
		Biopiles*	Excavated sediments are mixed with amendments and placed in aboveground enclosures. This is an aerated static pile composting process in which compost is formed into piles and aerated with blowers or vacuum pumps. Moisture, heat, nutrients, oxygen, and pH can be controlled to enhance biodegradation.
		Fungal biodegradation*	Fungal biodegradation refers to the degradation of a wide variety of organopollutants by using fungal lignin-degrading or wood-rotting enzyme systems (example: white rot fungus).
		Slurry-phase biological treatment*	An aqueous slurry is created by combining sediment with water and other additives. The slurry is mixed to keep solids suspended and microorganisms in contact with the contaminants. Upon completion of the process, the slurry is dewatered and the treated sediment is removed for disposal (example: sequential anaerobic/aerobic slurry-phase bioreactors).
		Enhanced biodegradation*	Addition of nutrients (oxygen, minerals, etc.) to the sediment to improve the rate of natural biodegradation. Use of heat to break carbon-halogen bonds and to volatilize light organic compounds (example: D-Plus [Sinre/DRAT]).
	Chemical*	Acid extraction*	Contaminated sediment and acid extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use.
		Solvent extraction(s)*	Contaminated sediment and solvent extractant are mixed in an extractor, dissolving the contaminants. The extracted solution is then placed in a separator, where the contaminants and extractant are separated for treatment and further use (example: B.E.S.T.™ and propane extraction process).
	Chemical/ Physical	Reduction/ Oxidation*	Reduction/oxidation chemically converts hazardous contaminants to nonhazardous or less toxic compounds that are more stable, less mobile, and/or inert. The oxidizing agents most commonly used are hypochlorites, chlorine, and chlorine dioxide.
		Slurry oxidation*	The same as slurry-phase biological treatment with the exception that oxidizing agents are added to decompose organics. Oxidizing agents may include ozone, hydrogen peroxide, and Fenton's reagent.
		Dehalogenation*	Dehalogenation process in which sediment is screened, processed with a crusher and pug mill, and mixed with sodium bicarbonate (base catalyzed decomposition) or potassium polyethylene glycol. The mixture is heated to above 630 °F in a rotary reactor to decompose and volatilize contaminants. Process produces biphenyls, olefins, and sodium chloride.

Table 7-1 Initial Screening of Candidate Remedial Technologies (continued)

GRA	Technology Type	Process Option	Description
Ex Situ treatment (cont)	Chemical/ Physical (cont)	Soil washing	Contaminants sorbed onto fine soil particles are separated from bulk soil in an aqueous-based system on the basis of particle size. The wash water may be augmented with a basic leaching agent, surfactant, pH adjustment, or chelating agent to help remove organics and heavy metals.
		Radiolytic dechlorination*	Sediment is placed in alkaline isopropanol solution and gamma irradiated. Products of this dechlorination process are biphenyl, acetone, and inorganic chloride. Process must be carried out under inert atmosphere.
	Physical	Particle Separation	Contaminated fractions of solids are concentrated through gravity, magnetic, or sieving separation processes.
		Solar detoxification*	Through photochemical and thermal reactions, the ultraviolet energy in sunlight destroys contaminants.
		Solidification	The mobility of constituents in a "solid" medium is reduced through addition of immobilization additives.
	Thermal	Incineration*	Temperatures greater than 1,400°F are used to volatilize and combust organic contaminants. Commercial incinerator designs are rotary kilns equipped with an afterburner, a quench, and an air pollution control system.
		High Temperature Thermal Desorption*	Temperatures in the range of 600-1,200°F are used to volatilize organic contaminants. These thermal units are typically equipped with an afterburner and baghouse for destruction of air emissions. Wastes are heated to volatilize water and organic contaminants. A carrier gas or vacuum system transports volatilized water and organics to the gas treatment system (examples: X*TRAX™, DAVES, Tacuik Process, and Holoflite™ Dryer).
		Low Temperature Thermal Desorption*	Temperatures in the range of 200-600°F are used to volatilize and combust organic contaminants. These thermal units are typically equipped with an afterburner and baghouse for treatment of air emissions.
	Thermal (cont)	Pyrolysis*	Chemical decomposition is induced in organic materials by heat in the absence of oxygen. Organic materials are transformed into gaseous components and a solid residue (coke) containing fixed carbon and ash.
		Vitrification*	Current technology uses oxy-fuels to melt soil or sediment materials at extremely high temperatures (2,900-3,650°F).
		High-pressure oxidation*	High temperature and pressure are used to break down organic compounds. Operating temperatures range from 150-600°C and pressures range from 2,000-22,300 MPa (examples: wet air oxidation and supercritical water oxidation).

Table 7-1 Initial Screening of Candidate Remedial Technologies (continued)

GRA	Technology Type	Process Option	Description
Disposal	On-site disposal	Level-bottom cap*	Relocation of contaminated sediment to discrete area and capping with a layer of clean sediments. Provides similar protection as capping, but requires substantially more sediment handling that may cause increased releases to surface water.
		Contained Aquatic Disposal (CAD)	Untreated sediment is placed within a lateral containment structure (i.e., bottom depression or subaqueous berm) and capped with clean sediment.
		Confined Disposal Facility (CDF)	Untreated sediment is placed in a nearshore CDF that is separated from the river by an earthen berm or other physical barrier and capped to prevent contact. A CDF may be designed for habitat purposes.
	Off-site Disposal	Subtitle D landfill	Off-site disposal at a licensed commercial facility that can accept nonhazardous sediment. Regional landfills can accept both dewatered and wet sediments.
		Subtitle C landfill	Off-site disposal at a licensed commercial facility that can accept hazardous dewatered sediment removed from dredging or excavation. Dewatering required to reduce water content for transportation.
		TSCA-licensed landfill*	Off-site disposal at a licensed commercial facility that can accept TSCA sediment. Dewatering required to reduce water content for transportation.
		DMMP open water non-treated (if acceptable) disposal	Treated or separated sediment is placed at the Elliott Bay DMMP disposal site. Requires that the placed sediment be at, or below, DMMP disposal criteria for priority pollutants and potentially bioaccumulative contaminants.
		Upland MTCA confined fill (commercial/industrial – beneficial use)*	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, MTCA cleanup levels at an off-site location and meet nondegradation standards. Location may require cap or other containment devices based on analytical data.
		Upland MTCA fill (residential/clean – beneficial use)	Treated or untreated sediment is placed at an off-site location. Requires that sediment be at, or treated to, a concentration at or below MTCA cleanup levels for unrestricted land use and meet nondegradation standards.
		In-water beneficial use	Sediments treated to below DMMP guidelines may be beneficially reused for habitat creation, capping, or residual management.

Notes:

[shaded box] Shaded technologies and process options are retained at end of initial screening as potentially feasible at the end of the Table 7-2 series, where more detailed screening information is provided. These process options were retained at the conclusion of the detailed screening and are evaluated in Table 7-3 for applicability in the LDW with the exception of institutional controls, which do not lend themselves to comparison on the same terms as other technologies. Institutional controls are discussed only within Section 7.2 and are not included in Tables 7-2 and 7-3.

A detailed description of these process options is not included in the FS text. Details regarding these technology and process options are provided in the document *Identification of Candidate Cleanup Technologies for the Lower Duwamish Waterway* prepared by The RETEC Group Inc. (2005). These process options were eliminated in the detailed screening process shown in Table 7-2 series. The *in situ* treatment (activated carbon and organoclay amendments) have been added to this table as a result of recent advances in these technologies and project case studies now available for review.

CAD = contained aquatic disposal; CDF = confined disposal facility; COC = contaminant of concern; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; GRA = general response action; MTCA = Model Toxics Control Act; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; TSCA = Toxic Substances Control Act; TSS = total suspended solids; UECA = Uniform Environmental Covenants Act

Table 7-2a Detailed Screening of Process Options: No Action, Institutional Controls, and Monitoring

GRA	Technology Type	Process Option	Effectiveness		Implementability				
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	Cost
No Action	None	Not Applicable	—	Retained per NCP requirement	Technically implementable for conditions within the LDW.	—	—	Retained per NCP requirement	Low
Institutional Controls				All retained				All retained	Low
Monitoring	Physical and Chemical Assessment	Baseline Monitoring	Can be effective for evaluating changes.	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate
		Construction Monitoring	Can be effective for evaluating changes.	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Low
		Post-construction Performance Monitoring	Can be effective for evaluating changes	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Low
		Operation and Maintenance Monitoring	Can be effective for evaluation and maintenance of LDW following remedial actions	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate
		Long-term Monitoring	Can be effective for evaluating sediment, tissue and water quality over an extended period of time following remedial actions	Retained for further evaluation	Technically implementable for conditions in the LDW.	Available and demonstrated	—	Retained for further evaluation in the FS	Moderate to High

Note:
COC = contaminant of concern; CTM = Candidate Technologies Memo; FS = feasibility study; GRA = general response action; NCP = National Contingency Plan

Table 7-2b Detailed Screening of Process Options: Monitored Natural Recovery and Enhanced Natural Recovery

GRA	Technology Type	Process Option	Effectiveness Screening		Implementability				Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Monitored Natural Recovery	Chemical Degradation	Natural Désorption, Diffusion, Dilution, Volatilisation	Potentially effective for immobilizing COCs through TOC or sulfide sorption.	Retained for further evaluation	Technically implementable for conditions within the LDW	—	—	Retained for further evaluation in the FS	Low
Monitored Natural Recovery	Biological Degradation	COC Metabolism (aerobic and anaerobic)	Effective for SVOCs and PAHs but does not result in complete destruction of PCBs or TBT in acceptable time frame. Not applicable to metals.	Retained for further evaluation	Technically implementable for conditions within the LDW	—	—	Retained for further evaluation in the FS for SVOCs only	Low
Monitored Natural Recovery	Physical/Burial Processes	Natural Sedimentation and Burial (resuspension and transport are minor components of MNR)	Potentially effective for LDW COCs via deposition and reburial. Requires demonstration of long-term deposition and burial.	Retained for further evaluation	Technically implementable for conditions within the LDW	Preliminary results at some projects show some success.	—	Retained for further evaluation in the FS	Low
Enhanced Natural Recovery	Thin-layer Placement	Thin-layer Placement	Effective for all LDW COCs. Applicable: 1) at areas where MNR processes are demonstrated, but faster recovery is required; or 2) as a residual management tool after completion of a removal action.	Retained for further evaluation	Technically implementable for conditions within the LDW.	Thin-layer placements for ENR and residuals management have been applied in multiple locations in Puget Sound and nationally.	—	Retained for further evaluation in the FS	Low to Moderate

Note:

CTM = Candidate Technologies Memorandum; COC = contaminant of concern; ENR = enhanced natural recovery; FS = feasibility study; GRA = general response action; MNR = monitored natural recovery; PAHA = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; SVOC = semivolatile organic compound; TOC = total organic carbon; TBT = tributyltin

Table 7-2c Detailed Screening of Process Options: Containment Process Options

GRA	Technology Type	Process Option	Effectiveness		Implementability				Cost
			LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	
Containment	Capping	Conventional Sand Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for consideration throughout the LDW	Applicable to LDW conditions. Easily applied *in situ;* however, scouring must be considered. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation.	Conventional sand caps have been applied in multiple locations in Puget Sound and nationally.	—	Retained for consideration in the FS for all areas of the LDW.	Low to Moderate
		Conventional Sediment/Clay Cap	Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact. Sediment with silt and clay is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption	Retained for consideration throughout the LDW	Generally applicable to LDW conditions. Placement of clay caps is considered in shallow water depth areas where minimal cap thickness is required. Special engineering controls will be needed to place clay cap in the LDW.	Conventional sediment caps using river-dredged sediments have been applied in multiple locations in Puget Sound and nationally. Application of clay caps is relatively new, but demonstrated.	—	Retained for consideration in the FS for all areas of the LDW.	Low to Moderate
		Armored Cap	Applicable to LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained for limited use in high-energy sections of the LDW	Applicable to areas of LDW where increased velocities from river flow, or potential scouring associated with propeller wash might be expected. Decreased water depth may limit future uses of waterway and may impact flooding, stream bank erosion, navigation, and recreation. Limited use in intertidal areas that support clamming and recreational activities.	Armored caps have been implemented at several sites in Puget Sound and nationally.	—	Retained for limited use in the FS for high-energy sections of the LDW.	Low to Moderate
		Composite Cap (geotextile, HDPE)	Effective for LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants. Can be used: 1) to limit cap thickness, 2) for low solids underlying sediments where additional floor-support is required, 3) as a bioturbation barrier, or 4) as a barrier for areas where methane generation may be an issue.	Retained for consideration throughout the LDW	Applicable to LDW site conditions. Application must consider that decreased water depth may limit future uses of waterway and impact flooding, stream bank erosion, navigation, and recreation. Limited use in intertidal areas that support clamming and recreational activities.	Application of composite capping is relatively new, but commercially demonstrated for projects with similar size and scope.	—	Retained for consideration in the FS for all areas of the LDW.	Low to Moderate
		Spray Cap	Confines COCs by encapsulating with shotcrete (usually concrete) placed over underlying surface.	Retained for consideration throughout the LDW	Applicable to hard to access areas under piers and wharves. Shotcrete cap reduces the habitat value of the intertidal sediment bed.	Shotcrete was used at the Todd Shipyards effectively encapsulating existing debris (slag) mounds under dock structures from the aquatic environment.	Demonstrated effective at recent Puget Sound region remediation project.	Retained for consideration in the FS for application in hard to access areas under piers or wharf structures.	Low to Moderate
		Reactive Cap	Effective for LDW COCs. Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants.	Retained	Reactive caps may be applicable to site conditions on the LDW. Limited use in intertidal areas that support clamming and recreational activities.	Addition of materials to increase sorptive capacity of cap has been implemented in Puget Sound. Long-term effectiveness data may be available during the LDW FS.	Reactive capping is an innovative technology that is in the demonstration phase on the Anacostia River. Results of those tests are expected during the LDW FS.	Retained for consideration in the FS as an innovative technology.	Low to Moderate

Notes:

COC = contaminant of concern; FS = feasibility study; GRA = general response action; HDPE = High-density polyethylene

Table 7-2d Detailed Screening of Process Options: Treatment Process Options

GRA	Technology Type	Process Option	Effectiveness: LDW COCs	Effectiveness: Screening Decision	Final Screening: Site Conditions	Final Screening: Available and Demonstrated	Final Screening: Innovative Technology	Final Screening: Screening Decision	Cost[1]
In Situ Treatment	Biological	*In Situ* Slurry Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		In Situ Aerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		In Situ Anaerobic Biodegradation	Biodegradation has not been demonstrated to effectively remediate metals, PCBs, or TBT within a reasonable time frame.	Eliminated	—	—	—	—	—
		Imbiber Beads™	Potentially applicable to PCBs and SVOCs, not metals. No data on effectiveness with TBT. Not demonstrated for remediation of sediments. Removal and disposal of the blanket is not demonstrated.	Eliminated	—	—	—	—	—
	Chemical	Aqua MecTool™ Oxidation	Technology is effective for PCBs, SVOCs in soils. Process should be effective for TBT, but not metals.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Not demonstrated in pilot- or full-scale sediment projects. Technical difficulties in field trials injecting high air flows into caisson with standing water while preventing generation of TSS.	Not considered innovative or available during LDW FS.	Eliminated	—
		In Situ Oxidation	Has not been demonstrated to be effective for LDW COCs in sediments.	Eliminated	—	—	—	—	—
		Electro-chemical Oxidation	Applicability for use in water is not known. No demonstrated sediment application.	Eliminated	—	—	—	—	—
	Physical-Extractive Processes	Sediment Flushing	Bench scale effectiveness for all LDW COCs.	Retained for further consideration	Potentially applicable to LDW. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	No known pilot or full-scale applications.	Not considered innovative or available during LDW FS.	Eliminated	—
		In Situ Slurry Oxidation	Not demonstrated in full-scale applications effective for LDW COCs. Requires in-water steel piling around treatment area and extensive water quality monitoring outside piles.	Eliminated	—	—	—	—	—
	Physical-Immobilization	Aqua MecTool™ Stabilization	Proprietary technology that has been effective in stabilizing metals, PCBs and SVOCs in soil. No data available on TBT, but physical process likely to be effective on butyltins.	Retained for further consideration	Could be applicable to conditions in LDW. Requires treating sediments in place using caisson and proprietary injectors.	Proprietary technology that was tested in a pilot-scale application in Wisconsin with coal tar-contaminated sediments, and found to be not implementable. Previous trials with this technology created water treatment problems inside the caisson.	Not considered innovative or available during LDW FS.	Eliminated	—
		Activated Carbon Amendment	Effective at adsorbing organic contaminants in sediment applications. Pilot studies (in five pilot-scale demonstration projects in the United States and Norway) and research indicates technology has promising long-term effectiveness. Carbon-amended sediment provides a suitable habitat for benthic communities.	Retained for further consideration	Potentially applicable to LDW. Easily applied *in situ*; may require armoring in scour areas.	Demonstrated effective in recent pilot-scale remediation projects (San Francisco-CA, Lower Grasse River-NY, Canal Creek-MD, and Trondheim-Norway) in various aquatic environments (tidal mudflat, freshwater river, marine harbor, deep-water fjord, tidal creek, and marsh).	Activated carbon amendment is considered innovative and available during the LDW FS.	Retained for consideration in the FS	Low to Moderate
		Organoclay Amendment	Effective at adsorbing organic contaminants in sediment applications. Long-term effectiveness shown in pilot-scale demonstration projects in Anacostia River (Washington, DC).	Retained for further consideration	Potentially applicable to LDW. Easily applied *in situ*; may require armoring in scour areas.	Demonstrated effective at the Anacostia River in a recent pilot-scale remediation project that used AquaBlok® (proprietary clay polymer composite).	Organoclay amendment is considered innovative and available during the LDW FS.	Retained for consideration in the FS	Low to Moderate

Table 7-2d Detailed Screening of Process Options: Treatment Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness: LDW COCs	Effectiveness: Screening Decision	Final Screening: Site Conditions	Final Screening: Available and Demonstrated	Final Screening: Innovative Technology	Final Screening: Screening Decision	Cost[1]
In Situ Treatment	Physical-Immobilization	Vitrification	Effective at stabilizing COCs in soil applications, but requires less than 60% water content. Remaining sediment surface may not provide suitable habitat. No known sediment applications.	Eliminated	—	—	—	—	—
In Situ Treatment	Physical-Immobilization	Ground Freezing	Not permanently effective for LDW COCs. Long-term effectiveness in presence of standing water has not been demonstrated. Standing water likely provides a significant sink for cold temperatures and would substantially increase cost.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Biological	Landfarming/ Composting	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Biological	Biopiles	Not effective for metals, PCBs, dioxin or TBT. Used for reducing concentrations of petroleum constituents in soils. Applied to treatment of nonhalogenated VOCs and fuel hydrocarbons. Requires large upland area.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Biological	Fungal Biodegradation	Not effective for metals, PCBs, dioxins or TBT. No known full-scale applications. High concentrations of contaminants may inhibit growth. The technology has been tested only at bench scale.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Biological	Slurry-phase Biological Treatment	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation. Large volume of tankage required. No known full-scale applications.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Biological	Enhanced Biodegradation	Not effective for metals, PCBs, dioxin or TBT. PAHs and some SVOCs are amenable to aerobic degradation.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Chemical	Acid Extraction	Suitable for sediments contaminated with metals, but not applicable to PCBs or SVOCs. No data on TBT.	Eliminated	—	—	—	—	—
Ex Situ Treatment	Chemical	Solvent Extraction	Potentially effective for treating sediments containing PCBs, dioxins, or SVOCs. Not applicable to metals. No data on TBT. Extraction of organically-bound metals and organic contaminants creating residuals with special handling requirements. At least one commercial unit available.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW containing primarily organic contaminants such as PCBs. Extracted organic contaminants from the process will need to be treated or disposed. Requires pre-treatment that involves screening of sediments.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology has been used to demonstrate under the EPA SITE program, but there are no data for similar implementation of this technology for large-scale PCB-impacted sediment. No current or planned projects.	Eliminated	—
Ex Situ Treatment	Chemical	Solvent extraction: Solvent Electron Technology (SET™)	Effective for SVOCs and PCBs, but not metals. No data on TBT. Full scale system commercially available for treatment. Mobile units can be set up to meet project requirements. Nationwide TSCA treatment permit for SET™ issued by EPA for mobile PCB chemical destruction in soils.	Retained for further consideration	Potentially applicable to dewatered (dry) sediments on the LDW. This technology results in destruction of PCBs and other organic contaminants. Operates on a closed loop system and does not produce secondary hazardous waste or off-gas.	Not demonstrated in pilot- or full-scale sediment projects.	—	Eliminated	—
Ex Situ Treatment	Chemical	Solvent Extraction; Peroxide and Ferrous Iron Treatment	Oxidation using liquid hydrogen peroxide (H_2O_2) in the presence of native or supplemental ferrous iron (Fe^{+2}) produces Fenton's Reagent which yields free hydroxyl radicals (OH^{-}). These strong, nonspecific oxidants can rapidly degrade various organic contaminants.	Retained for further consideration	Potentially applicable to LDW.	Technology is neither commercially available nor demonstrated on a project of similar size and scope.	This technology has been used for pilot studies for treating PAH-impacted sediment from Utica Harbor, but there are no data for similar implementation of this technology for PCB-impacted sediment. No current or planned projects.	Eliminated	—

Table 7-2d Detailed Screening of Process Options: Treatment Process Options (continued)

			Effectiveness		Final Screening				
GRA	Technology Type	Process Option	LDW COCs	Screening Decision	Site Conditions	Available and Demonstrated	Innovative Technology	Screening Decision	Cost[1]
Ex Situ Treatment (continued)	Chemical (continued)	Solvent Extraction: High Energy Electron Beam Irradiation	Full-scale system commercially available for treatment of PCBs and SVOCs, and process is limited to slurried soils, sediments, and sludges. Slurrying is a required pre-treatment for this technology. Not demonstrated to be effective in sediments. Pilot-scale testing has been performed to treat wastewaters with organic compounds. Metals are not amenable to treatment. No data on TBT.	Retained for further consideration	Potentially applicable to slurried sediments in the LDW consisting primarily of organic contaminants such as PCBs.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale.	This technology demonstrated under the EPA SITE program to treat wastewater with organic compounds, but no data for similar implementations are available for PCB-impacted sediment. No current/planned projects.	Eliminated	—
		Reduction/ Oxidation	Target contaminant group for chemical redox is inorganics. Less effective for nonhalogenated VOCs, SVOCs, fuel hydrocarbons, and pesticides. Not cost-effective for high contaminant concentrations because of large amounts of oxidizing agent required.	Eliminated	—	—	—	—	—
		Dehalogenation	PCB and dioxin-specific technology. Generates secondary waste streams of air, water, and sludge. Similar to thermal desorption, but more expensive. Solids content above 80% is preferred. Technology is not applicable to metals.	Eliminated	—	—	—	—	—
		Slurry Oxidation	Applicable to SVOCs, but not PCBs or metals. TBT treatment unknown. Large volume of tankage required. No known full-scale applications. High organic carbon content in sediment will increase volume of reagent and cost.	Eliminated	—	—	—	—	—
		Soil Washing with Air Stripping	Full-scale testing of Biogenesis™ Advanced washing process showed demonstrated effectiveness for metals, SVOCs and PCBs in sediments. Limited data suggests not effective for TBT. High recalcitrant (e.g., PCB) contaminant concentration, increased percentage of fines, and high organic content increases overall treatment costs.	Retained for further consideration	Potentially applicable to dewatered sediments on the LDW. Would require upland processing space, storage capacity for dredged sediments, wastewater treatment, and discharge. Treated residuals would still require disposal.	Equipment is commercially available, but has not been demonstrated on a project of similar scope and scale. Tests to date have been on 15,000 cy.	Full-scale testing has been performed. Mobile units available for setup. Continuous flow process designed to process up to 40 cy of sediments per hour for the full-scale system.	Retained as innovative technology to consider further in the FS.	Moderate to High
		Radiolytic Dechlorination	Only bench-scale testing has been performed. Difficult and expensive to create inert atmosphere for full-scale project.	Eliminated	—	—	—	—	—
	Physical	Particle Separation	Reduces volumes of COCs by separating sand from fine-grained sediments. Some bench scale testing has suggested that at high PCB concentrations, the sand fraction retains levels that still require landfilling.	Retained for further consideration	Potentially applicable dredged sediments in the LDW.	Separation technologies available and have been used in several programs of similar size and scope.	—	Retained to consider further in the FS.	Low
		Solar Detoxification	The target contaminant group is VOCs, SVOCs, solvents, pesticides, and dyes. Not effective for PCBs, dioxins or TBT. Some heavy metals may be removed. Only effective during daytime with normal intensity of sunlight. The process has been successfully demonstrated at pilot scale.	Eliminated	—	—	—	—	—
		Solidification	Bench-scale studies have added immobilizing reagents ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents with varying success. Dependent on sediment characteristics and water content. Lime is particularly effective at volatilizing PCBs in wet sediment (by a phase transfer mechanism).	Retained for further consideration	Potentially applicable to LDW.	Lime has been successfully added to dredged material at other projects. Considered for use during the dewatering operation to remove excess water and prepare material for disposal.	—	Retained to consider further in the FS.	Moderate

Table 7-2d Detailed Screening of Process Options: Treatment Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness: LDW COCs	Effectiveness: Screening Decision	Final Screening: Site Conditions	Final Screening: Available and Demonstrated	Final Screening: Innovative Technology	Final Screening: Screening Decision	Cost[1]
Ex situ Treatment (continued)	Thermal	Incineration	High temperatures result in generally complete decomposition of PCBs and other organic contaminants. Effective across wide range of sediment characteristics but fine grained sediment difficult to treat. Not effective for metals.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm). Only a small portion of LDW sediments are above TSCA.	Only one off-site fixed facility incinerator is permitted to burn PCBs and dioxins. Metals not amenable to incineration. No data on TBT, but should be effective. Mobile incinerators are available for movement to a fixed location in close proximity to the contaminated sediments.	—	Eliminated	—
		High-temperature Thermal Desorption (HTTD) then Destruction	Target contaminants for HTTD are SVOCs, PAHs, PCBs, TBT and pesticides, which are destroyed by the heating process. Metals not destroyed.	Retained for further consideration	Technically applicable to LDW site conditions. Especially effective and potentially required where COCs exceed TSCA limits (e.g., PCB >50 ppm).	Technology readily available as mobile units that would need to be set up at a fixed location in close proximity to the contaminated sediments. Cement-Lock® Technology demonstration projects partially destroyed organics and encapsulated metals in the product matrix. The Cement-Lock® product passes the TCLP test for priority pollutants.	Cement-Lock® Technology -Two demonstration projects started. Both experienced equipment related problems and were shut down.	Eliminated	—
		Low-temperature Thermal Desorption (LTTD)	Target contaminants for LTTD are SVOCs and PAHs. May have limited effectiveness for PCBs. Metals not destroyed. Fine-grained sediment and high moisture content will increase retention times. Widely-available commercial technology for both on-site and off-site applications. Acid scrubber will be added to treat off-gas.	Retained for further consideration	Potentially applicable to LDW.	Demonstrated effectiveness at several other sediment remediation sites. Vaporized organic contaminants that are captured and condensed need to be destroyed by another technology. The resulting water stream from the condensation process may require further treatment.	—	Eliminated	—
		Pyrolysis	High moisture content increases treatment cost. Generates air and coke waste streams. Target contaminant groups are SVOCs and pesticides. It is not effective in either destroying or physically separating inorganics from the contaminated medium	Eliminated	—	—	—	—	—
		Vitrification	Thermally treats PCBs, SVOCs, TBT, and stabilizes metals. Successful bench-scale application to treating contaminated sediments in Lower Fox River, and in Passaic River.	Retained for further consideration	Potentially applicable to LDW.	Not commercially available or applied on similar site and scale.	No known pilot or full-scale applications in sediments planned.	Eliminated	—
		High-pressure Oxidation	Predominantly for aqueous-phase contaminants. Wet air oxidation is a commercially-proven technology for municipal wastewater sludges and destruction of PCBs is poor. Supercritical water oxidation has demonstrated success for PCB destruction.	Eliminated	—	—	—	—	—

Notes:

1. Costs indicated here are relative to incineration costs.
2. Institutional controls are retained as potentially feasible and applicable to the LDW, and carried forward in the detailed screening; however, they do not lend themselves to comparison on the same terms as other technologies. Therefore, they are discussed only within Section 7.2 and are not included in Tables 7-2 and 7-3.

COC = contaminant of concern; CTM = Candidate Technologies Memorandum; cy = cubic yards; EPA = U.S. Environmental Protection Agency; FS = feasibility study; GRA = general response action; HTTD = high-temperature thermal desorption; LTTD = low-temperature thermal desorption; MNR = monitored natural recovery; NCP = National Contingency Plan; PAH = polycyclic aromatic hydrocarbon; PCB = polychlorinated biphenyls; SET™ = Sediment Electron Technology; SVOC = semivolatile organic compound; TBT = tributyltin; TCLP = Toxicity Characteristic Leaching Procedure; TOC = total organic carbon; TSCA = Toxic Substances Control Act; TSS = total suspended solids; VOC = volatile organic compound

Table 7-2e Detailed Screening of Process Options: Removal Process Options

GRA	Technology Type	Process Option	Effectiveness: LDW COCs	Effectiveness: Screening Decision	Implementability: Site Conditions	Implementability: Available and Demonstrated	Implementability: Innovative Technology	Implementability: Screening Decision	Cost
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Best suited to low density, high water solids with little debris. Requires nearshore dewatering facilities and right-of-way for slurry pipeline. Water treatment and disposal required.	Hydraulic environmental dredging is available and demonstrated in similar size projects, but is less frequently used for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
		Mechanical Dredging	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental buckets suitable for softer materials with low debris; clamshell buckets suitable for harder, dense sediments.	Mechanical environmental dredging is available and demonstrated in similar size projects, and is commonly employed for projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
		Mechanical Dredging (Excavator)	Applicable to all LDW COCs	Retained for consideration throughout the LDW	Generally applicable to LDW in-water site conditions. Better suited for higher density, low water solids, and more effective at handling debris. Environmental excavators are suited for all materials (soft and dense), better able to handle debris, but may be depth limited.	In-water excavators are available and demonstrated in similar size projects, including projects in Puget Sound.	—	Retained for consideration in the FS for all areas of the LDW.	Moderate
	Dry Excavation	On-land or Intertidal excavator, backhoes, specialty equipment	Applicable to all LDW COCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	Retained for further consideration for intertidal or nearshore areas in the LDW	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft unconsolidated sediments.	Equipment is commercially available and has been applied on projects of similar scope in Puget Sound.	—	Retained for consideration in the FS for shallow and/or intertidal areas of the LDW.	Moderate

Note:
COC = contaminant of concern; FS = feasibility study; GRA = general response action

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
No Action	None	Required by NCP	Applicable to all LDW COCs.	Applicable to all COCs. Effective where risk assessment demonstrates low to no risk to human health and environment.	COCs remain in place.	Applicable throughout LDW where COC concentrations are low.	1) Readily implemented with no construction or monitoring requirements; 2) Minimal impact on industrial and shipping uses of waterway.	1) Requires source controls to be in place.	Low
Monitoring	Physical and Chemical Assessment	Monitoring	Applicable to all LDW COCs.	Can be effective for evaluating changes during implementation phase and over the long-term	1) A lot of variability in data results, difficult to discern trends; 2) Relationships not well understood for some contaminants.	Applicable to all subtidal areas of LDW.	1) Readily implementable; 2) Minimal impact on industrial and shipping uses of waterway; 3) Good for risk communication to public.	1) Requires long-term financial commitment to ensure maintenance of engineered structures (i.e., cap, CAD) and monitoring/sampling.	Moderate
Monitored Natural Recovery	Chemical Degradation	Combination of natural desorption, diffusion, dilution, volatilization, resuspension, and transport	Effective principally to LDW organic COCs including SVOCs and PCBs. Inorganics not subject to degradation.	Effective where chemical degradation of COCs is demonstrated to occur in the short- and long-term.	1) Effective where risk assessment demonstrates low to no risk to human health and environment; 2) Physical/chemical degradation demonstrated for SVOCs, but less effective for metals, PCBs, TBT and pesticides; 3) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 4) Potentially low level of short-term effectiveness for ecological receptors because COCs remain in place, but can provide adequate long-term protection; 5) Requires implementation of long-term monitoring study and risk assessment objectives.	Applicable to all areas of the LDW.	1) Readily implemented with no construction requirements; 2) Minimal impact on current or future industrial and shipping uses of waterway; 3) May be used in conjunction with other technologies in a combined alternative.	1) Must be implemented in conjunction with a well-designed, long-term monitoring program; 2) May require future active remediation where MNR risk-expectations are not achieved.	Low
	Biological-Degradation	COC Metabolization (aerobic and anaerobic)	Effective principally to SVOCs. PCBs and TBT will degrade, but not within an acceptable time frame. Metals will not degrade.	Biodegradation is a demonstrated and proven remedial technology for volatiles and SVOCs. Effective where degradation of COCs are demonstrated to occur in the short- and long-term.	1) Biological degradation less effective for PCBs and TBT; 2) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) Less effective for ecological receptors because COCs remain in place; 4) Requires implementation of long-term monitoring study and risk assessment objectives.	Applicable in areas with low concentrations of SVOCs in well-mixed sediments.	1) Readily implemented with no construction requirements; 2) Minimal impact on current or future industrial and shipping uses of waterway; 3) May be used in conjunction with other technologies in a combined alternative; 4) Implemented in areas with biodegradable COCs.	1) Must be implemented in conjunction with a well-designed long-term monitoring program; 2) May require future active remediation where MNR risk-expectations are not achieved.	Low
	Physical Burial Processes	Sedimentation/ Burial Resuspension and Transport (minor components of MNR)	Effective for all LDW COCs where concentrations are low.	1) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; 2) Effective for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact.	1) Requires implementation of long-term monitoring study and risk assessment objectives; 2) Short-term impacts to human health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) Less effective for ecological receptors because COCs remain in place; 4) COCs not actively removed and remain in place. 5) Facilitates PCB contamination of the marine food chain when resuspension and transport occur	Applicable where geochronological studies and hydrodynamic modeling demonstrate long-term sedimentation and burial processes are in-place.	1) Readily applied and demonstrated process; 2) Can be combined with institutional controls until long-term risk-objectives are demonstrated; 3) Minimal impact on industrial and shipping uses of waterway.	1) Requires long-term monitoring and continuing financial commitment until risk-objectives are achieved; 2) Associated institutional controls may limit future uses of waterway.	Low

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness: COCs	Effectiveness: Advantages	Effectiveness: Disadvantages	Implementability: Site Conditions	Implementability: Advantages	Implementability: Disadvantages	Cost[1]
Enhanced Natural Recovery	Enhanced Physical Burial	Thin-layer placement to augment natural sedimentation	Effective for all LDW COCs where MNR processes are demonstrated.	ENR dilutes COC concentrations while not resulting in the resuspension and transport of contaminants that occurs with dredging.	1) Requires implementation of long-term monitoring study and risk assessment objectives; 2) Short-term impacts to human and ecological health may continue, and require use in conjunction with seafood consumption advisories and/or other site restrictions; 3) COCs not actively removed, but attenuated by addition of clean sediments.	Applies where data and modeling indicate placement of a thin-layer of material, combined with natural recovery processes will result in achievement of risk-based sediment objectives. Particularly useful for critical habitat areas, and/or shallow intertidal areas where active remedial methods could result in unwanted habitat loss. Potentially suitable for management of dredge residuals.	1) Puget Sound-demonstrated technology with local construction knowledge; 2) Sediment for thin-layer placement readily available.	1) Requires long-term monitoring, institutional controls and continuing financial commitment until cleanup objectives are achieved; 2) Institutional controls may limit future uses of waterway.	Low
Containment	Capping	Conventional Sand Cap	Applicable principally to PAHs, other SVOCs, metals, and PCBs; Limited applicability to VOCs.	1) Demonstrated effectiveness for isolating contaminants in the LDW; 2) Isolates contaminants from the overlying water column and prevents direct contact between aquatic biota and contaminants; 3) Capping does not result in the resuspension and transport of contaminants that occurs with dredging.	1) Sand cap may be subject to bioturbation and release of buried COCs; 2) Sand caps may be susceptible to propeller and/or high-flow scour, methane generation, and earthquakes; 3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 4) Requires long-term monitoring, institutional controls, and financial commitment.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COCs into the clean cap surface.	1) Readily applied and demonstrated technology. Local construction experience; 2) Capping materials readily available from navigation dredging at the Upper Turning Basin.	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway; 4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design.	Low to Moderate
		Conventional Sediment/Clay Cap	Applicable principally to COCs with potentially higher solubilities and lower sorption.	1) Sediment with high fines (silt and clay) and or TOC is effective in limiting diffusion of contaminants. Sediment caps are generally more effective than sand caps for containment of contaminants with high solubility and low sorption; 2) Natural TOC present in conventional sediments more effective at adsorbing COCs such as PCBs.	1) Clay liners in caps are potentially more susceptible to breaches caused by methane generation through the cap; 2) Caps may be susceptible to propeller and/or high-flow scour, methane generation, and earthquakes; 3) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 4) Requires long-term monitoring, institutional controls, and financial commitment.	Applicable in sections of LDW with low erosion potential and where placement of finer-grained material can be managed. May be useful in nearshore, or intertidal applications where thinner caps with higher sorbtive capacities are required. Sediments must still have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COCs into the clean cap surface.	1) Readily applied and demonstrated technology; 2) Placement of high TOC and/or high fine sediments minimizes thickness of cap in areas with shallow water depth; 3) Materials readily available through upland sources or from navigation dredging at other systems.	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway; 4) Impacts to flooding, stream bank erosion, navigation, and recreation must be addressed in design; 5) Utilization of navigation dredged material for capping has potential logistical issues.	Low to Moderate
		Armored Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	Effective in combination with conventional caps to isolate contaminants and protect cap against physical erosion and/or bioturbation.	1) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 2) Armor rock may be less productive habitat for benthic organisms. 3) Requires long-term monitoring, institutional controls, and financial commitment.	Applicable in conjunction with other cap configurations in areas of LDW, but can be applied where erosion potentials are higher.	(1) Readily applied and demonstrated technology; 2) Armor placement can be used to minimize thickness of cap in areas with shallow water depth; 3) Armor materials can be combined with habitat-enhancing materials (e.g., "Fish Mix").	1) Requires long-term maintenance and financial commitment; 2) May not be implementable for shallow, intertidal areas where elevation changes would result in unacceptable ecological impacts; 3) May require permanent institutional controls and limit future uses of waterway.	Low to Moderate
		Composite Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	1) Provides physical isolation of COCs from the overlying water column; 2) Assists in preventing bioturbation breaches of caps and prevents direct contact between aquatic biota and contaminants; 3) Rigid HDPE layers used in small areas to assist in NAPL containment, control hydraulic gradient, and methane containment and diffusion.	1) Composite caps at other sites have resulted in catastrophic breaches as a result of methane generation under the cap; 2) Rigid HDPE layers do not have long-term demonstrated effectiveness; 3) Use of geotextiles may not be necessary for contaminants with low solubility and high sorption where the main concern is resuspension and direct contact; 4) Geotextiles by themselves do not limit advective or diffusive flux of COCs; 5) Requires long-term monitoring, institutional controls, and financial commitment.	Composite caps with impermeable layers such as HDPE are generally applicable where control of NAPL or groundwater movement is needed in a limited area. Composite caps may also be potentially applicable in intertidal areas where physical separation between receptors and COCs are required, but where minimal change to the slope or bathymetric configuration is needed.	1) Increasingly applied technology; 2) Placement of geotextile or rigid HDPE can be used to minimize thickness of cap in areas with shallow water depth.	1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; 2) Tidal ranges in the LDW can affect ability to place materials; 3) Requires long-term monitoring and financial commitment.	Low to Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
Containment	Capping	Spray Cap	Applicable to all LDW COCs as described for sand and/or conventional caps.	Good for application under hard to access areas such as piers and wharves. Provides good physical barrier between contaminants and overlying surfaces.	1) Creates a hard surface. If habitat surface values are required, habitat-suitable material would need to be placed on top of the shotcrete. 2) Must be applied in the dry with time to set. Areas of application are limited to high intertidal areas. 3) Requires long-term monitoring and maintenance, institutional controls, and a potential requirement for replacement habitat.	Labor intensive process to implement in difficult working conditions under docks and piers.	Good for application under hard to access areas such as piers and wharves.	1) Potentially dangerous work because of obstructions, slippage, and presence of contaminants next to workers applying the shotcrete. 2) Requires specialty equipment to place the shotcrete. 3) Tidal ranges can affect placement location. 4) Not applicable in habitat areas.	High
		Reactive Caps	Potentially applicable to all LDW COCs as described for conventional sand and/or conventional sediment caps.	Similar to advantages described for other caps. Provides an additional level of contaminant-sorbing materials to caps.	Long-term effectiveness not demonstrated. Retained as innovative technology. Requires long-term monitoring, institutional controls, and financial commitment. Probably not acceptable in beach areas.	Applicable in conjunction with other cap configurations in areas of LDW.	Adds an additional level of environmental protection with contaminant sorbing materials. May allow for construction of thinner caps.	1) Requires specialty equipment for placement, sinking, and securing to the sediment floor; 2) Tidal ranges in the LDW can affect ability to place materials; 3) Requires long-term monitoring and financial commitment; 4) Long-term implementability not demonstrated. Retained as innovative technology.	Low to Moderate
Removal	Dredging	Hydraulic Dredging	Applicable to all LDW COCs at higher concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	1) Effective removal with lower resuspension and recontamination/residual rate relative to mechanical dredging; 2) Can be readily incorporated into treatment trains such as chemical and/or physical separation.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of low solid sediments, generally less than 20 ft. of water depth and low levels of debris.	(1) Various hydraulic dredges readily available on the West Coast and at least one dredging contractor has equipment on the LDW; (2) More effective lateral and vertical cut control may be achieved, relative to mechanical dredges; (3) High utility when used in conjunction with CDFs; (4) Local experience of use for the Sitcum and Blair Waterway projects.	1) Hydraulic dredges limited in heavy-debris environments; 2) Environmental hydraulic dredges are depth limited, and difficult to size to accommodate steady solids flow under varying tidal regimes; 3) Requires separation of solids from water, resulting in large volumes of water that may require treatment prior to discharge back to LDW; 4) Treatment facilities must be located near-waterway with enough land space to accommodate retention basins, mechanical dewatering equipment, sand and carbon filtration, and transfer of dewatered material to trucks or trains for transfer to regional landfill.	Moderate to High
		Mechanical Dredging	Applicable to all LDW COCs at concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	Effective for removal in areas with high debris and sediments with high sand or heavy clay content that require digging buckets.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of high percentage solids sediments, including areas with heavy debris, sand, and clay. Mechanical dredging is not depth restricted, and not affected by tidal exchange.	1) Various mechanical dredges, including environmental buckets and clamshells readily available on the LDW and in Puget Sound; 2) Recent construction experience in LDW and Puget Sound with skilled operators; 3) Environmental buckets useful in softer, unconsolidated materials with low debris; 4) Digging buckets (e.g., clamshells) useful in harder clays or compacted sediments, or where debris is high; 5) Existing infrastructure for barge transport, off-loading, and transfer to railcars for transport to regional landfills; 6) Depth and tidal limitations within the LDW do not restrict use of mechanical buckets.	1) Not all river segments may be accessible to a barge-operated mechanical dredge; 2) Can result in potentially higher resuspension and residual rates than hydraulic dredges; 3) Lower vertical and horizontal operational control relative to hydraulic dredges.	Low to Moderate
		Mechanical Dredging (Excavator)	Applicable to all LDW COCs at concentrations that either pose unacceptable risks to human health and the environment, and/or serve as sources for downstream recontamination.	Effective for removal in areas with high debris and sediments with high sand or heavy clay content that require digging buckets.	Requires management of contaminant residuals after dredging.	Applicable in areas with high volumes of high percentage solids sediments, including areas with heavy debris, sand, and clay. Mechanical dredging is not depth restricted, and not affected by tidal exchange.	1) Equipment is available to the Puget Sound region but to lesser extent than standard clamshell dredges; 2) Recent construction experience in LDW and Puget Sound with skilled operators; 3) Offer high level of vertical and horizontal control during dredging.	1) Not all river segments may be accessible to a barge-operated mechanical dredge; 2) Can result in potentially higher resuspension and residual rates than hydraulic dredges; 3) Lower vertical and horizontal operational control relative to hydraulic dredges.	Low to Moderate
	Excavating	Dry Excavating	Applicable to all LDW COCs. Effective for nearshore and/or intertidal areas where depths limit conventional dredging equipment	1) Contaminated sediments removed; 2) Residuals can be minimized or eliminated by dry excavation.	Effective only in relatively small and narrow shoreline areas of limited intertidal bands. Requires either only working during low tides, or using cofferdams or sheet pile walls to create a contained, dry area.	Limited in application to nearshore shallow and/or intertidal areas that can be reached from shore or by specialty equipment designed to work on soft, unconsolidated sediments.	Equipment and construction experience in Puget Sound.	1) Construction costs may involve contingencies to address potential spills and leaks	Low to Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability			Cost[1]
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	
In Situ Treatment	Physical-Immobilization	Activated Carbon Amendment	Applicable to certain LDW COCs at concentrations that pose unacceptable risks to human health and the environment	1) Contaminants adsorb to activated carbon particles; 2) porewater concentrations (sediment-to-water fluxes), contaminant concentrations, and bioavailability for uptake by organisms are reduced; and 3) promising pilot-scale results.	May require armoring in areas susceptible to propeller and/or high-flow scour. Requires long-term monitoring, institutional controls, and financial commitment. Retained as innovative technology. Long-term effectiveness not demonstrated at full scale.	Easily implementable, and applicable to most areas of the LDW. Sand could be mixed with the activated carbon as a form of modified ENR.	1) Recently demonstrated implementable technology; 2) activated carbon for placement readily available, and 3) commercial products have been developed to improve the deployment of the activated carbon, by using a weighting particle (sand, gravel, etc.) coated with an inert binder and activated carbon.	1) Can require specialized equipment depending on application method; 2) requires long-term monitoring.	Low to Moderate
		Organoclay Amendment	Applicable to certain LDW COCs at concentrations that pose unacceptable risks to human health and the environment	1) Chemically binds metal ions, replacing them with amines or other functional groups; 2) physically isolates the contaminated sediment from receptors (because of low permeability of clay); 3) stabilizes sediment preventing resuspension and transport of contaminants, and 4) promising pilot-scale results.	May require armoring in areas susceptible to propeller and/or high-flow scour. Requires long-term monitoring, institutional controls, and financial commitment. Retained as innovative technology. Long-term effectiveness not demonstrated at full scale	Easily implementable, and applicable to most areas of the LDW.	1) Recently demonstrated implementable technology; 2) organoclays for placement commercially available.	1) Can require specialized equipment depending on application method; 2) requires long-term monitoring.	Low to Moderate
Ex Situ Treatment	Chemical/Physical	Soil Washing	Applicable to all LDW COCs. Principal application would be for high volumes of organic-contaminated sediments.	1) Full-scale testing demonstrated ability to take high concentrations of COCs and treat to equivalent of MTCA soil standards; 2) Potential beneficial reuse for residuals.	1) Tests to date have treated hazardous waste-level materials. No data on treatment of lower concentrations of contaminants; 2) Effective treatment when starting with high sands materials—lower effectiveness when treating low solids and high fine-grained sediments; 3) Solid-waste classification in Washington state unclear, which may require disposal of treated materials at a Subtitle D landfill.	Applicable to potential dredge areas containing organic and coarse-grained sediment.	1) Readily implementable, resulting in reduced contaminated sediment volume; 2) System could be coupled with hydraulic dredging for continuous treatment train; 3) Mobile units are available 4) Continuous flow process designed to process up to 40 cy of sediments per hour for the full-scale system; 5) May be available for potential beneficial reuse.	1) Waste streams include hydraulic-dredge decant water, reagents used in soil washing, and the treated residuals; 2) Water will require filtration and treatment prior to discharge; 3) Treated residuals may require off-site disposal; 4) Volume/long-term supply of sediments to be treated and local market for beneficial use products affect the economics of implementing this technology.	Moderate
	Physical	Particle Separation	Only applicable to adsorptive COCs that would adhere to the fine-grained soil. Offers greatest utility and cost saving benefits where concentrations of COCs would otherwise require incineration or Subtitle C disposal.	1) Demonstrated effectiveness for reduction in volume of highly contaminated sediments with a high percentage of sand-content; 2) Used to increase effectiveness of dewatering dredged material.	1) Not effective for contaminants with high concentrations and high organic content; 2) Previous work at other sites with PCB-contaminated sediments has shown that PCBs are retained on sand particles (as emulsion), requiring Subtitle D disposal.	Applicable to potential dredge areas containing higher sand content.	1) Readily implementable, resulting in reduced contaminated sediment volume; 2) Can be combined with soil washing to improve contaminant separation and/or destruction; 3) Mobile units are available; 4) Separated sand may be available for potential beneficial reuse, capping, or disposal at DMMP Elliott Bay site.	Will require disposal of separated waste stream at a Subtitle D landfill. Fines could also require Subtitle C disposal or incineration.	Moderate
		Solidification	Applicable to all LDW COCs. Principal application would be for high volumes of PCB-contaminated sediments that exceed hazardous waste criteria and would otherwise require incineration or Subtitle C disposal.	1) Lime has been successfully added to dredged material at other projects; 2) Effective during the dewatering operation to remove excess water and prepare material for disposal.	High contaminant concentration and high water content results in higher project costs.	Applicable to all dredge areas of LDW.	1) Readily implementable; 2) Reagent materials readily available.	1) Immobilizing reagents, ranging from Portland cement to lime cement, kiln dust, pozzolan, and proprietary agents, have been applied with varying success. Dependent on sediment characteristics and water content; 2) Contaminants remain in place. Stabilized product requires disposal in regulated landfill.	Moderate

Table 7-3 Summary Assessment of Effectiveness, Implementability, and Cost for Retained Remedial Technologies and Process Options (continued)

GRA	Technology Type	Process Option	Effectiveness			Implementability			
			COCs	Advantages	Disadvantages	Site Conditions	Advantages	Disadvantages	Cost[1]
Disposal	On-Site	Contained Aquatic Disposal (CAD)	Applicable to all LDW COCs below hazardous waste designations.	1) Demonstrated local experience and effectiveness in the LDW and Puget Sound; 2) Effective containment of metals, organics, and PCBs; 3) Can be designed to include habitat enhancement for salmonids.	1) CADs must be engineered to withstand bioturbation, advective flux, and release of buried COPCs, propeller and/or high-flow scour, and earthquakes; 2) Changes in bed elevation may result in unacceptable ecological impacts to salmonid habitat; 3) Requires long-term monitoring, institutional controls, and financial commitment.	Applicable to subtidal areas where sediments have sufficient bearing strength to support cap, and have low erosive potential. Not suitable for areas where groundwater can advect COPCs into the clean cap surface.	1) Technically readily implemented within the LDW with contaminated sediments contained on-site; 2) Local construction experience; 3) Excavated clean pit-materials can be used for beneficial uses and/or to cap CAD; (4) Does not interfere with current industrial uses of LDW.	1) Volume-limited on LDW as a large area would be required to accommodate dredged sediments; 2) Requires long-term commitment to monitoring with the potential for additional actions if CAD fails; 3) Requires permanent institutional controls (e.g., deed restrictions, dredging moratorium) that may affect future development and uses of the LDW; 4) Requires concurrence with land owner.	Low to Moderate
		Confined Disposal Facility (CDF)	Applicable to all LDW COCs below hazardous waste designations.	1) Demonstrated local experience and effectiveness in Puget Sound; 2) Effective containment of metals, SVOCs and PCBs; 3) A subtidal CDF could be designed to include habitat enhancement for salmonids.	1) CDFs must be engineered to withstand advective flux and release of buried COCs, propeller, and/or high-flow scour, and earthquakes; 2) Filling of nearshore lands would result in unavoidable loss of aquatic lands that will require mitigation.	Requires large suitable near-shore or upland containment site. Former slips or similar in-water areas would be best suited to construct a CDF.	1) Puget Sound-demonstrated technology with local construction knowledge; 2) Cap sediments or soils readily available; 3) Could contain large volumes of contaminated sediments, depending upon site availability; 4) Beneficial upland industrial and/or residential reuse of filled site.	1) Site-limited on LDW. Few potential locations without other current uses; 2) Requires long-term commitment to monitoring with the potential for additional actions if CDF fails; 3) Requires permanent institutional controls (e.g., deed restrictions, dredging moratorium) that may affect future development and uses of the LDW; 4) Requires concurrence with land owner.	Moderate to High
	Off-Site	Subtitle D Landfill	Applicable to all LDW COCs below hazardous waste designations.	Subtitle D landfills highly effective for long term, permanent containment of contaminated materials.	COCs contained, but not permanently destroyed.	Applicable throughout LDW for both dewatered and wet sediments.	1) Several licensed landfills in Washington exist that can receive dredged materials in Puget Sound; 2) Transfer facilities for moving sediments from LDW to the landfills exist on-site; 3) Transport infrastructure in-place on the LDW; 4) Options exist for moving wet sediments - eliminating need for on-site dewatering facilities.	1) Transfer and barge offload facilities may not be present at the time the project is completed so a separate offload facility may need to be constructed; 2) Landfills in Eastern Washington and Eastern Oregon requires train transport with potential for spillage.	Moderate
	Off-Site	Subtitle C Landfill	Applicable to all LDW COCs exceeding hazardous waste designations.	Subtitle C landfills are federally-regulated facilities and are highly effective for long-term, permanent containment of highly contaminated materials.	1) COCs contained, but not permanently destroyed; 2) Requires dewatering of dredged sediments.	Applicable throughout LDW for dewatered sediments	Option for disposal of listed, hazardous wastes	Transport of hazardous materials to facility expensive.	High
		DMMP Open Water Disposal	Applicable to all LDW COCs in sediments that are separated or treated to below the DMMP disposal standards.	DMMP is a well-established and effective program with a long-term track record of monitoring to verify environmental protectiveness.	None	Applicable throughout LDW	The DMMP disposal site is located in nearby Elliott Bay	Sediments that require remediation are not likely to meet the open water disposal criteria.	Low
		MTCA Reuse (upland or in-water beneficial reuse)	Applicable to all LDW COCs in sediments that are either below, or treated-to below the reuse standards for uplands and in-water.	Beneficial reuse of sediments	Some residual COCs may remain after treatment	Applicable throughout LDW	Potential use of sediments that meet the MTCA Level A soil requirements as upland fill, or other beneficial upland uses including daily landfill cover. Potential beneficial reuse as in-water ENR, capping material, and habitat enhancement. May be implementable for high volumes of materials with low concentrations of COCs, or for treated sediments.	No specific beneficial upland reuse has been identified. As such, requires the additional costs for transport of material and/or tipping fee to send to landfill.	None

Notes:

1. Cost assessment is based on the relative cost of a process option in comparison to other process options within a given technology type.

CAD = contained aquatic disposal; CDF = confined disposal facility; COC = contaminant of concern; CTM = Candidate Technologies Memorandum; cy = cubic yards; DMMP = Dredged Material Management Program; ENR = enhanced natural recovery; FS = Feasibility Study; GRA = general response action; HDPE = High-density polyethylene; HTTD = high-temperature thermal desorption; LTTD = low-temperature thermal desorption; MNR = Monitored Natural Recovery; MTCA = Model Toxic Control Act; NCP = National Contingency Plan; PCB = polychlorinated biphenyls; SVOC = semivolatile organic compound; TBT = tributyltin; TOC = total organic carbon; TSCA = Toxic Substances Control Act; TSS = total suspended solids; UECA = Uniform Environmental Covenants Act

Table 7-4 Remedial Technologies and Process Options Retained for Potential Use in Developing Remedial Alternatives

General Response Action	Technology Type	Process Option	Comments Related to Technology Assumptions for the FS
No Action	None	Not Applicable	Per NCP requirements
Institutional Controls	Proprietary controls and Informational Devices (EPA 2000)	Proprietary Controls	Access to much of the LDW shoreline from the uplands is already restricted by general security measures put in place by private and public property owners. The LDW is a public waterway and public access to nearshore areas is generally not prohibited.
		Seafood Consumption Advisories, Education, and Public Outreach	Public advisories regarding fish and shellfish consumption are currently posted for the entire LDW. Public advisories regarding sediment contact risks are not currently posted. Advisories are a likely element of all remedial alternatives and will remain in place until monitoring data confirms that the advisories can be modified or removed entirely.
		Monitoring and Notification of Waterway Users	As needed, these will be tailored to specific remediation activities and site constraints.
		Enforcement Tools	CERCLA or MTCA consent decrees for settling potentially responsible or liable parties, or unilateral orders for non-settling parties, issued by EPA or Ecology are anticipated.
		Site Registry	Provides information on applicable restrictions associated with Restricted Navigation Areas and other proprietary controls.
Monitoring	None	Baseline Monitoring	Establishes a statistical basis for comparing conditions before and after the cleanup action.
		Construction Monitoring	Short-term monitoring during remediation used to evaluate whether the project is being implemented in accordance with specifications (i.e., water quality monitoring, bathymetric surveys)
		Post-Construction Performance Monitoring	Post-construction performance monitoring evaluates post-removal surface and subsurface sediment conditions in dredging or containment areas to confirm compliance with project specifications.
		Operation and Maintenance Monitoring	Operation and maintenance monitoring of dredging areas, containment, and/or disposal sites (i.e., CAD sites, ENR and capping areas) required to ensure long-term effectiveness and continued stability of the structure.
		Long-term Monitoring	Long-term monitoring evaluates sediment, tissue, and water quality at the site for an extended period following the remedial action.
Monitored Natural Recovery (MNR)	Natural Physical, Biological, and Chemical Recovery	Multiple potential mechanisms: burial (sedimentation), immobilization, desorption, dispersion, diffusion, dilution, volatilization, resuspension, biological degradation.	Surface sediment chemistry is monitored over time to track recovery by multiple physical, chemical, and biological mechanisms that operate naturally in the estuarine environment of the LDW. Burial by the comparatively cleaner sediments coming into the LDW from the Green River is the principal mechanism for recovery in the LDW. Natural recovery is operative in the waterway as supported by analysis of the empirical data and predicted by the STM. Areas potentially suitable for MNR must be depositional, not subject to significant physical disturbances from high river flows, vessel propeller scour, anchor drag, and routine dredging. Future construction activity in MNR zones is not precluded; however, the applicant/owner must be prepared to appropriately handle any contaminants that may be encountered as part of the project.
Enhanced Natural Recovery (ENR)	Thin-layer Placement	Placement of a thin layer of granular media (e.g., sand) to augment natural recovery	ENR differs from MNR with respect to the modification of initial conditions (i.e., placing clean material onto the contaminated sediment surface). In other respects, siting, monitoring, and future use restrictions and considerations are the same. Placement also can serve as a means of managing contaminated dredging sediment residuals, called thin-layer sand placement. The composition of ENR/*in situ* treatment may include carbon amendments and/or habitat mix.
Containment	Capping	Conventional Sand Cap	Conventional capping is restricted to net deposition areas that are not subject to appreciable sustained or episodic erosion. Cap thickness must be sufficient to prevent reintroduction of buried contaminants into biologically active zone (upper 10 cm).
		Conventional Sediment/Clay Cap	Cap thickness must be sufficient to prevent reintroduction of buried contaminants into biologically active zone (upper 10 cm).
		Armored Cap	If capping is considered in erosion areas, armoring will likely be required to maintain the cap integrity.
		Spray Cap (Technology not addressed by CTM)	Shotcreting is potential approach for confining, isolating contaminants under dock or overwater structures. The shotcrete application at Todd Shipyards effectively encapsulated existing debris (slag) mounds from the aquatic environment.
		Composite Cap	Application would be location- and contaminant-specific where space or pollutant constraints indicate conventional sand capping is not adequate.
		Reactive Cap	Application would be location- and contaminant-specific where space or pollutant constraints indicate conventional sand capping is not adequate.
Removal	Dredging	Hydraulic Dredging (including diver-assisted dredging)	Hydraulic dredging has several constraints that limit its project-wide application: the cost and logistics of managing large volumes of water including large land area adjacent the dredging area; potential for water quality impacts; debris leads to operational difficulties and dredging inaccuracies; interruption of waterway use caused by placement of the hydraulic discharge pipeline in the LDW. Application of hydraulic dredging in the LDW may be appropriate on a small scale (e.g., diver-assisted dredging in under dock/pier areas) or on location-specific basis.
		Mechanical Dredging	Demonstrated effective in the Puget Sound region and nationwide sediment remediation projects. Readily available and least-cost dredging option in the Puget Sound region.
		Mechanical Dredging (Excavator)	Excavator dredges offer a high level of control in the placement of the dredge bucket because it uses fixed linkages instead of cables. This yields a higher degree of accuracy resulting in less volume of dredged sediment and reduced water quality impacts as compared to a conventional derrick barge. Often used for debris removal and/or shallow in-water dredging operations.
	Excavating	Dry Excavating	Generally applicable to nearshore areas above elevation -2.0 ft MLLW or 25-ft reach from top of bank.

Table 7-4 Remedial Technologies and Process Options Retained for Potential Use in Developing Remedial Alternatives (continued)

General Response Action	Technology Type	Process Option	Comments Related to Technology Assumptions for the FS
In Situ Treatment	Physical/Immobilization	Activated Carbon Amendment	Demonstrated effective in nationwide sediment remediation projects at pilot-scale level. Readily available and low-cost *in situ* treatment technology. Sand could be mixed with the activated carbon as a form of modified ENR (see above).
		Organoclay Amendment	Demonstrated effective in nationwide sediment remediation projects at pilot-scale level. Readily available and low-cost *in situ* treatment technology. May require armoring in LDW areas susceptible to propeller and/or high-flow scour.
Ex Situ Treatment	Chemical/ Physical	Soil Washing	Mechanically dredged sediment is screened to remove oversize debris and is then processed through a series of unit operations resulting in the following products or waste streams: wastewater, sludge (fines fractions), and sand/gravel. Wastewater requires treatment, the sludge is typically disposed (upland landfill), and the sand/gravel component may be reused for in-water applications if it tests suitable for beneficial use pursuant to the Washington State Sediment Management Standards (i.e., less than SQS criteria). Soil washing/particle separation is potentially effective and implementable in the LDW where the percentage of sand in the sediment exceeds ~ 30% by weight. It is anticipated that most of the COCs will concentrate on the remaining sludge (fines fraction), which will then need disposal. This concentrating process, if too great, could cause the sludge to be designated as hazardous waste.
	Physical	Separation	Presented as unit costs in FS.
		Solidification	If future designs require further water reduction methods and to remove free water prior to landfilling.
Disposal	On-site Disposal	Contained Aquatic Disposal (CAD)	The overall space (volume) capacity for CAD is limited. However, adequate capacity may be available to contain substantial portion of the contaminated dredged sediment for those alternatives requiring the least amount of dredging. However, for most alternatives, CAD will not be adequate for project-wide application, but could serve to contain a portion of the contaminated sediment. Substantial implementability logistics issues need to be addressed with CAD. Also, constraints with long-term institutional controls (e.g., conflict if located within established dredging areas) and multiple agency approvals to authorize the site are a concern.
		Confined Disposal Facility (CDF)	Not applicable to LDW site-wide application because of limited locations (and capacity) without other current uses. May be applicable for smaller-scale location-specific application.
	Off-site Disposal	Subtitle D Landfill	Applies specifically to sediment that is characterized as non-hazardous in accordance with federal or state regulations. Regional landfills that can accept nonhazardous sediment are Allied Waste Inc. (Roosevelt, Washington) and Waste Management (Arlington, Oregon).
		Subtitle C Landfill	Applies specifically to sediment that is characterized as hazardous or dangerous in accordance with federal or state regulations. This condition is not expected to occur on a large scale and more likely will be limited to localized hot spot removal areas, if triggered at all.
		Dredged Material Management Program (DMMP) Open water Disposal	This is a potentially viable disposal option where the average concentration of COCs in the entire dredged material management unit is determined to be less than the DMMP disposal requirements.
		Beneficial Use (In-Water and Upland)	Sediment that tests suitable for beneficial use pursuant to the Washington State Sediment Management Standards (i.e., less than SQS criteria) may be beneficially reused for habitat creation, capping, or residual management. In case of treatment (e.g., soil washing), the sediment may qualify for beneficial reuse.

Notes:

[shaded] Representative site-wide process options included in the development of the remedial alternatives and cost estimates for this FS. Other process options may have location-specific applicability; but not site-wide applicability.

1. These technologies and process options were screened and retained in Tables 7-2a through 7-2e, and summarized in Table 7-3 with the exception of institutional controls, which do not lend themselves to comparison on the same terms as other technologies. Institutional controls are discussed only within Section 7.2 and are not included in Table 7-3.

CAD = contained aquatic disposal; CDF = confined disposal facility; COC = contaminant of concern; CTM = Candidate Technologies Memo; DMMP = Dredged Material Management Program; Ecology = Washington State Department of Ecology; ENR = enhanced natural recovery; EPA = U.S. Environmental Protection Agency; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; MLLW = mean lower low water; NCP = National Contingency Plan; SQS = Sediment Quality Standards; STM = Sediment Transport Model

Table 7-5 Sediment Dredging and Handling Methods Used on Representative Projects in the Puget Sound Region

Sediment Remediation Project	Completed	Dredge Method	Disposal Method	Predicted Volume of Dredged Sediment (cubic yards)	Actual Volume of Dredged Sediment (cubic yards)
Wyckoff/Eagle Harbor West Operable Unit	1997	Mechanical	CDF	1,300 to 9,200	6,000
Norfolk Sediment Remediation	1999	Mechanical	Subtitle D landfill and Subtitle C landfill	4,050	5,190
Cascade Pole Site	2001	Mechanical	CDF	n/a	40,000
Puget Sound Naval Shipyard	2001	Mechanical	CAD	300,000	n/a
Weyerhaeuser	2002	Mechanical	Landfill	n/a	n/a
Hylebos Waterway – Area 5106	2003	Hydraulic	CDF	20,000	n/a
East Waterway	2004	Mechanical	Subtitle D landfill	n/a	n/a
Lockheed Shipyard	2004	Mechanical	Subtitle D landfill	46,625	70,000
Todd Shipyard	2004	Mechanical	Subtitle D landfill	116,415	220,000
Duwamish/Diagonal	2004	Mechanical	Subtitle D landfill	42,500	66,000
Middle Waterway	2004	Mechanical	CDF	75,000	109,000
Hylebos Waterway – Segments 3-5	2004	Mechanical	CDF	n/a	>100,000
Pacific Sound Resources	2004	Mechanical	Subtitle D landfill	3,500	10,000
Head of Hylebos Waterway	2005	Mechanical	Subtitle D landfill	217,000	419,000
Thea Foss – Wheeler Osgood Waterways	2005	Hydraulic/Mechanical	CDF	620,000[a]	422,535
Denny Way	2007	Mechanical	Subtitle D landfill	13,730	14,400

Notes:

a. Volume from combined projects from Commencement Bay Nearshore/Tideflats Explanation of Significant Differences (EPA 2000e)

CAD = contained aquatic disposal; CDF = confined disposal facility; n/a = not available

Figure 7-1 Pilot-scale Demonstrations of Activated Carbon Amendment Delivery into Sediment

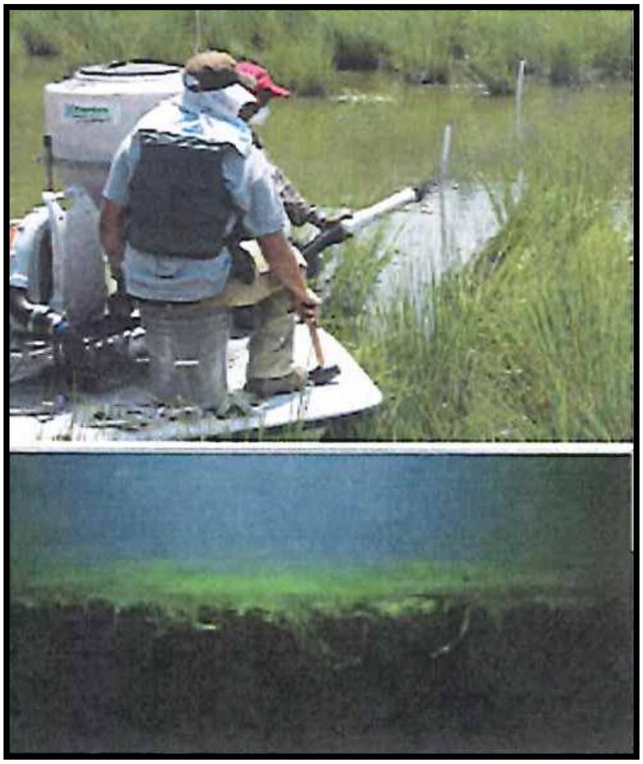
A) *Application of activated carbon in a tidal mudflat at Hunter's Point Naval Shipyard, San Francisco Bay, CA using two application devices (2004 and 2006). The Aquamog (top) using a floating platform approached the site from water and used a rototiller arm while the slurry injection system (bottom) was land based and applied a carbon slurry directly into sediment.*

Source: Ghosh et al., "In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management", *Env.Sci&Tech.*, 45, 1163–1168, 2011.

B) *Application of activated carbon under 15 feet of water at Lower Grasse River, NY (2006). The site was enclosed with a silt curtain and application was performed using a barge mounted crane. Placement and mixing of the activated carbon was achieved using two devices: 1) a 7-by 12-foot rototiller-type mixing unit (top); and 2) a 7-by-10-foot tine sled device (bottom).*

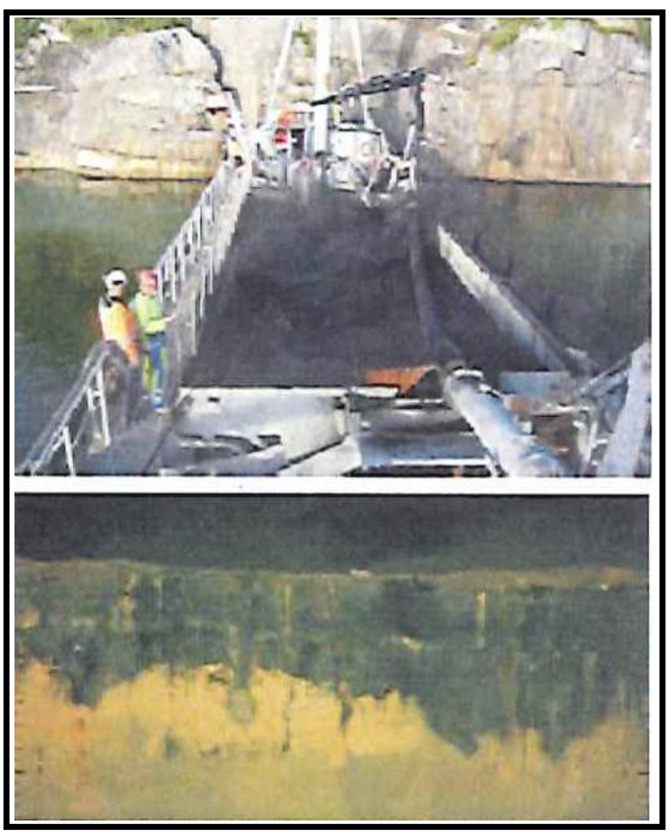
Source: 2006 Activated Carbon Pilot Study Project (thegrasseriver.com).

Figure 7-1 Pilot-scale Demonstrations of Activated Carbon Amendment Delivery into Sediment (continued)



D) *Application of activated carbon in a pelletized form (SediMite™) using an air blown dispersal device (top) over a vegetated wetland impacted with PCBs near the James River, VA (2009). Picture below illustrates bioturbation induced breakdown and mixing of pelletized carbon with a fluorescent tag in a laboratory aquarium (bottom).*

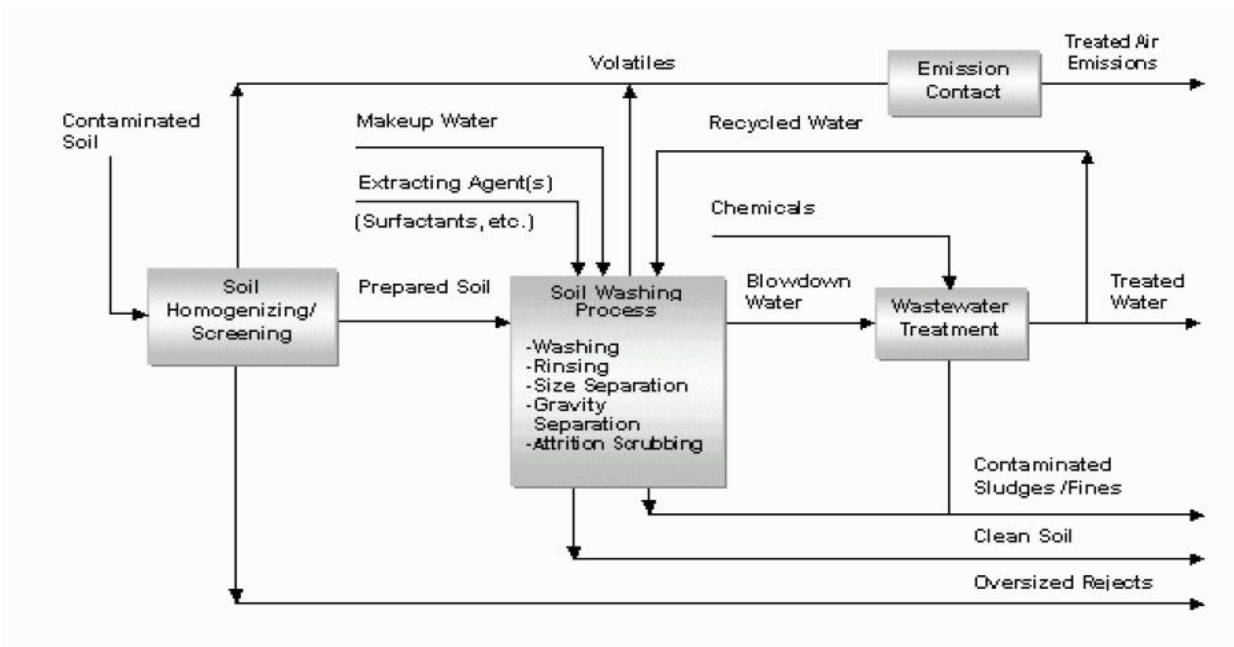
Source: Ghosh et al., "In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management", *Env.Sci&Tech*., 45, 1163–1168, 2011.



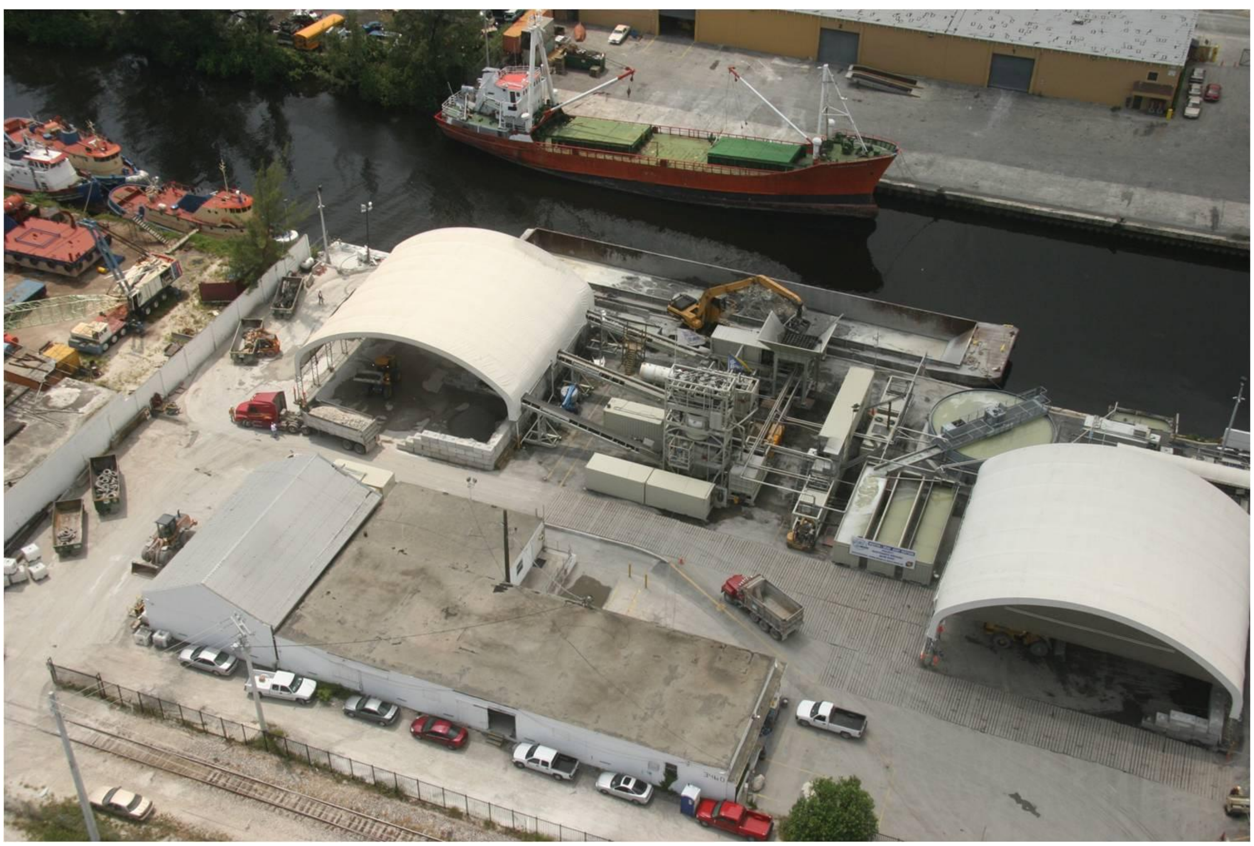
E) *Application of activated-carbon-clay mixture at 100- and 300-ft depth, Grenlandsfjords, Norway (2009), led by NGI and NIVA. A hopper dredger was used to pick up clean clay from an adjacent site. After activated-carbon-clay mixing, the trim pipe was deployed in reverse to place an activated-carbon-clay mixture on the sea floor. Sediment-profile imaging and sediment coring (bottom figure) showed that placement of an even active cap was successful.*

Source: Ghosh et al., "In-situ Sorbent Amendments: A New Direction in Contaminated Sediment Management", *Env.Sci&Tech*., 45, 1163–1168, 2011.

Figure 7-2 Soil Washing



Process Diagram *http://www.frtr.gov/matrix2/section4/4-19.html*

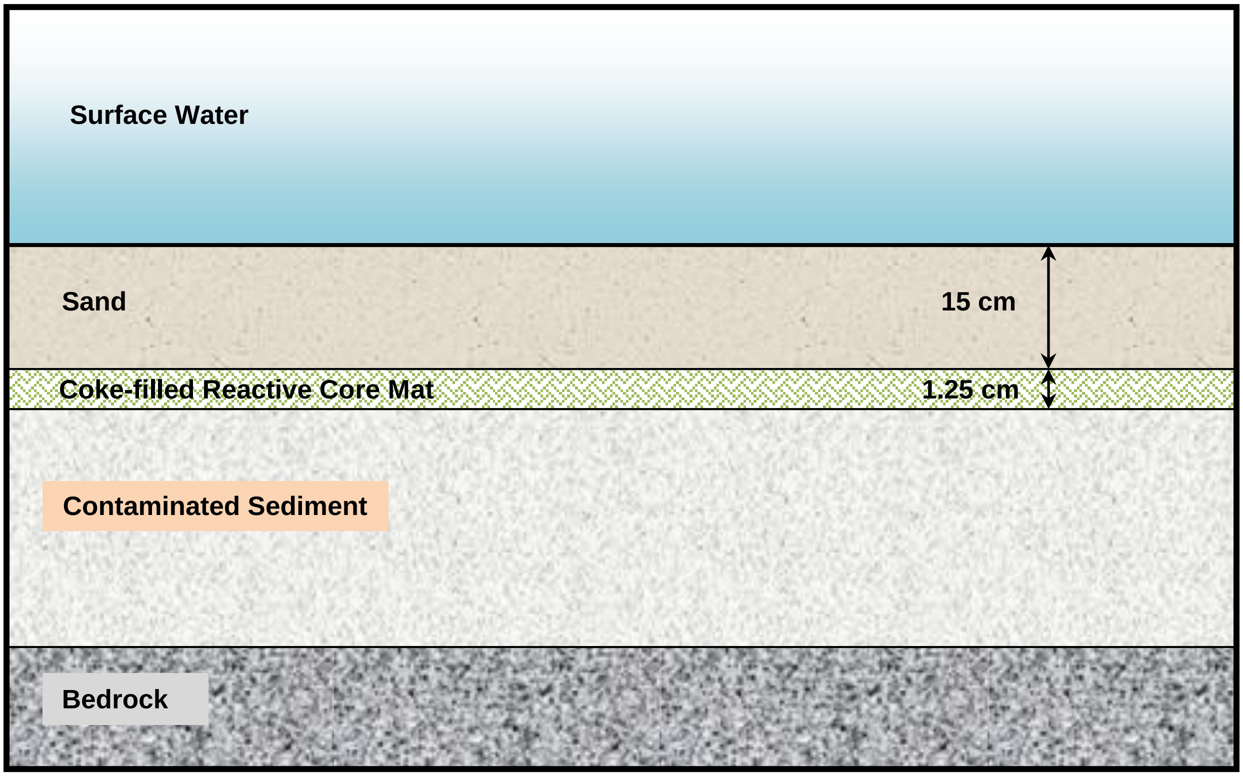


Soil Washing. Miami River Soil /Sediment Separation Plant.
Source: Boskalis-Dolman 2006

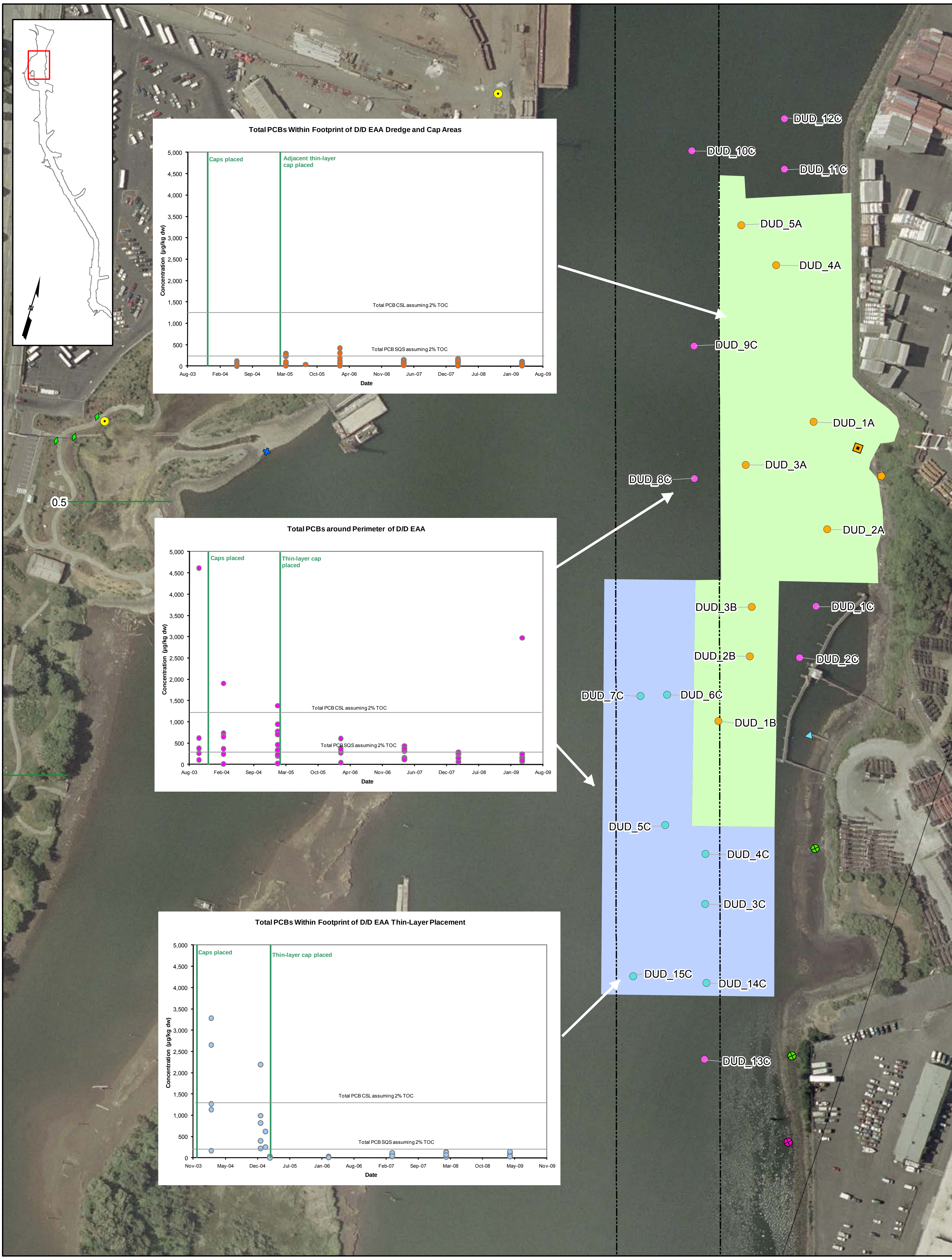
Figure 7-3 Mechanical Placement of Cap at Ward Cove, Alaska

Source: Candidate Technologies Memorandum, Retec 2005.

Figure 7-4 Schematic of Reactive Cap from Anacostia River



Note:
This reactive core mat (RCM) was designed to accurately place a 1.25-cm thick sorbent (coke) layer in an engineered sediment cap in twelve 3.1-m × 31-m sections. The RCM was overlain with a 15-cm layer of sand to secure it. It was placed in the Anacostia River (Washington D.C.) during the Anacostia River Active Capping demonstration project in April of 2004 (McDonough et al. 2006).



Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. Data provided by Windward Environmental in Access database accompanying Final Remedial Investigation (Windward 2010).
3. CSO= combined sewer overflow; EOF= emergency overflow.
4. Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and LDWG personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications.

Outfall Location

- Private storm drain
- Permitted private storm drain
- Public storm drain
- CSO/storm drain
- EOF
- Stream, channel, or swale Abandoned
- Pipe of unresolved origin and/or use

Legend

- Dredge and Cap (2003-2004)
- Thin-layer Sand Placement (2005)

Sampling Location

- Dredging/Cap
- Thin-layer Sand Placement
- Perimeter
- River Mile Marker
- Navigation Channel

0 120 240 480 Feet

AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

Lower Duwamish Waterway
Final Feasibility Study
60150279-14.39

Surface Sediment Total PCB Trends at Duwamish/Diagonal EAA

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE 7-5

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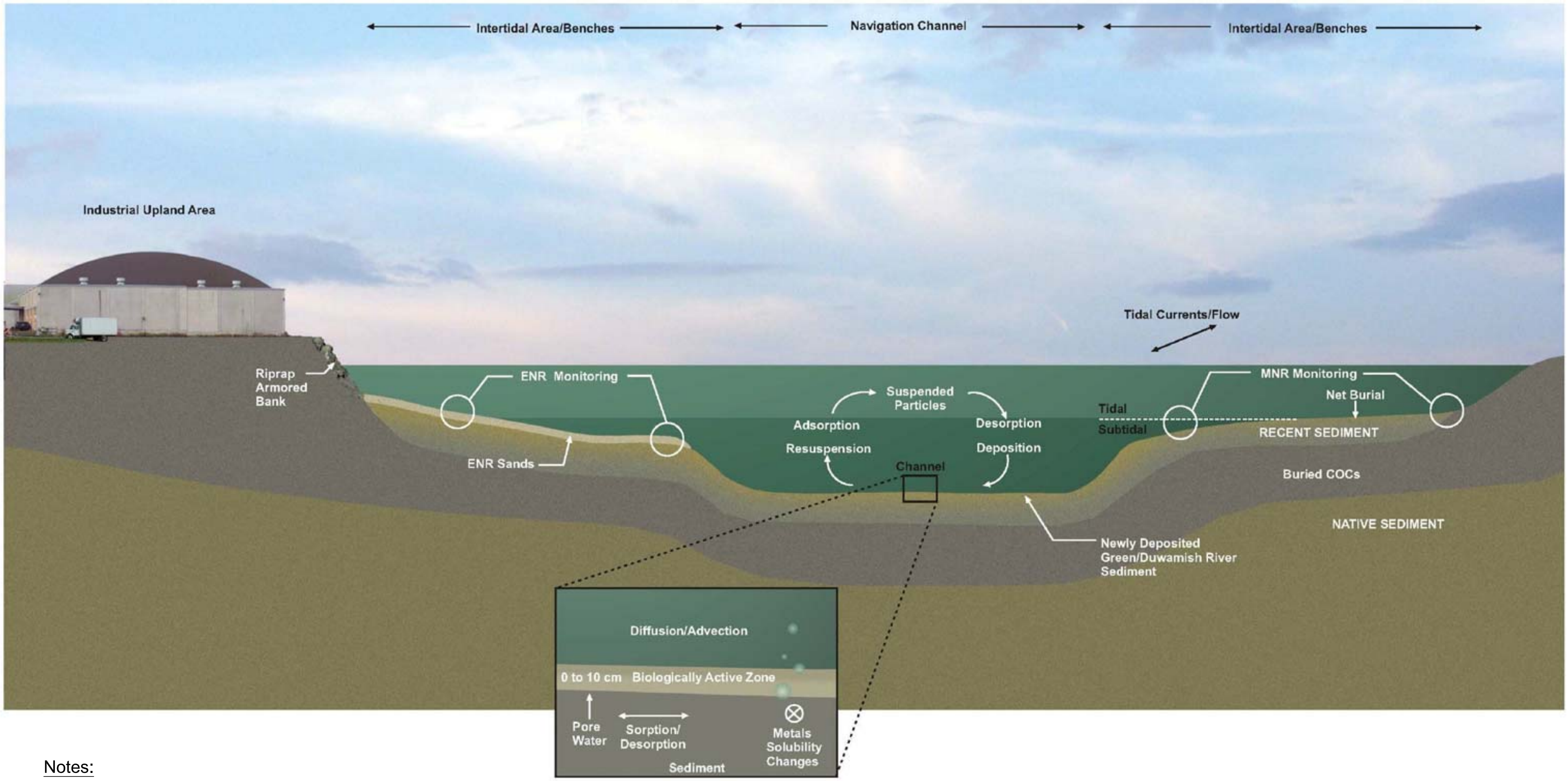
Figure 7-6 Placement of Under-pier Capping Sand between Bents by Sand Throwing Barge

Source: Interim Construction Inspection Report, Todd Shipyards (McCarthy and Floyd|Snider 2005)

Figure 7-7 Finished Shotcrete Surface on Debris Mound

Source: Interim Construction Inspection Report, Todd Shipyards (McCarthy and Floyd|Snider 2005)



Notes:

COCs = Contaminants of Concern
ENR = Enhanced Natural Recovery
MNR = Monitored Natural Recovery

AECOM Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

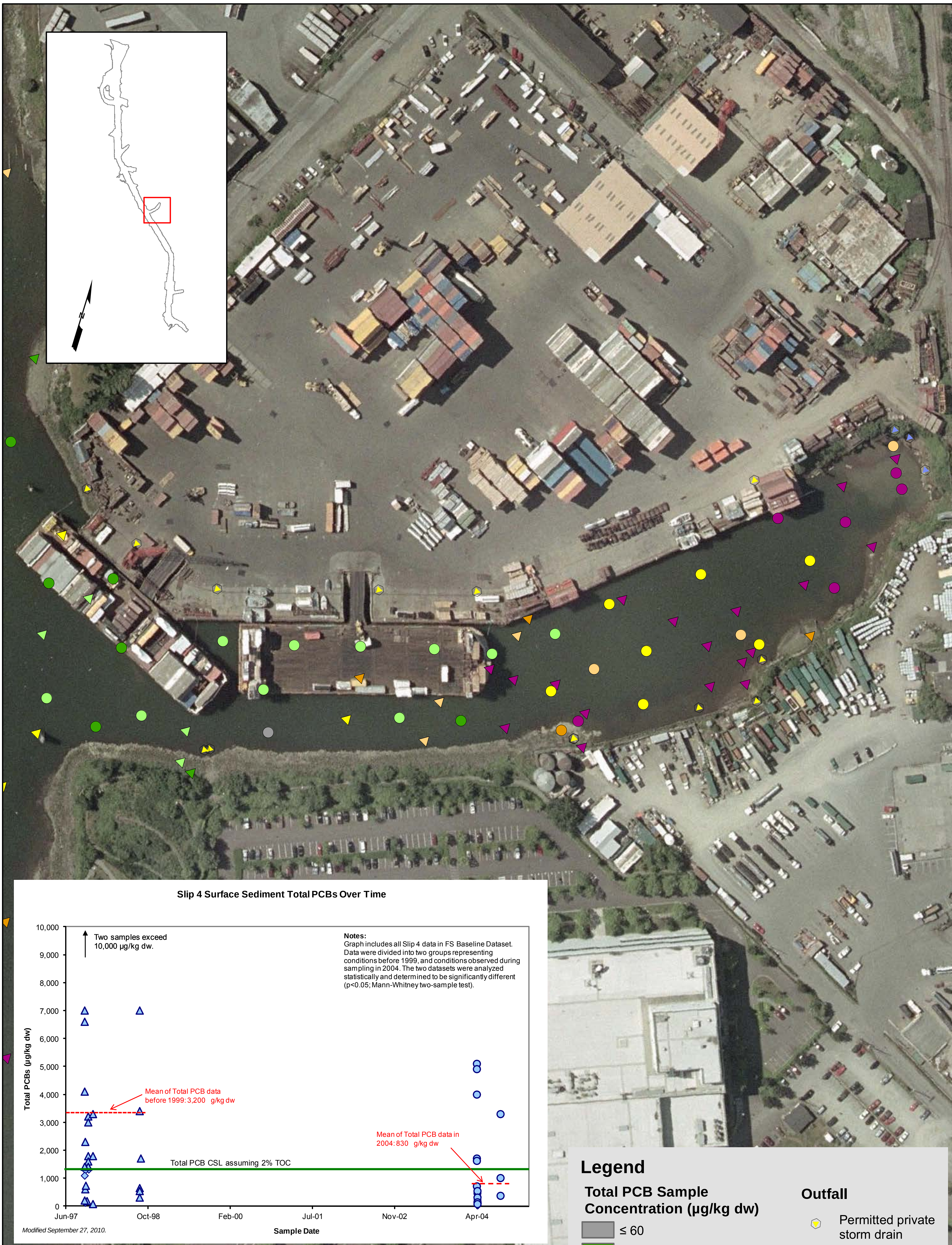
LOWER DUWAMISH WATERWAY
FINAL FEASIBILITY STUDY
60150279-14.39

CONCEPTUAL DIAGRAM OF MONITORED NATURAL RECOVERY AND ENHANCED NATURAL RECOVERY

DATE: 10/31/12 | DRWN: E.M./SEA

FIGURE 7-8

File: G:\PROJECTS\CADD\Lower Duwamish\harmonie pictures\figure 7-7-REV.dwg Layout: ANSL_A1-CP User: oliveriam Plotted: Oct 30, 2012 - 11:42am Xref's:



Notes:
1. USGS 2002 photograph provided by Windward Environmental.
2. Outfalls shown were identified during a City of Seattle low-tide survey in 2003 (Herrera 2004). Some locations were initially identified using drainage maps from Ecology's National Pollutant Discharge Elimination System (NPDES) permit files and other relevant agency databases. These locations were later surveyed in the field. Review of agency files and interviews with agency and LDWG personnel provided additional outfall-specific information. Some locations were field-verified by LDWG members; some additional outfall locations were identified during these subsequent verifications.
3. SQS value of 240 µg/kg dw based on conversion of 12 mg/kg oc to a dry weight value using 2% TOC.

Feet
0 50 100 200

Legend

Total PCB Sample Concentration (µg/kg dw)
- ≤ 60
- > 60 - 120
- >120 - 240
- >240 - 480 (> SQS)
- > 480 - 720
- >720 - 1,300
- > 1,300 (> CSL)

- In 2004
- Before 1999

Outfall
- Permitted private storm drain
- Public storm drain

Lower Duwamish Waterway Final Feasibility Study 60150279-14.39	**Surface Sediment Total PCB Trends in Slip 4**
DATE: 10/31/12 DWRN:MVI/sea Revision: 1	**FIGURE 7-9**

AECOM

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Figure 7-10 Sloping Drain Barge (Hylebos Waterway, Tacoma, WA)

Source: "Barge Dewatering on Contaminated Sediment Projects" WEDA Pacific Chapter 2007 Annual Meeting Honolulu, Hawaii. Presented by Integral Consulting Inc., October 26, 2007

8 Development of Remedial Alternatives

This section presents the rationale, assembly, and description of remedial alternatives for cleanup of the Lower Duwamish Waterway (LDW). The alternatives are assembled in a manner consistent with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) guidance (EPA 1988) and the Model Toxics Control Act (MTCA) requirements. With the exception of Alternative 1 (no further action), each of the alternatives is designed to achieve the cleanup objectives. Cleanup objectives in this feasibility study (FS) mean achieving the preliminary remediation goals (PRGs) or as close as practicable to the PRGs where the PRGs are not predicted to be achievable. This FS uses long-term model-predicted concentrations as estimates of "as close as practicable to PRGs."[1]

Through the use of different remedial action levels (RALs) and types of remedial technologies, the remedial alternatives present a range in the spatial extent of active remediation,[2] time frames to achieve cleanup objectives, volumes of sediment removed, and costs. These ranges of characteristics allow a comparison of the remedial alternatives in subsequent sections of the FS.

Twelve remedial alternatives have been developed (Table 8-1). The process used to develop the remedial alternatives is both sequential and iterative, and is outlined in the following sections:

- Section 8.1, Framework and Assumptions for Making Technology Assignments, describes the criteria and the approach to assigning remedial technologies for each alternative.
- Section 8.2, Common Elements for all Remedial Alternatives, describes elements applicable to all remedial alternatives, including source control, site preparation, staging, transloading, disposal, and additional details on the application of remedial technologies.
- Section 8.3, Detailed Description of Remedial Alternatives, presents the detailed elements of each remedial alternative, including actively remediated acres, volumes of dredged sediment, and numbers of years to implement.
- Section 8.4, Uncertainties, highlights assumptions used to develop remedial alternatives for this FS that are likely to be refined during remedial design and remedial action.

1 For further details on cleanup objectives, see Section 9.1.2.3.

2 For the FS, "active remediation" refers to enhanced natural recovery (ENR), capping, *in situ* treatment, dredging, or some combination of the four. "Passive remediation" refers to monitored natural recovery (MNR), site-wide monitoring, institutional controls, or some combination of the three.

The development of remedial alternatives is a culmination of the analyses and findings in previous sections of this FS. These include:

- Regulatory requirements, remedial action objectives (RAOs), and PRGs, as defined in Section 4.
- Areas of potential concern (AOPCs), as defined in Section 6, represent areas of sediment that have potentially unacceptable risks and will likely require application of active or passive remedial technologies. AOPC 1 represents the area needing remediation to achieve the cleanup objectives for RAOs 2 through 4. AOPC 2 expands AOPC 1 to include areas that would need to be actively remediated to achieve the long-term model-predicted concentrations immediately following construction (i.e., assuming no natural recovery).
- RALs were developed in Section 6. The RALs form the primary basis for developing remedial alternatives. A RAL is defined as the point-based sediment concentration above which an area is actively remediated using dredging, capping, enhanced natural recovery (ENR), *in situ* treatment, or a combination of these technologies. The RALs for the primary risk drivers (polychlorinated biphenyls [PCBs], arsenic, carcinogenic polycyclic aromatic hydrocarbons [cPAHs], and dioxins/furans) are grouped and assigned to the remedial alternatives.
- Representative remedial technologies retained following screening in Section 7 form the basis for the remedial alternatives. These include both active remedial technologies (i.e., dredging, capping, upland disposal, contained aquatic disposal (CAD), treatment, ENR, *in situ* treatment) and passive remedial technologies (i.e., monitored natural recovery (MNR), site-wide monitoring, and institutional controls).

The remedial technologies identified in Section 7 have been assembled into the 12 remedial alternatives listed in Table 8-1. These include one no further action alternative (Alternative 1), seven removal-emphasis alternatives (“R,” Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-Treatment, and 6R) and four combined-technology alternatives (“C,” Alternatives 3C, 4C, 5C, and 6C). All of the alternatives other than Alternative 1 are referred to herein as active remedial alternatives. The various technologies are represented consistently among the remedial alternatives in the following ways:

- Institutional controls are required for all remedial alternatives because no alternative can allow for unlimited use and unrestricted exposure with respect to RAOs 1 and 2. Risks can be reduced to protective levels through a combination of active remediation, source control, natural recovery, and institutional controls, with institutional controls being used only to the extent further remedial measures cannot practicably achieve further risk reductions. All remedial alternatives use institutional controls to protect human health pursuant to making progress toward achieving RAO 1 Additional institutional controls are used for long-term protection of engineered containment systems (e.g., caps or on-site CAD facilities), ENR/*in situ* treatment, and anywhere contamination remains above levels needed to meet cleanup objectives. Alternative 1 includes only the existing Washington State Department of Health (WDOH) seafood consumption advisory; it does not include the full complement of institutional controls assumed for the other alternatives. All of the alternatives include LDW-wide monitoring to assess risk reductions over time.

- Sediment removal (e.g., dredging) is incorporated into all active remedial alternatives. For the alternatives that emphasize removal (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-Treatment, and 6R), dredging/excavation and disposal are the primary technologies used for active remediation. These alternatives include some isolation capping or partial dredging and capping in locations where removal is unlikely to be feasible (e.g., on banks and around structures). The "combined-technology" alternatives (Alternatives 3C, 4C, 5C, and 6C) use dredging and excavation only when capping and ENR/*in situ* treatment are not considered to be implementable (i.e., because of elevation requirements in habitat areas, the navigation channel, or berthing areas, see Section 8.1.2).

- Upland disposal of dredged sediment is incorporated into all active remedial alternatives. In conjunction with upland disposal, CAD is incorporated into Alternative 2R-CAD and sediment treatment is incorporated into Alternative 5R-Treatment. The CAD and sediment treatment components could be incorporated into any alternative, but are presented once to facilitate comparisons with other remedial technologies and disposal options in Sections 10 and 11.

- The combined technology alternatives emphasize the use of capping, ENR, and *in situ* treatment based on the decision criteria in Section 8.2. For these alternatives, ENR is used where considered feasible based on site conditions (e.g., low scour potential, moderate sediment contaminant concentrations), capping is used where ENR is not considered to be feasible, and partial dredging and capping are used when elevation constraints preclude capping. *In situ* treatment has similar engineering assumptions as ENR with the added use of amendments as described in Section 7, and is assumed to be incorporated into approximately half of the area assigned to ENR (e.g., areas with the greatest potential to reduce bioavailability of risk drivers).

For this reason, ENR will be designated as ENR/*in situ* treatment within this section.

- Section 7 and Appendix F provide evidence that natural recovery is an ongoing process in the LDW (primarily via burial) that is predicted to reduce surface sediment concentrations across much of the site to some degree whether or not active remediation is undertaken. The contribution of natural recovery will be tracked in the context of long-term monitoring (Section 8.2.4) LDW-wide. This type of monitoring will be conducted regardless of the remedy that is selected for cleanup. For the purposes of this FS, the term “MNR” refers to more intensive monitoring in specific areas, defined in Alternatives 2, 3, and 4, that are below the RALs but above the sediment quality standards (SQS) of the Washington State Sediment Management Standards (SMS). Natural recovery in these areas would be monitored over time with the goal of achieving the SQS on a point basis, and additional cleanup would occur if the SQS is not met within a specified time frame. Once this goal is reached, the model predicts that natural recovery would continue to reduce contaminant concentrations until a steady state is reached. Monitoring would continue in a broader and less intensive site-wide context to track progress toward the goal of getting as close as practicable to RAO 1 PRGs.

Table 8-1 presents the remedial alternatives and their RALs. The remedial alternatives were developed based on the RALs described in Section 6. In addition to a No Further Action Alternative (Alternative 1), Alternatives 2 through 6 have been developed based on five groups of RALs (Table 8-1). These groups of RALs define the actively and passively remediated areas for the remedial alternatives. The bullets below list the remedial alternatives and the goals that each alternative is designed, at a minimum, to achieve:[3]

- **Alternative 1 –** No further action following cleanup of the early action areas (EAAs), which encompass a total of 29 acres, other than long-term monitoring. This alternative provides a baseline against which to compare the other remedial alternatives; its inclusion is required by CERCLA.

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3 Natural recovery assumptions made for the purpose of developing the remedial alternatives in Section 8 differed from and were more conservative than those made for evaluating the remedial alternatives in the remaining sections of the FS. In Section 8, natural recovery was not accounted for during construction because, at this point, the construction time frames for the alternatives were unknown. In Section 9, natural recovery was assumed to occur during construction (i.e., in areas of the site not being subjected to active remediation). Because of this methodological difference, Section 9 shows lower predicted contaminant concentrations in LDW surface sediments than those used to develop alternatives in this section.

- **Alternatives 2R and 2R-CAD –** Actively remediate 32 acres (in addition to the 29 acres in the EAAs) with contaminant concentrations above the Alternative 2 RALs. These alternatives are designed to achieve, at a minimum:
  - Incremental risk reduction for RAO 1 (human health seafood consumption) through active remediation
  - RAO 2 (human health direct contact) PRGs within 10 years following construction
  - The cleanup screening levels (CSL) of the SMS within 10 years following construction and the SQS within 20 years following construction for RAO 3 (protection of benthic community)
  - RAO 4 (river otter) PRG within 10 years following construction.

  MNR is used where viable in areas with concentrations below the RALs to achieve cleanup objectives for RAOs 2 through 4 following construction (e.g., SQS within 20 years following construction). For areas exceeding the RALs, Alternatives 2R and 2R-CAD emphasize removal (dredging) using upland and CAD disposal, respectively.

- **Alternatives 3R and 3C –** Actively remediate 58 acres (in addition to the 29 acres in the EAAs) with contaminant concentrations above the Alternative 3 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 2, plus:
  - Achieve further incremental risk reduction for RAO 1 through additional active remediation
  - Achieve the cleanup objectives for RAOs 2 and 4 immediately following construction, rather than 10 years following construction
  - Achieve the CSL immediately following construction, rather than 10 years following construction, for RAO 3. Achieve the SQS within 20 years following construction for RAO 3 (protection of benthic community).

  MNR is used where viable in areas with concentrations below the RALs to achieve the RAO 3 PRGs during a specified time frame following construction (i.e., SQS within 20 years following construction). For areas exceeding the RALs, Alternative 3R has a removal emphasis (i.e., dredging) and Alternative 3C uses a combined technology approach (i.e., a combination of dredging, capping, and ENR/*in situ* treatment).

- **Alternatives 4R and 4C –** Actively remediate 107 acres (in addition to the 29 acres in the EAAs) with contaminant concentrations above the

Alternative 4 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 3, plus:

- Achieve further incremental risk reduction for RAO 1 through additional active remediation
- Achieve the SQS for RAO 3 within 10 years following construction, as opposed to 20 years following construction.

MNR is used where viable in areas with concentrations below the RALs to achieve the RAO 3 PRGs during a specified time frame following construction (i.e., SQS within 10 years following construction). Like Alternative 3, Alternative 4R emphasizes a removal technology approach and Alternative 4C uses a combined technology approach.

- **Alternatives 5R, 5R-Treatment, and 5C –** Actively remediate 157 acres (in addition to the 29 acres in the EAAs) with contaminant concentrations above the Alternative 5 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 4, plus:
  - Achieve further incremental risk reduction for RAO 1 through additional active remediation
  - Achieve the SQS for RAO 3 immediately following construction, as opposed to 10 years following construction.

  MNR is not used in these alternatives. However, natural recovery outside of AOPC 1 contributes to risk reduction for RAO 1. For areas exceeding the RALs, Alternative 5R emphasizes removal with upland disposal, Alternative 5R-Treatment also emphasizes removal and adds soil-washing treatment, and Alternative 5C uses a combined technology approach.

- **Alternatives 6R and 6C** – Actively remediate 302 acres (in addition to the 29 acres in the EAAs) with contaminant concentrations above the Alternative 6 RALs. These alternatives are designed to achieve, at a minimum, the outcomes of Alternative 5, plus:
  - Achieve the approximate long-term model-predicted concentrations immediately after construction for the human health risk drivers.

  MNR is not used in these alternatives. However, natural recovery outside of AOPC 1 contributes to risk reduction for RAO 1. For areas exceeding the RALs, Alternative 6R emphasizes removal and Alternative 6C uses a combined-technology approach.

8.1 Framework and Assumptions for Making Technology Assignments

This section describes the criteria and assumptions used to guide the assignment of remedial technologies for the remedial alternatives. The criteria used to select remedial technologies were developed for the purposes of the FS and are subject to modification and refinement during remedial design, as discussed in Section 8.4. A two-step process was used for assigning technologies to the remedial alternatives.

First, the spatial extent of active and passive remediation is developed for each alternative (see Section 8.1.1 and Figure 8-1). This is based on the extent of RAL exceedances, taking into account recovery potential and constructability considerations. For the removal-emphasis alternatives (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-Treatment, and 6R), the active remedial footprint indicates where removal or partial removal followed by capping will occur. For the combined-technology alternatives (Alternatives 3C, 4C, 5C, and 6C), the active remedial footprint indicates where removal, capping, or ENR/*in situ* treatment will occur. Outside of the active remedial footprints, passive remediation will occur, including MNR and/or institutional controls and site-wide monitoring.[4]

Second, after the active and passive remedial footprints are established, remedial technologies are assigned (see Section 8.1.2 and Figures 8-1 and 8-2), based on whether the alternative is focused on removal or combined technologies. This is done by using a set of defined technology criteria assumptions based on the predicted effectiveness of the remedial technologies under various conditions in the LDW. These assignments apply to all remedial alternatives and are summarized in Tables 8-2 and 8-3.

8.1.1 Spatial Extent of Active and Passive Remediation

This section describes the development of the active and passive remedial footprints for the remedial alternatives (Figure 8-1). A RAL exceedance triggers the need for active remediation. The sediment concentrations were compared to the RALs in different ways depending on location. RAL exceedances site-wide and in localized areas (i.e., beaches, potential scour areas) were determined as follows:

- Site-wide, the point of compliance is the uppermost 10 centimeters (cm) of the sediment. Therefore, concentrations for all risk drivers in the upper 10 cm of sediment were compared with the RALs. The spatial extent of RAL exceedances for individual risk drivers was defined by the interpolated area of the LDW with surface sediment concentrations exceeding the RALs (see Section 6.4.1.2 for interpolation methods).

4 Natural recovery is operative across much of the site at all times and its influence is determined by long-term monitoring.

- In areas where significant scour is possible (more than a 10-cm scour depth during a 100-year high-flow event or observed vessel scour areas; see Sections 5 and 6), contaminated subsurface sediment could be uncovered and exposed. In these areas, the maximum risk-driver concentrations in the upper 2 feet (ft) of the sediment cores were compared to the RALs. The spatial extent of the RAL exceedance within potential scour areas was conservatively assumed to be the entire extent of the potential scour area if there was only a single subsurface sample within that area. If more than one core was located in a scour area, the spatial extent of the RAL exceedance was governed by the nearest core.
- In intertidal areas,[5] the point of compliance for human health risk drivers is established as the upper 45 cm of the sediment because of potential human direct contact during clamming or beach play.[6] For the FS, the maximum concentrations of arsenic, CPAHs, and dioxins/furans at any depth in the upper 45 cm of cores or in surface sediment samples were compared to the RALs listed in Tables 6-2 and 8-1 as "intertidal RALs".[7] For SMS criteria, risk-driver concentrations within the upper 10 cm were compared to the RALs unless the core was in an area with significant scour potential. The spatial extent of RAL exceedances in intertidal areas was based primarily on surface sediment concentrations (i.e., interpolated area or Thiessen polygons, as described above) and core data, when available. In instances where core exceedances were outside areas represented by the surface grab exceedances, the active remedial footprint was expanded an appropriate amount based on analysis of the chemical and physical conditions at that location.

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5 Intertidal areas correspond to areas with mudline elevations from -4 ft mean lower low water (MLLW) to +11.3 ft MLLW.

6 A compliance depth interval of 45 cm is a health-protective assumption for both the beach play and clamming scenarios. Although the sediment depth to which young children may be exposed during beach play has not been documented, EPA considers a depth of 45 cm to be sufficiently protective. With respect to clamming, Eastern soft-shell clams (*Mya arenaria*), the predominant clam species of harvestable size in the LDW, have been reported to burrow to depths that range from 10 cm to 20 cm based on two Pacific Northwest species guidebooks (Kozloff 1973, Harbo 2001) and from 10 to 30 cm based on studies conducted throughout the United States (e.g., Blundon and Kennedy 1982, Cohen 2005, Hansen et al. 1996, Evergreen State College 1998).

7 In other words, any sample interval overlapping the upper 45 cm (1.5 ft) of sediment was compared to "intertidal" RALs listed in Table 8-1. Where core data were not available, the concentration in a 0- to 10-cm surface sediment sample was assumed to extend to 45 cm depth. Also, as discussed in Section 6, total PCBs were not included in the top 45 cm evaluation because the clamming and beach play direct contact PRGs for this contaminant are predicted to be achieved after remediation of the EAAs and hot spots (Alternative 2).

- ♦ In beach play areas, the FS baseline total (all risk drivers combined) excess cancer risk for each individual beach was compared with the 1×10^{-5} risk threshold to ensure that the active remedial footprint based on the RALs was sufficiently protective for each beach.

For all alternatives, the area with concentrations exceeding the RALs was assigned to the active remedial footprint. For Alternatives 2 and 4, the RALs for SMS contaminants (including PCBs) are a range. In most locations, the higher RAL was employed. In areas not predicted to achieve the CSL (Alternative 2) and SQS (Alternative 4) within 10 years following construction, the lower RAL was used (see Table 8-1). Specifically, the lower RAL was employed: 1) in areas where the bed composition model (BCM) predicted concentration was greater than the CSL (Alternative 2) or SQS (Alternative 4) within 10 years; and 2) in Recovery Categories 1 and 2 (see Section 8.1.2.4 for more detail on recovery categories).

For FS purposes, the spatial extent of the active remedial footprint was modified for constructability (e.g., minimum 100 ft x 100 ft constructible areas). The active remedial footprints will be refined during remedial design.

Passive remedial technologies are described in Section 8.2, including a discussion of adaptive management and potential contingency actions (Section 8.2.5). MNR is assigned to all areas within AOPC 1 that are not actively remediated (see Section 8.2.2.4). A subset of these areas is predicted to be below the PRGs for RAO 3 (SQS) at the time of construction (data are isolated and more than 10 years old, or data indicate that natural recovery has occurred). These areas are designated for verification monitoring during remedial design.

Institutional controls are required as part of all alternatives to manage residual risks. Alternative 1 (the no further action alternative) provides no institutional controls beyond those specific to the EAA projects and the existing WDOH seafood consumption advisory. A more extensive institutional control program is assumed for Alternatives 2 through 6. Site-wide monitoring applies to all alternatives, including Alternative 1.

8.1.2 Assigning Remedial Technologies

Figures 8-1 and 8-2 describe the decision process for assigning active or passive remediation to an area for each alternative. The criteria used for technology assignments included contaminant concentration upper limits, contamination thickness, navigation and berthing elevation requirements, recovery categories, habitat, and overwater structures (Table 8-2). Technology assignment criteria are described briefly in the following sections, and additional details regarding remediation are described in Section 8.2.

These preliminary technology assignments are intended to facilitate development and comparative analysis of remedial alternatives for this FS. Additional information on location-specific characteristics and technology effectiveness may change the technology application during remedial design. Section 8.4.3 discusses uncertainties with respect to technology assignments and provides examples of how technology assignments and assumptions may change during remedial design.

8.1.2.1 Contaminant Concentration Upper Limits

The contaminant concentration upper limit (UL) of each technology is assumed to be the highest concentration in surface sediment that can be remediated to achieve the identified goals for the technology. No ULs were assumed for removal and capping technologies. Establishing ULs for ENR/*in situ* treatment required consideration of location-specific conditions such as net sedimentation rate, sediment stability (including scour potential), organic carbon content of the underlying sediment and the placed material, amount of mixing with underlying sediment, and groundwater flux. The ENR/*in situ* treatment UL is 3 times the site-wide RAL for all risk drivers. In intertidal areas, the ENR/*in situ* treatment UL is 1.5 times the intertidal RAL for arsenic, cPAHs, and dioxins/furans because of the deeper depth of compliance for protection of human health from direct contact exposure during clamming or beach play. For Alternative 4, the contaminant UL for ENR/*in situ* treatment is three times the higher RAL. Table 8-3 provides the ENR/*in situ* treatment UL for the combined-technology alternatives.

An upper limit of 3 times the RAL is a reasonable assumption for assembling site-wide remedial alternatives. The addition of activated carbon or other amendment to ENR material (i.e., *in situ* treatment) may expand the applicability of ENR/*in situ* treatment into areas with higher surface sediment concentrations for organic contaminants.

In intertidal areas, the ENR/*in situ* treatment UL of 1.5 times the intertidal RAL is based on achieving the RAL immediately following construction. ENR/*in situ* treatment is considered to be a viable remedial technology if the estimated average concentration for risk drivers after ENR placement (6 inches of sand) is below the intertidal RAL over the 45 cm vertical compliance depth assumed for the FS. This criterion assumes that during beach play and clamming, equal exposure to sediment from 0- to 45-cm depths would occur. However, in reality, exposure would probably occur in greater proportion to near-surface sediments than to sediments at greater depth.

The MNR UL is, by definition, the RAL (i.e., MNR is appropriate only where risk-driver concentrations are below the RALs). Cap modeling (Appendix C) predicts no UL is needed for capping to protect the upper 45 cm of sediment for total PCBs or cPAHs. Cap modeling was not performed for metals, a consideration that should be addressed during remedial design.

8.1.2.2 Contamination Thickness

For the combined-technology alternatives, partial dredging and capping is warranted if more than 1 ft of contamination remains after dredging 3 ft of material for cap placement. Partial dredging and capping is applicable in locations with topographic grade restriction, including habitat areas, berthing areas, and the navigation channel. For example, in habitat areas, if the contamination thickness is greater than 4 ft, then partial dredging and capping to accommodate a 3-ft thick cap is the assigned technology. If the contamination thickness is 4 ft or less, then full removal is assumed. The contamination thickness layer developed in Appendix E was used to generate the volume estimates as described in Section 8.2. The contaminated sediment thickness estimate and evaluation of cost effectiveness of partial dredging/capping will be refined during remedial design.

8.1.2.3 Navigation and Berthing Area Elevation Requirements

Authorized navigation channel depths and permitted depths for berthing areas influence technology implementation. The remedial alternative technology assignments must be compatible with reasonably anticipated future use, including future dredging of the navigation channel and berthing areas. Also, caps must be placed far enough below anticipated future dredge depths to prevent damage that could affect their integrity. Figure 2-26 identifies the authorized depths for the navigation channel and Figure 2-27 identifies the permitted depths for berthing areas. For costing purposes, the FS assumes that the post-construction cap and ENR/*in situ* elevations must be at least 3 ft and 2 ft, respectively, below the authorized depth in the navigation channel. Accounting for an assumed 3-ft cap and 0.5-ft ENR/*in situ* treatment layer, the current bathymetric elevation needs to be 6 ft and 2.5 ft below the authorized navigation depth to fit a cap and ENR/*in situ* treatment layers, respectively (without partial removal prior to placement). In berthing areas, this FS assumes that the post-construction cap and ENR/*in situ* elevations must be at least 2 ft and 0 ft, respectively, below the permitted depths. These correspond to current bathymetric elevations of 5 ft and 0.5 ft below the permitted berthing area maintenance dredge depths, respectively. This FS assumes that 18 inches is a typical vertical dredge tolerance for maintenance dredging, and that 2 ft of clearance is sufficient to ensure the integrity of the remedial action. In the federally authorized navigation channel, an additional 1-ft margin of safety was assumed for capping to achieve the 3-ft clearance noted above. However, this is less than the 2 ft of vertical overdraft tolerance and an additional 2 ft of clearance needed to avoid potential navigation channel maintenance conflicts, as stated by the U.S. Army Corps of Engineers (USACE) in their letter to the U.S. Environmental Protection Agency (EPA) (USACE 2010b). Final clearances in the navigation channel or berthing areas will be determined in consultation with EPA and other relevant parties during remedial design. Additional engineering approaches, such as thinner cap design, additional dredging before capping, or cap armoring will also be evaluated during remedial design.

Elevation controls may also apply outside of the navigation channel or berthing areas. For example, the USACE horizontal dredge tolerance is typically 10 ft to either side of the navigation channel, so post-construction clearance elevations may apply in these areas. By extension, additional constraints may be placed on capping side-slopes that angle from the navigation channel because of the possibility that maintenance dredging within the horizontal and vertical dredge tolerances may undermine the slope. These additional elevation considerations require detailed design analysis, and additional dredge volumes attributable to this consideration are assumed to be addressed by the dredge volume contingency (see Appendix E), but are not used in assigning remedial technologies.

Although the depth criteria above are sufficient for FS-level analyses of remedial alternatives, these are subject to change during remedial design. Both the dredge tolerance assumptions and the assumptions of the permitted depths in berthing areas are subject to refinement during remedial design.

8.1.2.4 Recovery Categories

Recovery categories are an FS-level surrogate for design-level, location-specific analysis. The intent of using recovery categories for technology assignments is to apply more aggressive cleanup technologies (capping, dredging) in areas with less potential for natural recovery, and to optimize use of less aggressive cleanup technologies (ENR/*in situ* treatment, MNR) in areas where recovery is predicted to occur more readily. Recovery categories were delineated in Section 6 to group areas of the waterway that have similar conditions with respect to predicted rates of natural recovery. The criteria used to delineate the recovery categories are developed in Section 6 and presented in Table 6-3. Figures 6-4a and 6-4b illustrate their spatial extent. Recovery categories are delineated independent of RAL exceedances or AOPCs. The factors that were incorporated into recovery categories include the sediment transport model (STM)-predicted high-flow event scour >10 cm depth, vessel scour, net sedimentation rates, berthing areas with low sedimentation rates, and empirical chemical trends.

Table 8-4 shows which remedial technologies are applicable within each recovery category. Table 8-5 relates the recovery categories to the RALs and remedial technologies for each remedial alternative. The following bullets describe how the recovery categories were used to make technology assignments:

- Recovery Category 1 represents areas where recovery is presumed to be limited. These areas are assumed to be candidates for dredging and capping, but are not candidates for either ENR/*in situ* treatment or MNR within 10 years (MNR(10); see Table 8-4).
- Recovery Category 2 represents areas that have a less certain recovery potential. These areas are assumed to be candidates for dredging, capping,

and ENR/*in situ* treatment, but are not candidates for MNR(10) (see Table 8-4).

- Recovery Category 3 represents areas that are predicted to recover relatively quickly. These areas are therefore candidates for dredging, capping, ENR/*in situ* treatment, or MNR.

8.1.2.5 Elevation Requirements in Habitat Areas

The maintenance of existing habitat area elevations in the LDW is an important aspect of all remedial alternatives. Intertidal and nearshore habitats are home to diverse communities of fish, birds, mammals, and invertebrate species. These areas are defined to be locations with a depth shallower than -10 ft mean lower low water (MLLW). This FS assumes that habitat within this zone (up to the approximate mean higher high water (MHHW) elevation, which is estimated to be +11.3 ft MLLW) will be managed in ways that approximately restore current elevations. Post-construction bathymetric elevation contours are assumed to be restored to the initial grade, and material placed in these areas will provide suitable habitat substrate. A sandy gravel material (referred to as "fish or habitat mix") is assumed to be applied as a top dressing in intertidal areas. For areas shallower than -10 ft MLLW, the FS assumes that:

- Dredged or excavated sediment will be backfilled to original grade.
- Areas identified for isolation capping will be partially dredged to accommodate cap thickness. Caps that are sited in potential clamming areas may be designed with a greater thickness (e.g., 5 ft) such that the isolation functions of the cap are not affected by potential clamming activities; however, for this FS, a cap thickness of 3 ft is assumed in habitat areas.
- Elevations of habitat areas are assumed to be unaffected by ENR/*in situ* sand placement or MNR, regardless of location. The placement of ENR/*in situ* sand in habitat areas must not modify or degrade existing habitat. This will require careful selection of ENR/*in situ* materials, and potential mitigation measures if sensitive habitat is impacted.

The assumptions above were employed in all areas with depths shallower than -10 ft MLLW with the exception of under-pier areas (see Section 8.1.2.6 for assumptions under piers). Not all intertidal areas are viable habitat areas (e.g., vertical bulkheads). Engineered slopes, bulkheads, and riprap shorelines are also present in the LDW and provide structural support to the shoreline; they may be more difficult to remediate and/or restore to grade (see shoreline conditions in Section 8.1.3). At depths deeper than -10 ft MLLW, restoration to the original grade is assumed not to be required; however, the natural resource agencies and tribes will be consulted in the remedial design phase to ensure that capping or dredging without backfill at depths deeper than -10 ft MLLW does not adversely impact habitat. Additional opportunities to maintain or improve habitat areas may be evaluated during remedial design. For example, to create more intertidal acreage, some projects have placed an isolation cap on top of existing subtidal grades, or have over-excavated bank areas prior to capping.

8.1.2.6 Overwater Structures

Piers, dolphins, piling, and other overwater structures are important considerations in determining if capping and dredging can be implemented. Numerous overwater structures (generalized here by the term piers) exist along the shoreline of the LDW (Figure 2-28). These piers present special challenges for addressing contaminated sediment residing underneath and adjacent to these structures. All remedial actions under piers need to account for the potential structural ramifications of sediment removal or sediment addition (e.g., capping) and the difficulties of implementing remedial actions in limited access areas. For these and other reasons, under-pier areas will require location-specific evaluation, but individual overwater structures are not evaluated for this analysis. Instead, a set of assumptions were used for developing and costing the site-wide remedial alternatives.

Because the remedial investigation (RI) dataset contains little information on sediment contamination under piers, the active remedial footprint below piers was defined by the sediment conditions adjacent to the piers and assumed to extend underneath.

For the removal-emphasis alternatives, partial dredging and capping is assumed for all areas under overwater structures that are above the RALs because it will be difficult to perform full removal in these limited access areas. For cost estimating, dredging is assumed to be performed by a means other than open water dredging, such as diver-assisted hydraulic dredging or partial demolition of the pier structure to provide access (see Section 7.1.1). Where it is used, partial dredging would be followed by capping to the extent feasible. For the combined-technology alternatives, capping is assumed under piers in areas above the RALs. In practice, various cap thicknesses may be viable in under-pier areas, ranging from a thin 6-inch cap to a thicker isolation cap. For cost estimating, 3 ft capping is assumed to be performed by a means other than open water capping, such as casting of sand under piers using a belt conveyor, dry application using small construction equipment, or grout mats (see Section 7.1.4).

Each under-pier area will need to be evaluated during remedial design. Additional design considerations include: the practicability of sediment removal or containment, the structural state and use of the pier, the hydrological and geological conditions under the pier, elevation restrictions, presence of debris, access, and the use of other remedial technologies (such as ENR/*in situ* treatment).

8.1.2.7 Constructability and Best Professional Judgment Modifications

When the criteria described above are considered together and applied to the geographic information system (GIS) layers, the resulting technology footprints include some small, 10 ft by 10 ft irregular areas that may be impractical to remediate. To ensure better approximation of a constructible footprint, the remedial alternative footprints were modified to account for constructability and location-specific conditions.

Elements that went into the final modification of the remedial footprints include:

- Establishing minimum technology application areas on the order of 100 ft by 100 ft; constrained, in some cases, to smaller sizes by physical considerations (e.g., if an intertidal area is 50 ft wide, and dredging is necessary only for the intertidal area).
- Evaluating berthing depths based on frequency of maintenance dredging, bathymetric survey data, and access issues.
- Evaluating chemical data and empirical time trends for recovery to ascertain potential preconstruction sediment contaminant concentrations relative to RALs (i.e., verification monitoring areas; see Appendix D).

8.1.3 Other Considerations Not Addressed in Technology Assignments

This section addresses some additional considerations that need to be evaluated during remedial design, but were not used to assign remedial technologies in the FS. These include utilities, slope stability, and shoreline conditions.

8.1.3.1 Utilities

Utilities are important site features to understand and factor into remedial alternatives. Figure 2-28 maps known utility lines or corridors (in-water and overhead). More detailed utility information will be needed during remedial design. Location-specific evaluations will be needed regarding whether material can be placed over underwater utilities (i.e., capping and ENR/*in situ* treatment), and what setback distances will be required when dredging in areas that contain utilities. For the FS, the presence of utilities (particularly in-water) is acknowledged as a consideration for implementation, but is not assumed to prevent the use of dredging, capping, or ENR/*in situ* technologies, and was therefore not incorporated as a line item in the cost estimate.

8.1.3.2 Seismic Effects

As noted in Section 2.1.4, the Puget Sound region is seismically active. Liquefaction, surface deformation, and lateral spreading associated with earthquakes could lead to instability, damage, or remedy failure. Table 8-6 summarizes prior geotechnical analyses from projects in the LDW, around Harbor Island, and adjacent Elliott Bay. It is important to consider the geographic location of these projects, because the lower portions of the East and West Waterways at the head of Elliott Bay (e.g., the Lockheed West and Pacific Sound Resources Superfund sites) are on a large deltaic deposit, which is more susceptible to submarine landslides, and are also located closer to the center of the Seattle Fault than the LDW. The peak ground accelerations (PGAs), expressed in terms of the acceleration of gravity, vary according to several factors: 1) event recurrence (estimated interval between events), 2) distance from fault slip, and 3) site soils' potential to magnify the ground motion. A wide range of PGAs and moment magnitudes[8] were used in site-specific and location-specific seismic evaluations, as described below.

In the Tetra Tech (2011) FS for the Lockheed West Superfund site, located near the mouth of the Duwamish River, an evaluation was done of in-place banks, sediments, and possible caps. For this site, which has extensive deltaic deposits underlying it, liquefaction was predicted under all modeled conditions for 20 or more ft below ground surface (bgs), with lateral spreading ranging from <1 ft up to 8.5 ft along the shoreline. For a 475-year recurrence event (with an approximate 10% probability of occurrence in 50 years) and a 2,475-year recurrence event (with an approximate 5% probability of occurrence in 50 years), significant slope stability issues, and the potential need for cap repair and corrective measures were identified.

For Boeing Plant 2 (river mile [RM] 2.8 – 3.4), AMEC Geomatrix et al. (2011) evaluated structural stability following implementation of the proposed remedy. The Boeing Plant 2 study evaluated future post-construction conditions for an area that will be substantially altered over much of the shoreline (e.g., geometry and change in slope) compared to other areas of the LDW. The remedy is not a cap placed on an unaltered surface, and thus may not be applicable to estimating potential liquefaction and cap stability elsewhere in the waterway. The Boeing study considered both 100-year and 475-year recurrence events. Under these conditions, the evaluation predicted minor liquefaction and deformation in a 5-ft thick layer below the groundwater table and only minor lateral spreading in the upland areas away from the slope face.

The recurrence event evaluations for the two projects (Lockheed West and Boeing Plant 2) have different results, and therefore serve to bracket the possible slope failure consequences in the LDW. This FS does not establish a "life cycle" for the alternatives (as is typically done in remedial design), and assumes that repairs can be made to address earthquake damage up to the 475-year event.

In general, the potential for earthquakes to damage elements of the sediment remedy increases with the magnitude and proximity of the epicenter to the LDW. Lateral displacement of caps could occur in whole or in part. For seismic events up to and including the 475-year recurrence event, repairs would be the likely outcome for managing sediment disturbance, and not full cap replacement. For low-probability

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8 Magnitude is a number that characterizes the relative size of an earthquake. Moment magnitude (commonly abbreviated by a capital M followed by a number) measures the size of an earthquake as determined by: 1) area of rupture of a fault, 2) the average amount of relative displacement of adjacent points along the fault, and 3) the force required to overcome the frictional resistance of the materials in the fault surface and cause shearing.

(higher severity) events, complete cap replacement could become necessary. Areas that are remediated by ENR and natural recovery, more so than areas that are capped, could be impacted by:

- Transport of subsurface sediments to the surface by liquefaction-induced surface eruptions of subsurface sediment (e.g., as were observed at Kellogg Island following the 2001 Nisqually earthquake)
- Collapse of marine and nearshore infrastructure
- Vessel groundings
- Wave effects (e.g., tsunamis).

The effects from these events on recontamination of surface sediment in the LDW are difficult to predict, either individually or in aggregate. In part, this is because recontamination can stem from: 1) the exposure of contaminated subsurface sediment, and 2) new sources unrelated to contaminated sediment remaining after remediation.

As the severity of local earthquake impacts increases (e.g., to a low probability, longer-recurrence event such as the Seattle Fault Scenario), the potential for exposure of contaminated subsurface sediment in capped, ENR, and MNR areas also increases. In addition, as earthquake severity increases, so does the potential for the LDW to be inundated with new sources of contamination from chemical releases, embankment materials, and debris flows originating from upstream, lateral, and downstream sources. Depending on the extent and severity of these impacts on surface sediment conditions in the LDW, the post-event response could extend beyond simple repair or replacement of parts of the remedy.

8.1.3.3 Slope Stability

This FS does not attempt a design-level analysis of the potential for slope failure and consequences of liquefaction for nearshore caps at individual LDW locations. Capping in some areas is not precluded, but will require a higher level of engineering design effort and appropriate long-term management controls to ensure long-term integrity.

Dredging in sloped areas needs to be carefully evaluated during remedial design to prevent sloughing and adverse impacts to engineered structures (e.g., slope armoring, piles, and bulkheads used to support docks, wharfs, and upland structures). In some cases, these considerations are expected to preclude complete removal of contaminated sediments in nearshore areas and areas with overwater structures, and capping or ENR/*in situ* treatment would then be used to reduce exposure to the remaining contaminated sediment.

For the FS, slope stability is not incorporated into technology assignments for specific locations of the LDW, but is accounted for in the form of a cost premium in developing the remedial alternative. During remedial design, engineering evaluations of bearing capacity and slope stability for susceptibility to liquefaction will be necessary, in addition to long-term management controls to ensure the long-term integrity of any containment remedy.

8.1.3.4 Shoreline Conditions

Shoreline conditions will have a large impact on nearshore remediation. Site features, such as the presence of riprap, sheet-pile walls, upland infrastructure, overwater structures, limited access areas, or previously restored habitat areas will affect the remedial design and ability, or need, to fully remove contaminated sediments. For example, remediation must be conducted such that engineered and load-carrying walls and slopes are not compromised by sediment removal actions. General shoreline conditions (armored slope or riprap, vertical bulkhead, or exposed bank) mapped in the RI are shown on the alternative maps for reference; however, location-specific analysis was not performed during development of site-wide remedial alternatives. The merits and difficulties of remediating these areas will be re-evaluated during remedial design.

Engineering challenges associated with shoreline conditions may result in additional costs. These additional costs are accounted for by adding a cost premium for technically challenging remediation areas. Technically challenging remediation areas are assumed to be 10% of the active remedial footprint for each remedial alternative (see Appendix I).

8.2 Common Elements for all Remedial Alternatives

This section provides additional details pertinent to all remedial alternatives. It includes common engineering assumptions (Section 8.2.1), technology-specific engineering assumptions (Section 8.2.2), remedial design investigations and evaluations (Section 8.2.3), monitoring (Section 8.2.4), adaptive management (Section 8.2.5), and project sequencing (8.2.6). Source control is also a common element of all alternatives (see Section 2.4). This FS assumes that source control work will be sufficiently complete before remediation begins to prevent recontamination.

8.2.1 Common Engineering Assumptions

This section discusses physical and logistical constraints related to implementation of all remedial alternatives and the engineering assumptions made to address them in the FS.

8.2.1.1 Site Preparation, Debris Removal, and Staging

Site preparation for sediment remediation projects is location-specific and generally limited to clearing the remediation areas of debris and other obstructions, as needed.

Debris of varying size and spatial density is likely in much of the LDW, given its long history of industrial and commercial use. The nature and extent of debris will be determined during remedial design. Standard practice in environmental dredging operations is to remove or "sweep" for debris (e.g., logs, concrete, sunken boats) concurrent with sediment removal and before beginning capping or ENR/*in situ* treatment. Each alternative assumes that some degree of debris removal is required for dredging, capping, and ENR/*in situ* treatment projects, and that these sweeps will be conducted using a derrick barge and clamshell dredge. The debris is then barged and offloaded at a transloading facility for subsequent shipment to an upland landfill or for potential recycling (i.e., beneficial reuse). Side-scan sonar surveys, magnetometer surveys, and others methods may be used to assess the presence/absence of debris. If no debris is detected, a debris removal pass may not be required. The amount of debris clearance necessary could vary based on the remediation area and the type of technology employed. For the FS, debris removal is incorporated into the cost estimate by assuming a decreased bucket efficiency over a portion of the dredge footprint (assumed to be 10%) (Appendix I, Table I-5). Similarly, debris removal is assumed necessary for 10% of the capping and ENR/*in situ* areas. However, for these technologies, a per acre unit cost is applied to 10% of the ENR/*in situ* treatment and capping footprint (see Appendix I). The assumption of 10% for the dredge footprint area is adequate for FS cost estimating purposes, but the extent of debris in the LDW is not well known at this time and will need to be refined during remedial design.

Piling, dolphins, and other in-water infrastructure will be allowed to remain in place or will be removed prior to sediment remediation, depending on location-specific conditions. For this FS, dolphins are assumed to remain in place. Derelict piling and piers within actively remediated areas are assumed to be removed as part of the remediation. For cost estimating, pile and pier removal is not included as an independent line item; however, this cost is incorporated as an additional cost premium (assumed to be 10% of the LDW, see Appendix I). Piles are typically extracted or cut at the mudline, leaving any remaining pile stubs submerged in the mud where they will not impede boat traffic.

Staging for sediment remediation projects refers to upland operational areas that support material and equipment handling to and from the in-water project location. Upland staging areas are required to support land-based (dry) excavation operations. These staging areas are also needed to support the transloading of dredged sediment intended for upland landfill disposal (see Section 8.2.1.2). Other staging areas may be required for equipment and raw material transfers to barges. The LDW is a working industrial waterway serviced by multiple marine construction companies. Numerous docks, piers, and properties, potentially suitable for various staging functions, flank the LDW, although the availability and suitability of these properties to support remedial construction activities are not known at this time.

For planning purposes, this FS assumes that suitable land will be available adjacent to the LDW for staging and support activities. Specific staging areas have not been identified, and only rough assumptions have been made about specific staging area requirements. A line item is included in the cost estimates to account for leasing, site preparation, and set-up of an upland staging facility for the remedial alternatives (see Appendix I).

An additional facility cost is provided in the estimate for Alternative 5R-Treatment to account for staging of a soil washing treatment facility.

Because of likely physical access constraints, land-based excavation is anticipated to be feasible for only a small percentage of the LDW. This FS assumes that excavation will typically occur via barge-mounted dredge or excavation equipment. Excavation of most banks is assumed to occur during the in-water work window, although a small percentage of bank areas could be excavated in the dry at low tide outside of the in-water work window, subject to EPA approval.

8.2.1.2 Transloading and Upland Disposal

The availability and capacity of transloading and transportation infrastructure to manage dredged material is an important factor in the production or dredging rate. Allied Waste Inc. has leasing arrangements with a private property owner along the LDW, and can perform transloading operations that involve direct transfers from a barge to lined bulk-material shipping containers. This FS assumes that the containers would be trucked to the 3rd Avenue and Lander (Seattle, Washington) transfer facility (6 miles round trip), then transferred to rail (Burlington Northern Santa Fe Railway), and shipped to the Allied Waste Inc. landfill in Roosevelt, Washington (570 miles round trip see Appendix L). The transloading facility and rail operation capacity is expected to range between 1,000 and 2,000 tons/day based on the logistics of moving one train in/out of the Duwamish Valley per day on existing rails, and providing temporary storage for daily dredged material (Casalini 2010; personal communication). One rail car contains approximately 75 tons and one train is approximately 22 cars. The construction time frames are based on the transloading capacity of 1,600 tons/day (see Appendix I for details). The construction time frame for all the remedial alternatives is based on the same transloading rate. Other methods of transloading sediment, such as direct container loading on barges, may also be considered during remedial design.

Additional hauling and disposal capacity is feasible but not currently available without significant infrastructure upgrades or securing an alternate location. Property ownership, current land uses, prospects for leasing, adjacency to road and rail services, and permitting are all factors in whether and when new or expanded capacity can be made available. Additional capacity or alternate staging locations have been assumed to be available along the LDW and will be identified as needed during remedial design. In addition, existing docking and land-based infrastructure is assumed to be sufficient to support these operations, requiring only modest upgrades. The logistics and actual sizing (capacity) of the transloading operations will be determined during remedial design.

8.2.1.3 Water Management

This FS assumes that dredged sediment will initially be dewatered on the dredge scows and allowed to discharge back to the LDW within the active dredge area. The dredge scows will be equipped with appropriate best management practices (e.g., hay bales, filter fabric, etc.) to filter runoff as necessary to maintain compliance with applicable water quality criteria established for the dredging operations. Gravity drainage, filtering, and release of water drained from sediment on transfer barges consolidates the sediment load and reduces the volume of water that otherwise would need to be managed elsewhere (e.g., transloading facility or landfill). Common to most environmental dredging operations in the Puget Sound region, this FS assumes that water quality permitting will allow release of this water within the defined limits of the dredge operating area, subject to compliance with water quality criteria. The cost estimate includes a contingency for discharge to the sewer and publicly owned treatment works under permit with the King County Industrial Waste program.

Water management is a key component of dredged material transloading operations. Stormwater and drainage from sediments generated within the confines of the transloading facility are assumed to be captured, stored, treated, and either discharged to the local sanitary sewer under a King County Discharge Authorization or returned to the LDW. Dewatering is anticipated to be performed on a dewatering barge. Discharge into the LDW must comply with the substantive requirements of the Washington State National Pollutant Discharge Elimination System permitting regulations (Washington Administrative Code [WAC] 173-220) as administered by the Washington State Department of Ecology (Ecology). Water management is included in the dewatering costs (Appendix I).

The two regional Subtitle D landfills (Allied Waste Inc., Roosevelt, Washington, and Waste Management, Arlington, Oregon) are both permitted to receive wet sediment (i.e., that does not pass the paint filter test). Once transferred to lined shipping containers, any additional consolidation of sediment and corresponding accumulations of free water are managed at the landfill facility.

8.2.1.4 Sea Level Rise

Climate change is expected to increase sea levels over the next several hundred years (National Assessment Synthesis Team 2000; Ecology 2006), and this is a potentially important design consideration for cleaning up high elevation (i.e., nearshore and intertidal) areas of the LDW. The predicted sea level rise in the vicinity of the LDW is approximately 8 to 18 inches over the next century, with a maximum potential rise of up to 27 inches (Glick et al. 2007). The magnitude of this change directly affects the corresponding shift in the elevations that define intertidal habitat and jurisdictional boundaries. Further, the design of engineered shoreline infrastructure (e.g., piers, bulkheads, habitat construction/preservation) may need to address the long-term effects of sea level rise. Sea level may factor into certain remedial design elements in intertidal areas, but is not considered to be a significant factor in the selection or the analysis of the alternatives in this FS.

8.2.1.5 Cost and Construction

Table 8-7 presents the volume and construction assumptions used in developing FS remedial costs. The detailed cost estimates are described in Appendix I, and have been developed consistent with CERCLA guidance (EPA 2000a) with a target accuracy of +50% and -30%. Section 8.4.7 discusses uncertainty in the cost estimate and the cost sensitivity analysis presented in Appendix I.

8.2.2 Technology-Specific Engineering Assumptions

This section presents the assumptions that were used LDW-wide in applying each remedial technology for the purpose of estimating cleanup time frames and costs for the FS. Figure 8-3 presents a schematic showing how removal and off-site disposal may be implemented within the LDW. Figure 8-4 presents a schematic showing how the combined technologies may be implemented within the LDW. Uncertainties associated with performance of remedial technologies and how these have been addressed in the FS are discussed in Section 8.4.

8.2.2.1 Removal

Removal technologies used in the FS rely on different mechanical equipment in nearshore and subtidal areas. These technologies are described below. Table 8-8 presents the assumptions used to develop production rate estimates.

Mechanical Dredging

For this FS, mechanical dredging using a clamshell dredge mounted on a derrick barge is assumed, where conditions allow. In difficult to access areas (e.g., under piers, dry shoreline areas with limited barge access), alternate removal methods such as diver-assisted hydraulic dredging could be considered. This would be determined during remedial design. Dredge production rates used in cost and construction time frame estimation are detailed in Appendix I (Table I-5).

Precision Excavation

The use of precision excavator equipment operated from a barge is assumed for removing contaminated sediment along exposed shoreline and intertidal areas. Conventional excavation is assumed to be restricted to surfaces at elevations above -2 ft MLLW and the equipment is assumed to reach up to 25 ft from the front of the excavator treads. Although longer reach equipment is available, the production rate diminishes as the reach is extended because of the need to reduce the bucket size in proportion to the reach. Depending on tides, schedules, and other logistics, a portion of the work may be excavated in-the-dry, working above the water level to reduce turbidity generation. Land-based excavation is recognized as an alternative method that may be more suitable under certain location-specific conditions, and is schematically shown on Figure 8-3 for informational purposes, but it is not assumed for the FS.

All shoreline and intertidal excavation work would be conducted during the designated in-water work window, which is assumed to be October 1 to February 15. This work window will be confirmed in formal consultation with the agencies before construction begins. It may be possible to excavate certain areas in-the-dry at times outside of this window (subject to permitting and agency approval); however, this approach is not relied upon in this FS because it would have limited benefit to the overall project schedule. The percent of sediment that could potentially be removed by dry excavation is a nominal amount (less than 1%) of the total removal volume for the alternatives, primarily due to shoreline access limitations along the LDW.

Volume Estimation

Approximation of sediment dredge volumes is necessary to evaluate the remedial alternatives, support remedial cost estimates (Appendix I) and to assess certain short-term impacts from construction (e.g., vehicle traffic associated with handling of dredged sediments on land, emissions due to construction, elevated seafood consumption risks from dredging). In simple terms, the sediment volumes estimated for dredging are based on three factors: 1) the areas defined for dredging, 2) the thickness or depth of sediment contamination within these areas, and 3) any overdredge and contingency considerations. The areas defined for dredging in each remedial alternative are developed later in this section. The thickness of contamination across these areas is estimated using a GIS-based triangulated irregular network (TIN) method (Appendix E).

The key volume-related terms used in the FS are described below:

- **Neat-line volume:** A rectangular box-cut to the lateral edges of the dredge footprint (areal extent) with vertical side-slopes extending to the estimated depth of contamination.
- **Dredge-cut prism volume:** The neat-line volume multiplied by a factor of 1.5 representing multiple influences (e.g., overdredge allowances, side slopes, etc.; see additional considerations discussed later in this section) that, in practice, increase the actual dredge volume over the neat-line volume. The dredge-cut prism volume serves as the basis for remedial alternative construction period estimates.
- **Performance contingency volume:** An incremental dredge volume based on the assumption that 15% of verification monitoring, ENR/*in situ* treatment, and MNR areas will require active remediation as a result of future design considerations or performance monitoring results. For FS cost estimates, dredging is the assumed form of active remediation that would be carried

out in these areas, although other adaptive management strategies would be considered (see Appendix I). The performance contingency volume is not included in the construction duration estimates because this adaptive management measure could be implemented concurrent with, or following, the cleanup.

- **Total dredge volume:** The sum of the dredge-cut prism and performance contingency volumes for a given alternative. This represents a best-estimate of the total volume of sediment removed under a given remedial alternative. The total dredge volume is used for cost estimation purposes (see Appendix I).

The neat-line volume for the dredging footprint of each remedial alternative was estimated by: 1) multiplying the estimated thickness of sediment contamination in each 10-ft by 10-ft grid cell by the surface area of each grid cell (i.e., 100 ft^2), and 2) summing all product values from Step 1 covering the entire dredge footprint for the remedial alternative.[9] The thickness of sediment contamination was estimated using chemical and physical data from all available surface and subsurface sediment datasets. This information was used to develop a GIS-based TIN layer of contaminant thickness (Appendix E). All risk drivers were used to develop this layer. The vertical limit of contamination was defined by the following risk-driver concentration thresholds:[10]

- Total PCBs greater than 240 micrograms per kilogram dry weight (µg/kg dw) [11]
- Arsenic greater than 57 milligrams (mg)/kg dw (i.e., the SQS)
- cPAHs greater than 1,000 µg toxic equivalent (TEQ)/kg dw
- Dioxins/furans greater than 25 ng TEQ/kg dw
- SMS contaminants greater than the SQS.

These thresholds represent the depth of sediment contamination. For simplicity, "SQS exceedances" is the term adopted herein for discussing the TIN layer that was developed and the thickness of sediment contamination for Alternatives 2 through 5. Although cPAHs and dioxins/furans do not have SQS criteria, exceedances of threshold concentrations for these contaminants are typically shallower than the SQS exceedances. A different estimate of the thickness of sediment contamination is needed for

9 The dredge footprints for the remedial alternatives are defined later in this section.

10 The effect of lower intertidal RALs for cPAHs (900 µg TEQ/kg dw) and arsenic (28 mg/kg dw) on the neat-line dredge depth in intertidal areas was assumed to be small and adequately captured by the 50% factor used to estimate the dredge-cut prism volumes.

11 The total PCB exceedance threshold of 240 µg/kg dw is equivalent to the SQS (12 mg/kg organic carbon [oc]) for sediment with 2% organic carbon.

Alternative 6 because the Alternative 6 RALs are lower than the SQS (e.g., the total PCB RAL is 100 µg/kg dw and the arsenic RAL is 15 mg/kg dw). An analysis of core data presented in Appendix E showed that, on average, sediment exceeding the Alternative 6 RALs is approximately 1.4 ft deeper (approximately 34% deeper) than that defined by the SQS TIN layer. The Alternative 6 neat-line volumes were therefore estimated by increasing the depth of contamination 34 percent beyond that defined using the TIN.

The neat-line volume estimation methods for partial dredging and capping areas did not use the TIN as described above for dredging to the maximum depth of contamination. Here, simple thickness assumptions were adopted depending on location:

- Dredge 3 ft of sediment except in the navigation channel, berthing areas, and under piers.
- In the navigation channel and berthing areas, dredge as needed to allow construction of a 3-ft cap plus an additional clearance below the authorized depth (3 ft in the navigation channel and 2 ft in berthing areas as described in Section 8.1.2.3).
- In under-pier areas, remove only 1 ft of sediment because full removal is expected to be difficult. Under-pier areas will require location-specific analysis during remedial design.

The dredging volume and the partial dredging volume were added together to yield the total neat-line volume for each remedial alternative.

The dredge-cut prism volume is the estimated volume of sediment removed in practice under field conditions. This volume was assumed equal to the neat-line volume times a factor of 1.5 (i.e., a 50% adjustment). This adjustment is consistent with comparisons between FS volume estimates and the actual volumes removed during cleanup of large sediment sites (Palermo 2009). The 50% adjustment accounts for the combined influences of the following:

- A contract overdredge allowance exceeds the target dredge depth and is commonly used in contracting to accommodate operational characteristics and limitations of dredging equipment.
- An allowance for additional sediment characterization accounts for changes during remedial design sampling (e.g., presence of contaminants below the presently estimated depth of contamination), and changes caused by sedimentation or erosion occurring between site characterization and active remediation.

- Cleanup passes account for additional dredging often undertaken to manage dredge residuals or to remove contamination not identified during remedial design.
- Additional volumes required for constructability of dredge-cut prisms account for items such as stable side slopes, box cuts,[12] the spatial resolution of dredge equipment, and the slumping of sediments around the dredge-cut prism.

Performance contingency volumes are incremental dredge volumes from assumed contingency actions. The performance contingency dredge volume is based on the assumption that 15% of the combined area designated for ENR/*in situ* treatment, MNR, and verification monitoring in each alternative will be converted to active remediation either during remedial design or performance monitoring. Because these areas cannot be predicted, the TIN information cannot be used. Instead, the areas were assumed to be dredged to an average depth of 4 ft plus the construction volume adjustment factor of 50%.

The total dredge volume is the sum of the dredge-cut prism and performance contingency volumes for a given alternative. This represents a best-estimate of the total volume of sediment removed. The total dredge volume was used for cost estimation purposes (Appendix I).

Production Rates

Table 8-8 presents two daily dredge production rate estimates for two configurations of dredge equipment: one based on operating 24 hours per day and 6 days per week; the other based on operating 12 hours per day and 5 days per week. Both are common operating regimes for projects in the Puget Sound region and are largely a function of project size and location as well as commercial and community concerns (nighttime noise and illumination). The production rates were estimated consistent with methodologies and efficiency factors set forth in USACE guidance (USACE 2008c).

Table 8-8 presents daily production rates for dredge equipment identified in this FS:

- Barge-mounted clamshell dredge for open water operations (90% of volume)
- Barge-mounted precision excavator for open water operations with debris removal (10% of volume)
- Barge-mounted precision excavator for shallow-water operations.

[12] A box cut is a typical excavation method utilized by the dredge along the side slopes. In this method, the width of the dredge cut is sufficient to allow slope material to slough off to the natural underwater repose of that material.

The daily operating efficiency rate of 60% includes an allowance for non-production activities such as equipment maintenance and repair, water quality management, navigation systems, agency inspections, testing, movement of dredges and barges, traffic, standby for navigation, and refueling.

The estimated daily production rate for 24-hour operations with one deep-water operation and one shallow-water operation is 2,000 tons/day (1,300 cubic yards per day [cy/day]).[13] The estimated daily production rate for 12-hour operations is 1,000 tons/day (670 cy/day). Together, the estimated net annual dredge production rate for the remedial alternatives is about 140,000 tons (92,000 cy) per construction season (see Table 8-9). See Appendix I for details.

This estimate assumes two simultaneous dredging operations (one in open water and one in shallow water) for each construction season. These operations are assumed to be evenly divided across the construction window between the 24-hour and 12-hour operating regimes, with the 12-hour regime assumed in areas with community impacts and for smaller cleanup areas. For each construction season, the calculations account for five days of holidays and fifteen days of dredge downtime to accommodate ancillary construction (e.g., piling/dolphin, bulkhead, pier/dock related work), tribal fishing delays, weather-related delays, and a dredging-free period near the end of the construction window for finishing residuals management, backfilling, ENR/*in situ* treatment, and capping. Thus, approximately 140,000 tons (92,000 cy) of sediment are estimated to be removed during each construction season, consisting of 88 net days of removal operations. This corresponds to an average removal rate of 1,600 tons (1,000 cy) per day, which is approximately equal to the throughput capacity of existing offloading/rail transport in the Duwamish corridor.

Construction Time Frame

The FS makes the simplifying assumption that the total number of construction periods required to completely construct any given alternative is equivalent to that of open water dredging, which is the longest duration remedial activity for all alternatives. This FS assumes that other construction work (under-pier work, capping, and ENR/*in situ*) occurs largely in parallel with dredging activities. While this assumption is sufficient for the FS estimates of construction duration, planning, scheduling, and logistics may keep activities from all occurring simultaneously. For example, it may be deemed prudent to delay backfilling, residuals management, ENR/*in situ,* and capping work until after each season's dredging has been completed in certain areas to minimize potential recontamination from resuspended dredge material.

13 For dredging and disposal purposes, the FS assumes an average of 1.5 tons per cubic yard of dredged material.

In-water Work Window

The typical LDW in-water construction window is October 1 to February 15. This FS assumes that all in-water work is conducted during this period (e.g., dredging, excavation, capping, ENR/*in situ* treatment).

In recent years, the Muckleshoot Tribe's netfishing activities within the LDW have sometimes extended through October and well into November. The tribe might not want these activities to be compromised by active construction that could otherwise occur during the first part of the construction window for in-water work. Although tribal fishing delays were one of several reasons for assuming a total of 15 days of dredging downtime in the calculations, more extensive netfishing during the construction window could reduce the net dredging days per season, and result in a lower net annual production rate than proposed herein. This FS anticipates that EPA, Ecology, and the parties implementing the cleanup actions will work closely with the affected tribes to limit the conflicts between construction and netfishing activities.

The construction time frame for each alternative was determined based on the in-water work window, the total base case preliminary dredge volume (open water, not including partial dredging under piers), and the net annual dredge production rate. The construction time frame equaled the total base case preliminary dredge volume divided by the net annual dredge production rate (taking into account the limited yearly work window). See "Production Rates" above for a discussion of construction time frame assumptions with regard to the remedial technologies used for each alternative.

Residuals Management and Backfilling

Dredging typically releases contaminated sediment that settles back onto the dredged surface or is transported outside the dredged area (see Section 7.1.1.2). Depending on location-specific conditions, these residuals may contain elevated concentrations of risk drivers. To manage residuals, numerous design and operational controls will be evaluated during remedial design.

For the purposes of the FS, active residuals management is incorporated using the following assumptions:

- Additional dredge passes, accounted for in the dredging volume estimates described above.
- Thin-layer placement of 9 inches of sand over an area equivalent to the entire dredged footprint, with the goal of achieving a minimum of 6 inches of coverage throughout the application area. In some cases, placement of 6 inches of sand over the dredged area footprint, with the goal of achieving 3 inches of cover, may be adequate. However, the cost estimates are based on a 9-inch thin-layer sand gross placement for the entire removal footprint. This placement volume is assumed to include potential thin-layer placement

just outside of dredge areas to manage residuals that migrate outside of the dredge footprints.

As discussed in Section 8.1.2.5, backfilling of dredged areas may be required to conserve habitat areas. The unit cost assumptions for backfilling are the same as those for capping (see Appendix I). The volume of backfill material is assumed to be equal to the dredging volume in areas with mudline elevations shallower than -10 ft MLLW.

8.2.2.2 Isolation Capping

For the FS, construction of conventional caps using appropriate material gradations (e.g., filter layers, isolation layers, armor layers, etc.) has been assumed. This assumption does not prevent the use of caps amended with sorptive or reactive materials (see Section 7.1.4), which may be appropriate for consideration during remedial design. The assumed restrictions on capping associated with water depths in the navigation channel or berthing areas are provided in Section 8.1.2.3. Assumed restrictions on capping associated with habitat issues are provided in Section 8.1.2.5.

The gradation of material selected for capping depends on factors such as habitat, erosion, and scour potential. Spatially defined judgments about material gradations have not been made for the FS because material unit costs generally differ within a very narrow range and therefore are not expected to have a significant impact on estimated costs. A sand cap thickness of 3 ft has been assumed in all areas. Thinner or thicker caps may be developed during remedial design for elevation considerations such as navigation depths or habitat.

Source material for isolation capping or ENR/*in situ* has been assumed to be imported from commercial off-site vendors. Possible alternative material sourcing could include dredged materials excavated from Puget Sound maintenance dredging sites. Challenges to beneficial use of this material include:

- Determining suitability of material gradation and contaminant concentrations to meet the defined cap material specifications
- Coordinating contract requirements with the federally-procured USACE dredge contract
- Adjusting to mismatched production rates (e.g., maintenance dredged material may be generated at rates much less than or far exceeding cap placement rates)
- Accounting for rehandling needs and/or lack of suitable storage for dredged material awaiting beneficial use

- Working within the in-water construction window (e.g., maintenance dredging may occur near the end of the construction season, with no time for subsequent cap placement).

Coarse gravel or rock is required for engineered capping (i.e., armoring in areas prone to scour). These engineering requirements are assumed to be included within the assumed 3-ft cap thickness. A sandy gravel material (referred to as "fish or habitat mix") is assumed to be applied as a top dressing for riprap armoring in intertidal areas. Although armor, gravel, or riprap may be required in certain areas, the cost estimate assumes a single unit cost for all capping material (see Appendix I). During remedial design, the actual cap configuration will be determined based on an evaluation of contaminant breakthrough using the specific characteristics of the selected capping material and the cap design (e.g., permeability, total organic carbon or capping amendments, cap thickness).

Cost assumptions for capping are presented in Appendix I. Cost estimates include contingencies for the repair of isolation caps.

8.2.2.3 Enhanced Natural Recovery and *In Situ* Treatment

ENR, as used in this FS, means applying a thin layer of sandy material to accelerate the natural recovery processes of mixing and burial. This FS assumes ENR would involve spreading an average of 9 inches of sand (by clamshell from a material barge) with the goal of achieving a minimum 6 inches of coverage everywhere it is applied (King County 2005).

Material is assumed to be imported from off-site but could be obtained from local maintenance dredging, as discussed in Section 8.2.2.2. The FS assumes that half of the ENR footprint would warrant amendment with a material such as activated carbon for *in situ* treatment. This assumption provides a basis for estimating costs and comparing the remedial alternatives; however, during remedial design, the emphasis on ENR or *in situ* treatment will depend on location specific factors and additional testing of the implementability of these technologies. The composition of ENR/*in situ* treatment will depend on additional evaluation during remedial design; it may include carbon amendments, habitat mix, or scour mitigation specifications to increase stability and enhance habitat.

Cost assumptions for ENR/*in situ* treatment are presented in Appendix I. Cost estimates include contingencies for the repair of the ENR/*in situ* sand layer and for implementing adaptive management contingency actions, such as dredging, if ENR/*in situ* treatment is not effective.

8.2.2.4 Monitored Natural Recovery

MNR, as a component of CERCLA or MTCA remedial actions, embodies the establishment of cleanup levels and long-term goals, the assignment of a particular time frame for achieving those goals, the use of a monitoring program to track success, and a decision framework for implementing contingency actions if needed (adaptive management; EPA 2005b).

Evaluation of empirical data, as supported by the physical conceptual site model and the STM (see Appendix F), provides evidence that natural recovery, primarily from burial with relatively clean sediment from upstream of the LDW, is occurring in much of the LDW. As discussed in Section 7 (and supported by data presented in Section 5 and Appendix F), approximately 200,000 metric tons of material enters the LDW every year, including approximately 100,000 metric tons deposited onto the sediment bed. Natural recovery is predicted to continue in areas of the LDW not subject to significant scour and assuming ongoing contaminant sources are adequately controlled. Site-wide monitoring following active remediation and MNR will track the effectiveness of natural recovery and progress toward achieving RAO 1.

The goal of MNR, consistent with WAC 173-204-570(4), is to achieve the SQS to the extent practicable, or at a minimum the CSL. This is determined on a point basis, depending on the remedial goals and targeted time frame to achieve cleanup objectives for the RAOs for particular alternatives. The text below defines MNR(10) and MNR (20).

MNR(10) refers to monitoring to achieve alternative-specific target concentrations within 10 years following construction (e.g., the CSL for Alternatives 2R and 2R-CAD and the SQS for Alternatives 4R and 4C). The assumptions and criteria used for assigning MNR(10) are outlined in Table 8-1. These areas are predicted to recover to below the SQS (Alternatives 4R and 4C) and to below the CSL (Alternatives 2R and 2R-CAD) within 10 years following completion of remedy construction. Monitoring requirements are applicable at an appropriate area-specific scale over which the remedial technology is applied (see Operation and Maintenance [O&M] Monitoring in Appendix K). MNR(10) includes a commitment that the goals will be reached within 10 years after active construction is complete. Contingency actions for areas that do not achieve remediation goals include active remediation, additional investigation, and further monitoring. For cost estimating, this FS assumes that 15 percent of areas designated for MNR(10) would require active remediation by dredging based on remedial design considerations or future monitoring results. For assigning remedial technologies in the FS, MNR(10) is assumed to be applicable in areas that are either Recovery Category 3 areas (see Section 8.1.2.4) or where the BCM predicts recovery regardless of recovery category.

MNR(20) refers to monitoring to achieve the SQS within 20 years following construction. It is used in areas in Alternatives 2R, 2R-CAD, 3R, and 3C that are below the RALs but above the SQS.[14] MNR(20) includes a commitment to achieve the SQS on time scales to be determined, such as 20 years following construction. As with MNR(10), contingency actions for areas that do not achieve remediation goals may include active remediation, additional investigation, and further monitoring. The cost estimation assumptions for contingency actions stated above for MNR(10) also apply to MNR(20).

MNR is an integral component of Alternatives 2, 3, and 4. Although MNR is not used in either Alternative 5 or Alternative 6, natural recovery in areas not actively remediated and long-term monitoring are key components for achieving long-term model-predicted concentrations for all alternatives.

This FS assumes that area-specific MNR sampling would occur at prescribed intervals (see Appendix K). Adaptive management may occur at any time during the monitoring period.

8.2.2.5 Verification Monitoring

Verification monitoring areas were identified as areas with surface sediment concentrations above the Alternative 5 RALs, but at concentrations predicted to be below the Alternative 5 RALs by the time of construction based on recovery potential, empirical trends, and age of data (see Section 6.4.1.1). These areas are included in the AOPC 1 footprint, but are not assumed to require active remediation for Alternatives 2 through 5 (they are actively remediated in Alternative 6). In other words, verification monitoring areas are predicted to be below the Alternative 5 RALs at the time of construction, but above the Alternative 6 RALs. Generally, these areas have isolated RAL exceedances based on data that are greater than 10 years old; they are in Recovery Category 3; empirical evidence, if available, indicates recovery; and the BCM predicts recovery within 10 years. Two verification monitoring areas are exceptions to these rules. The mouth of Slip 4 is considered to be a candidate verification monitoring area given that recent sediment samples indicate that concentrations are at or below the SQS. The area is included in AOPC 1 because of older data that are not co-located within 10 ft of newer data. Similarly, the area near the Duwamish\Diagonal EAA has undergone placement of a sand-layer as ENR; recent sediment samples indicate that risk-driver concentrations are at or below the Alternative 5 RALs (Appendix J).

The need for active and passive remedial technology assignments in verification monitoring areas will be re-evaluated during remedial design. For cost estimating, this FS assumes that 15% of areas designated for verification monitoring would require active remediation by dredging based on the design-phase sampling results or future monitoring results.

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[14] As discussed later in Section 9, EPA and Ecology would need to authorize a restoration period longer than 10 years following construction of this alternative, based on considerations set forth in WAC 173-204-580 (3)(a) and (b).

8.2.2.6 Institutional Controls

The two major types of institutional controls considered for this FS are: 1) proprietary controls, typically as environmental covenants enforceable by EPA, Ecology, or the property owner, and 2) informational devices. Informational devices are further split into two primary components: a) monitoring and notification of waterway users, including the state's Environmental Covenants Registry, and b) seafood consumption advisories, public outreach, and education. These are discussed in Section 7.2, along with other institutional controls.

All types of institutional controls apply to all active remedial alternatives. Seafood consumption advisories, public outreach, and education would likely be similar in scope for all remedial alternatives. Proprietary controls and monitoring and notification of waterway users will vary in scope depending on the amount of contamination left on site. The degree to which each of these institutional controls is expected to be used for each remedial alternative is discussed in Section 8.3.

Costs for institutional controls are incorporated into the cost estimate for each remedial alternative, except for Alternative 1, as shown in Appendix I.

8.2.3 Remedial Design Investigations and Evaluation

Remedial design investigations include location-specific sampling or testing for the purpose of refining the design and engineering assumptions for the selected remedy. LDW-wide modeling and the associated data collection and testing that have been performed are useful for understanding overall LDW characteristics and making FS-level cleanup decisions, but additional testing and modeling may be needed for remedial design. It is anticipated that remedial design sampling will occur in conjunction with baseline sampling, and will include verification monitoring. These investigations are intended to:

- ♦ Clarify the nature and extent of contaminated sediment in portions of the LDW being considered for remediation, including both the vertical and horizontal extent of contamination above the RALs. Intertidal areas in particular need to be targeted in an RD sampling effort because few data were collected in these areas during the RI/FS. The nature and extent of contaminated sediment could affect the assignment of remedial technologies. Areas subject to verification monitoring will be re-evaluated at this time based on risk-driver concentrations. Estimates of the volume of contaminated sediment to be removed will be refined.
- ♦ Assess source control and recontamination potential based on contaminant concentration data and location-specific conditions and data. This includes assessment of recontamination from buried contaminated sediment.

- Evaluate location-specific sediment stability using *in situ* observation such as settling plates or bathymetric surveys, or *ex situ* erosion testing such as SedFlume. These tests could be used to evaluate sediment stability under predesign conditions or with stability enhancements such as ENR/*in situ* treatment.
- Evaluate shoreline conditions, including structures, engineered slopes, and native slopes. Evaluate shoreline habitat enhancement opportunities.
- Collect surface sediment samples to confirm current contaminant concentrations and bathymetric data to evaluate current elevations and sedimentation.
- Collect contaminant of concern (COC) and radioisotope sediment core data to assess area-specific rates of sedimentation and recovery.
- Perform geotechnical testing on sediment cores for physical properties to assess, for example, recontamination potential associated with dredge residuals, material handling properties, and sediment strength for capping.
- Reassess remedial technology assignments and assumptions based on the investigations above.
- Assess incoming Green/Duwamish River suspended sediments and deposition of Green/Duwamish River sediments in the LDW.

These types of data would allow refinement of the selected remedial technologies, design of the remedy, and evaluation of performance potential.

Costs and scope for remedial design sampling, baseline sampling, and verification monitoring are incorporated into the remedial alternative costs as a portion of the total remedial design cost (see Appendix I). The FS assumes that predesign investigations and remedial design activities would be complete approximately five years after the Record of Decision (ROD) is issued, at which point remedial construction activities would begin.

8.2.4 Monitoring

Monitoring is a key assessment technology for sediment remediation. Numerous guidance documents highlight the need for monitoring to verify achievement of project RAOs (EPA 1998c, EPA 2005b, NRC 2007). For contaminated sediment projects, monitoring can be grouped into five categories (EPA 2005b):[15]

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[15] Data collected as part of design-level investigations are another source of information that can overlap with or inform interpretation of other monitoring data (see Appendix K).

- **Baseline monitoring –** LDW-wide monitoring concurrent with remedial design studies, but separate in design and function[16]
- **Construction monitoring –** location-specific short-term monitoring during construction to ensure performance of the operations
- **Post-construction performance monitoring –** location-specific performance monitoring immediately following completion of active remediation
- **O&M monitoring –** area- and location-specific monitoring to confirm that technologies are operating as intended (such as MNR)
- **Long-term monitoring –** LDW-wide monitoring to confirm that the LDW is making progress toward and/or achieving the cleanup objectives.

Baseline and long-term monitoring have LDW-wide applications and are common to all alternatives, and are essentially the same in scope. They are used to assess the overall condition of the LDW in relation to achieving the cleanup levels set forth in the ROD. The other three monitoring categories apply at the location- or project-specific level.

The monitoring results from each category inform and direct adaptive management activities to assure long-term remedy implementation and achievement of cleanup objectives. All five of these monitoring categories are included in the FS cost estimates (Appendix I) and are described in Appendix K.

The terms used in this FS are generally consistent with compliance monitoring requirements described in MTCA (WAC 173-340-410), as shown in Table 8-10. MTCA specifies three types of monitoring requirements for site cleanup and monitoring:

- Protection monitoring confirms that human health and the environment are adequately protected during construction (called construction monitoring in this FS).
- Performance monitoring confirms that remedial actions have achieved the cleanup standards or other performance standards (called post-construction performance monitoring in this FS).
- Confirmational monitoring confirms the long-term effectiveness of a remedial action after the performance standards or remediation levels have

[16] The costs for remedial design are estimated at 20% of the capital costs. In addition to remedial design costs, this factor includes provisions for baseline monitoring, remedial design sampling, and verification monitoring (see Appendix I). This methodology is consistent with EPA guidance (EPA 2000a) and experience at other large sediment remediation sites. Although baseline sampling and verification monitoring would be similar for Alternatives 2 through 6, remedial design sampling would vary significantly from alternative to alternative depending on the scope of anticipated construction; therefore, 20% of the capital costs is reasonable for the FS.

been achieved. This would include monitoring of disposal, isolation, or containment sites to ensure protection (called O&M monitoring and long-term monitoring in this FS).

For specific application to contaminated sediments and the sediment cleanup decision process, the *Sediment Cleanup Standards Users Manual* (Ecology 1991, WAC 173-204-600) lists three general types of monitoring. The first, source control monitoring, is conducted prior to and following active cleanup to determine how ongoing sources may affect the success of active cleanup and natural recovery. The second, compliance monitoring for sediments, is considered to be long-term monitoring that is conducted following cleanup actions that include containment of contaminated sediments, or is conducted to assess the progress of natural recovery and to evaluate possible recontamination of the area. The third, closure monitoring, follows active cleanup to demonstrate successful cleanup of a site before delisting or site closure.

8.2.5 Adaptive Management

Adaptive management is the use of data collected during and after remediation to optimize further remedial actions. Because remediation in the LDW will span many years under all remedial alternatives and because of uncertainties in the LDW system, adaptive management will be important for achieving the cleanup objectives. In the context of the assignment of remedial technologies, adaptive management would be used to refine the areas in which remedial technologies are applied and to refine the methods employed during construction. Data collected during monitoring will be used to make location-specific and LDW-wide remedial decisions through adaptive management. Some of the ways that adaptive management may affect the implementation of specific remedial technologies are discussed below.

In dredging areas, data collected during construction monitoring may be used to more effectively employ best management practices while performing active remediation to reduce short-term environmental impacts. Post-construction performance monitoring provides information on whether RALs were achieved, which could identify the need for additional dredging or for managing dredge residuals. O&M monitoring and long-term monitoring could identify the need for additional source control efforts or additional remediation.

In capping areas, data collected during construction may be used to more effectively apply best management practices during active remediation to reduce impacts to the ecosystem during construction. Post-construction performance monitoring will immediately assess whether the cap has been affected by residuals. O&M monitoring will assess cap stability and effectiveness. The monitoring results may be used to improve capping designs for subsequent remedial action areas within the site, identify the need for supplemental sand placement, or change technology assignments in other parts of the LDW. Long-term monitoring will assess the need for additional source control efforts or further remediation.

In ENR/*in situ* treatment areas, post-construction performance monitoring will be used to assess whether RALs have been successfully achieved. Long-term monitoring will be used to assess the progress toward achieving cleanup objectives and whether additional source control efforts or further remediation are needed.

Monitoring in MNR areas will be used to track the performance of natural recovery in the specific area being remediated by MNR and, depending on the data, may inform the need for contingency actions if MNR is not progressing adequately. Three hypothetical MNR scenarios and example adaptive management contingency actions are as follows:

- MNR sampling results over a 10-year period are trending toward or have demonstrated that natural recovery occurred (e.g., achievement of the SQS on a point basis). Where improvement is documented by the monitoring results and recovery is progressing appropriately to predicted recovery within 10 years, MNR would continue until recovery is complete and documented. MNR would be discontinued and no further area-specific monitoring would occur after the monitoring results document that recovery has been achieved; however, long-term monitoring LDW-wide would continue to measure progress toward long-term model-predicted concentrations.
- MNR sampling results collected over a 10-year period indicate that an area is not recovering adequately to achieve the SQS. These results would trigger adaptive management review and the potential need for additional remedial actions, source control, or monitoring to achieve the SQS (or CSL for Alternatives 2R and 2R-CAD) within 10 years after construction is complete.
- MNR sampling results collected over a 20-year period indicate that an area is not recovering adequately to achieve the SQS. These results would trigger an adaptive management review and the potential need for additional remedial actions, source control, or monitoring to achieve the SQS within 20 years after construction is complete.

Long-term monitoring will provide important information on the natural recovery potential in the LDW, inform future source control actions, assess progress toward achieving cleanup objectives regardless of the remedial technology being used, and help inform remedial decisions in the future.

Additional long-term monitoring activities, as necessary, would be triggered after a disruptive event such as an earthquake, and repairs would then be required based upon the amount of damage or recontamination. As described in Section 8.2.2 and in Appendix I, contingency costs were included in the FS to address repairs to capped areas. Long-term monitoring, adaptive management, and contingency actions should be adequate to address needed repairs after a lower-level earthquake, but may not be adequate to address the impacts of a lower-probability, higher impact event.

8.2.6 Project Sequencing

Project sequencing refers to the order in which individual areas are remediated for a given alternative. Sequencing of sediment remediation with source control is an important consideration from a recontamination perspective. The timing of individual source control actions is expected to influence when it is appropriate for specific areas to undergo remediation (e.g., near some outfalls). However, the potential number and complexity of upland source areas and associated programmatic difficulties of sequencing individual in-water cleanup projects in a specific order is a major area of uncertainty (see Section 8.4).

This FS assumes that project sequencing starts with active management of the most contaminated areas. Active remediation is modeled in 5-year increments in the BCM. Each successive alternative fully captures and embeds the previous alternative's RALs within its RALs because the highest exceedances are managed first, followed by successively lower RAL exceedance areas. This provides a "continuum" of actions that addresses successive areas of progressively lower contaminant concentrations. This assumption is incorporated in the BCM sequencing, as discussed in Section 9.

8.3 Detailed Description of Remedial Alternatives

This section describes the remedial alternatives. Figures 8-5 through 8-17 present the remedial footprints for Alternatives 1 through 6, showing the spatial extent of active and passive technology assignments. Alternatives 2 through 5 address the AOPC 1 footprint. Alternative 6 addresses the AOPC 2 footprint, as well as all of AOPC 1. Appendix D presents additional physical and chemical considerations that affected the recovery category assignments, and hence the technology assignments. Appendix G presents a plan-view map of each alternative showing the location of sediment core contamination designated to be dredged, capped, or remain in place. Figure 8-18 is a generalized flow diagram of the active technology assignments that applies to any of the remedial alternatives. Table 8-11 presents a summary of areas, volumes, and costs associated with each remedial alternative. The estimated costs are presented in terms of net present value, as stated in EPA guidance (EPA 2000a); see Section 8.4 and Appendix I for additional details on the cost estimates.

8.3.1 Alternative 1 – No Further Action

Alternative 1 is the no action alternative. An assumed initial condition for Alternative 1 is that cleanup actions at the EAAs (29 acres) have been completed (Figure 8-5). The alternative includes no further actions other than long-term LDW-wide monitoring.

Alternative 1 provides no institutional controls beyond those specific to the EAA projects and the existing WDOH seafood consumption advisory.

The EAAs were previously identified as containing some of the highest levels of contamination in the LDW. Alternative 1 is not formulated with specific risk reduction goals in mind. However, it does provide a basis to compare the relative effectiveness of the other alternatives (see Section 10). Under CERCLA, a no action alternative is required as a baseline for comparison with the other alternatives. For this reason, Alternative 1 is included in the FS and considered in the evaluation and comparative analysis presented in Sections 9 and 10, respectively.

Although natural recovery processes are projected to continue as the Green/Duwamish River delivers new sediment to the LDW, recovery and eventual achievement of cleanup objectives is not ensured for Alternative 1. In addition, this alternative assumes that these processes will be tracked through the site-wide monitoring program, but no adaptive management contingency actions would be undertaken, even if recovery did not occur as predicted.

Regulatory goals, management approaches, and associated RALs for this alternative are specific to each individual EAA. The volume of sediment removed (or to be removed) from the EAAs has not been incorporated into sediment volume calculations in the FS. Nevertheless, these removal actions will result in overall LDW-wide SWAC reduction for all risk drivers. These outcomes are presented in Section 9. Contaminant reduction outside of the EAAs will occur only to the degree achieved by ongoing natural recovery processes. Under Alternative 1, long-term monitoring would occur to track changes in the study area. No institutional controls would be added beyond those put in place as part of EAA cleanups and the existing WDOH seafood consumption advisory for resident LDW fish and shellfish. Completion of the cleanup actions at the EAAs is assumed to be a common element of all subsequent alternatives, but costs for these actions have not been included in the FS alternative cost estimates. A summary of the status of the EAAs is provided in Section 2.7.

8.3.2 Alternatives 2R and 2R-CAD

Alternatives 2R and 2R-CAD are designed, at a minimum, to make progress toward achieving RAO 1 through a combination of active remediation, natural recovery, and institutional controls; achieve cleanup objectives for RAOs 2 and 4 within 10 years following construction; and achieve the minimum cleanup level (i.e., CSL) for RAO 3 within 10 years following construction and the SQS within 20 years following construction using MNR. Long-term model-predicted concentrations for the risk drivers are presented in Section 9.

Alternatives 2R and 2R-CAD are designed to comply with the minimum "threshold requirements" discussed in Sections 10 and 11. The regulatory basis for achieving the

CSL, which is the minimum cleanup level, within 10 years following construction for RAO 3 is WAC 173-204-570(3):

> *"Minimum cleanup level. The minimum cleanup level is the maximum allowed chemical concentration and level of biological effects permissible at the cleanup site to be achieved by year ten after completion of the active cleanup action."*

However, the next WAC section, 173-204-570(4), adds: "*The site-specific cleanup standards shall be as close as practicable to the cleanup objective but in no case shall exceed the minimum cleanup level. … In all cases, the cleanup standards shall be defined in consideration of net environmental benefit (including the potential for natural recovery of sediments over time), cost and engineering feasibility of different cleanup alternatives.*"

The regulatory basis for achieving the RAO 3 cleanup objective (i.e., SQS) is defined in WAC 173-204-570(2) and (4). However, Ecology may authorize a longer restoration time frame to achieve the cleanup objective per WAC 173-204-580(3)(b) "where cleanup actions are not practicable to accomplish within a 10-year period."

Alternative 2R emphasizes removal and upland disposal of sediment from within the designated active remediation areas. Alternative 2R-CAD emphasizes removal with disposal in one or more CAD facilities to be constructed within the LDW, although, because of capacity limitations, some material would go to upland disposal. Both remedial alternatives have the same active remedial footprint (32 acres) and technology assignments. For Alternatives 2R and 2R-CAD, the active remedial footprint represents the areas with surface sediment concentrations above the upper RALs, or above the lower RALs and not predicted to recover to the CSL within 10 years (e.g., Recovery Categories 1 or 2) (see Table 8-1 and Figure 8-1).[17] Actively remediated areas would be dredged (open water areas) or partially dredged and capped (under-pier areas) depending on location. Section 8.2 describes the assumptions common to all the remedial alternatives. The following subsections describe the details of Alternatives 2R and 2R-CAD.

8.3.2.1 Alternative 2R – Removal Emphasis with Upland Disposal

Alternative 2R addresses the AOPC 1 footprint (180 acres), by actively remediating 32 acres (in addition to the 29 acres in the EAAs) and passively remediating 148 acres. Figure 8-6 illustrates the areas estimated to be remediated under Alternative 2R and

[17] As discussed in Section 8.1.1, for Alternatives 2 and 4, the RALs for SMS contaminants (including PCBs) are a range. In most locations, the higher RAL was applied. In locations not predicted to achieve the CSL (Alternative 2) and SQS (Alternative 4) within 10 years following construction, the lower RAL was used (see Table 8-1). Specifically, the lower RAL was employed: 1) in areas where the BCM predicted concentration was greater than the CSL (Alternative 2) or SQS (Alternative 4) within 10 years; and 2) in Recovery Categories 1 and 2 (see Section 8.1.2.4 for more details on recovery categories).

Table 8-11 summarizes the remedial areas for all alternatives. The primary elements of Alternative 2R are as follows:

- **Dredging and upland disposal:** 29 acres would be dredged to sufficient depth to remove all contamination above the SQS (see Section 8.2.2.1). In dredged areas, residuals management would be used as needed to achieve a final surface sediment concentration below the SQS. Areas with existing grades shallower than -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 3 acres of under-pier areas would be partially dredged and covered with an isolation cap.
- **MNR(10):** 19 acres are predicted to recover to below the CSL within 10 years following the estimated remedy construction time frame of 4 years. MNR(10) would apply in areas between the upper Alternative 2 RALs and the lower Alternative 2 RALs (Table 8-1) that are predicted to recover to below the CSL within 10 years following active remediation. These areas are primarily classified as Recovery Category 3. Areas that do not recover to below the CSL within 10 years would be subject to active remediation. For cost estimating purposes, 15% of the 19 acres is assumed to eventually require active remediation by dredging, based on re-evaluation during remedial design or long-term monitoring. These areas would also be monitored for eventual recovery to the SQS within 20 years following construction.
- **MNR(20):** 106 acres are predicted to recover to the SQS within 20 years following the estimated construction time frame of 4 years. MNR(20) would apply in areas with concentrations below the lower Alternative 2 RALs but above the SQS. These areas may be in any recovery category. Alternative 2 includes adaptive management contingencies as needed to ensure that the SQS is achieved within 20 years following construction. For cost estimating purposes, 15% of the 106 acres is assumed to eventually require active remediation by dredging, based on re-evaluation during remedial design or long-term monitoring.
- **Verification Monitoring:** 23 acres are predicted to have already recovered to below the SQS by the time remedy implementation begins. If these areas are determined to be above the SQS during remedial design, they would be assigned to an appropriate active or passive remedial technology based on contaminant concentrations and physical conditions. For cost estimating, the FS assumes that 15% of these 23 acres would require active remediation by dredging based on remedial design sampling or long-term monitoring.

- **Institutional controls:** The types of institutional controls are discussed in Section 7.2 and summarized in Section 8.2.2.6. Alternative 2R includes the following:
  - Seafood consumption advisories, public outreach, and education would apply LDW-wide.
  - Proprietary controls and monitoring and notification of waterway users would apply in proportion to the area where contamination remains above levels needed to meet cleanup objectives. The amount of controls needed would be proportionate to the degree and the likelihood of exposure of remaining contamination, including 3 acres of engineered caps, 125 acres of MNR, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 29 dredged acres would have fewer controls because less contamination would remain.
  - The entire LDW would be subject to an institutional controls plan. Any institutional controls approved by EPA for any EAA would be incorporated into the LDW plan. If necessary, institutional controls plans for the EAAs would be modified to be consistent with the plans for the rest of the LDW.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes.** Monitoring and adaptive management are integral components of Alternative 2R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring
  - Construction monitoring would apply during the estimated 4 years of construction.
  - O&M monitoring would apply to the estimated 3 acres of engineered caps and 125 acres of MNR.
  - Long-term monitoring would apply LDW-wide until EPA and Ecology conclude that remedial action is sufficiently completed and monitoring is no longer required.
  - Natural recovery processes are predicted to improve sediment quality as estimated by long-term modeling. Changes in sediment quality over time will be evaluated by long-term monitoring.
  - Adaptive management would apply to the estimated 125 acres of MNR. All areas of the LDW would be required to achieve the CSL within

10 years following construction. Based on monitoring results, additional active remediation would be implemented as needed to achieve the CSL within 10 years following construction and to achieve the SQS within 20 years following construction. Adaptive management for all remedial alternatives is described in Section 8.2.5.

- Because this alternative would result in some contaminated sediments remaining on site at levels that do not allow unrestricted use, EPA and/or Ecology would review the effectiveness of the remedial alternative a minimum of every 5 years. These periodic reviews would inform adaptive management decisions needed to achieve cleanup objectives.

Estimated Quantities, Construction Time Frames, and Cost

As shown in Table 8-11, Alternative 2R would remove approximately 580,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS. Partial dredging of one foot and capping are assumed under overwater structures. Approximately 120,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material in partial dredging and capping areas.

The estimated construction time frame is 4 years.[18] The estimated net present value of the cost of Alternative 2R is $220 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.2.2 Alternative 2R-CAD – Removal Emphasis with CAD

Alternative 2R-CAD is identical to Alternative 2R in terms of areas remediated (32 acres actively remediated and 148 acres passively remediated) and volume of contaminated sediment removed (580,000 cy). The difference between the two alternatives is that Alternative 2R-CAD includes the construction and use of CAD facilities within the LDW, as shown in Figures 8-7, 8-8, and 8-9. Alternative 2R-CAD is the only alternative with a CAD option. However, a CAD could be incorporated into any remedial alternative during remedial design. Alternative 2R and 2R-CAD have the same

[18] Construction time frame is based on the volume of the open water dredge-cut prism (the time-limiting activity) and the yearly dredging rate. The open water dredge-cut prism excludes performance contingency volumes (see Section 8.2.2.1) and under-pier dredge volumes. For example, the unrounded open water dredge-cut prism volume for Alternative 2R is 358,308 cy as shown in Table I-36 (69,536 cy + 288,772 cy). The unrounded open water dredging production rate is 91,904 cy/year (see Table I-5), resulting in a construction time frame of 3.9 years. Performance contingency volumes are not incorporated into construction time frames because they could be added following a period of monitoring versus during initial construction.

technology assignments so that the CAD alternative can be directly compared to the non-CAD alternative in subsequent sections of the FS.

This FS assumes that CAD construction would occur concurrently with remediation and does not affect the overall construction time frame of the remedial alternative. However, it is possible that CAD construction could extend the construction time frame for this alternative. The primary elements of Alternative 2R-CAD are as follows:

- **Dredging, partial dredging and capping, MNR, and verification monitoring:** Alternative 2R-CAD remediates the same acreages using the same technologies as described for Alternative 2R above.
- **Capping:** The completed CAD facilities would encompass approximately 23 acres of capped contaminated sediment.
- **Institutional controls:** The types of institutional controls are the same as described for Alternative 2R except that proprietary controls and monitoring and notification of waterway users would apply to 26 acres of engineered caps, including the CADs, as opposed to 3 acres of engineered caps, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 29 dredged acres would have fewer controls because less contamination would remain.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes:** The type of monitoring is the same as described for Alternative 2R, but O&M monitoring would apply to an estimated additional 23 acres of the engineered caps covering the CAD cells. Adaptive management and periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frames, and Cost

The removal volume and the estimated construction time for active management of contaminated sediment above the RALs are the same as those for Alternative 2R. Plus, the construction of the CAD facilities is estimated to require the removal of 370,000 cy of clean sediment, which is assumed for costing purposes to be suitable for disposal at the Dredged Material Management Program open water disposal site in Elliott Bay. The completed CAD facilities would have a capacity of 310,000 cy of contaminated sediment[19] and require approximately 74,000 cy of capping material. For Alternative 2R-CAD, approximately 200,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material. Additional details on the construction of the CAD facilities are provided below.

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[19] Volume refers to the *in situ* volume of dredged sediment that would fit in the CAD facilities.

The estimated construction time frame is 4 years, the same as for Alternative 2R. The estimated net present value of the cost of Alternative 2R-CAD is $200 million. See Appendix I for cost estimate details and cost sensitivity analyses.

Potential CAD Locations

Two potentially suitable CAD locations within the LDW have been conceptually developed for the FS (Figures 8-7, 8-8, and 8-9). One location is just south of Harbor Island (RM 0.1 to 0.5; northern location) and the other is near the Upper Turning Basin (RM 4.4 to 4.8; southern location).

The northern location is a deep-water area partially within the authorized navigation channel. Preliminary estimates suggest that a CAD in this area could have a net storage capacity of 210,000 cy, assuming removal of 140,000 cy of sediment to prepare the area, and 44,000 cy of capping material to construct the final cap. A subsurface core collected from this area shows surficial contamination but no subsurface contamination. The sediment stratigraphy below the surface is dense, native alluvium.

The southern location is within the authorized navigation channel and Upper Turning Basin. Preliminary estimates suggest a net storage capacity of 100,000 cy. In this case, 230,000 cy of sediment would need to be removed to prepare the area, and 30,000 cy of sand capping material would be required to confine the contaminated sediment.

CAD construction and operation assumptions include the following:

- Sediment sampling and analysis of the sediment within the CAD prism would be required. This sampling would determine suitability of the dredged sediment for disposal at the Elliott Bay open water disposal site, for beneficial reuse, or upland off-site disposal.
- For costing purposes, this FS assumes that 100% of this material will be taken to the Elliott Bay open water disposal site. This disposal would require Section 404 Clean Water Act permitting by the USACE (in consultation with the Dredged Material Management Program agencies) because it is an off-site action.
- Total disposal capacity of the northern and southern CAD locations is 310,000 cy.
- The operation/logistics for CAD location preparation and filling is sequential by season. This FS assumes that the CAD construction would occur concurrently with remediation, so that the total construction time frame of four construction seasons is the same as for Alternative 2R. The northern CAD would be constructed first. Material excavated from the CAD would be sent to open water disposal, if suitable. Concurrently, contaminated dredged material would be sent to upland disposal until the

CAD is prepared to take contaminated sediment. Once the northern CAD is filled with contaminated sediment, material would be excavated from the southern CAD location. When excavation of the southern CAD is completed, the remaining areas would be dredged and dredged material sent to the southern CAD for disposal. The CAD would be covered with imported clean sand material. Excavated CAD development sediment would be disposed of at the Elliott Bay open water site or at an upland off-site disposal facility.

- The same guidelines used for capping would be applied for CAD development (see Sections 8.1.2.3 and 8.1.2.5). This FS assumes that the final CAD cap would be 3 ft below the authorized navigation channel elevation, with a 3:1 side slope outside of the channel. Nearshore habitat would be preserved.

Significant engineering remedial design effort would be required to develop and implement CAD at these locations. Key remedial design considerations include:

- Sediment sampling and analyses, as discussed above
- Determination of whether dredged sediments are suitable to prepare the CAD locations
- Development of a detailed dredging plan
- Engineering evaluation of: CAD capacities, bulking of the sediment resulting from dredging, subsequent compaction after placement and settling in the CAD, and slope stability
- Residuals and contaminated sediment controls when placing contaminated dredged sediment into the CAD
- Determination of the impact of the activities on navigation and commercial activities, including the potential for contaminant spread resulting from vessel propeller wash, and required navigation controls during construction activities
- Administrative and substantive requirements for siting a CAD in the LDW, including long-term monitoring and maintenance responsibilities and implementation of land use restrictions.

8.3.3 Alternatives 3R and 3C

Similar to Alternatives 2R and 2R-CAD, Alternatives 3R and 3C are designed, at a minimum, to make progress toward achieving RAO 1 through a combination of active remediation, natural recovery, and institutional controls; and achieve the cleanup objectives for RAOs 2 and 4 and the minimum cleanup level (i.e., CSL) for RAO 3 immediately following construction (rather than within 10 years following construction). Similar to Alternatives 2R and 2R-CAD, Alternatives 3R and 3C are designed to achieve the cleanup objective for RAO 3 (i.e., SQS) within 20 years following construction. Long-term model-predicted concentrations are presented in Section 9.

Alternative 3R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 3C emphasizes using combined technologies—dredging with upland disposal, capping, and ENR/*in situ* treatment where appropriate. Both remedial alternatives have the same active remedial footprint (58 acres) and the same passive remedial technology assignments. The active remedial footprint represents the areas above the Alternative 3 RALs. Section 8.2 describes the assumptions common to all the remedial alternatives. The following subsections describe the details of Alternatives 3R and 3C.

8.3.3.1 Alternative 3R – Removal Emphasis with Upland Disposal

Alternative 3R addresses the AOPC 1 footprint (180 acres) by actively remediating 58 acres (in addition to the 29 acres in the EAAs) and passively remediating 122 acres. Figure 8-10 illustrates the areas estimated to be remediated under Alternative 3R, and Table 8-11 summarizes the acres managed. The primary elements of Alternative 3R are as follows:

- **Dredging and upland disposal:** 50 acres above the Alternative 3 RALs would be dredged to sufficient depth to remove all contamination above the SQS. Other details are identical to those described for Alternative 2R.
- **Partial dredging and capping:** 8 acres of under-pier areas above the RALs would be partially dredged and covered with an isolation cap.
- **MNR(20):** 99 acres are predicted to recover to below the SQS within 20 years following the estimated construction time of 6 years. MNR(20) would apply in areas with concentrations below the Alternative 3 RALs but above the SQS. For other MNR(20) details, see Alternative 2R.
- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.
- **Institutional controls:** The types of institutional controls are discussed in Section 7.2. Alternative 3R includes the following:
  - Seafood consumption advisories, public outreach, and education would apply LDW-wide.
  - Proprietary controls and monitoring and notification of waterway users would apply in proportion to the area where contamination remains above levels needed to meet cleanup objectives. The amount of controls

needed would be proportionate to the degree and likelihood of exposure of remaining contamination, including 8 acres of engineered caps, 99 acres of MNR, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 50 dredged acres would have fewer controls because less contamination would remain.

- The entire LDW would be subject to an institutional controls plan. Any institutional controls approved by EPA for any EAA would be incorporated into the LDW plan. If necessary, institutional controls plans for the EAAs will be modified to be consistent with the plans for the rest of the LDW.

♦ **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes.** Monitoring and adaptive management are integral components of Alternative 3R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope is summarized as:

- Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring.
- Construction monitoring would apply during the estimated 6 years of construction.
- O&M monitoring would apply to the estimated 8 acres of engineered caps and 99 acres of MNR.
- Long-term monitoring would apply LDW-wide until EPA and Ecology conclude that remedial action is sufficiently completed and monitoring is no longer required.
- Natural recovery processes are predicted to improve sediment quality as estimated by long-term modeling. Changes in sediment quality over time will be evaluated by long-term monitoring.
- Adaptive management would apply within the estimated 99 acres of MNR. Based on the monitoring results, additional active remediation would be implemented as needed to achieve the SQS within 20 years following construction.
- Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 3R would remove approximately 760,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 260,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material.

The estimated construction time frame is 6 years. The estimated net present value of the cost of Alternative 3R is $270 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.3.2 Alternative 3C – Combined Technology

Similar to Alternative 3R, Alternative 3C addresses the AOPC 1 footprint (180 acres) by actively remediating 58 acres (in addition to the 29 acres in the EAAs), and passively remediating 122 acres. Figure 8-11 illustrates the areas estimated to be remediated under Alternative 3C and Table 8-11 summarizes the acres managed. The primary elements of Alternative 3C are as follows:

- **Dredging and upland disposal:** 29 acres would be dredged to sufficient depth to remove all contamination above the SQS. Dredging would occur in areas with surface sediment concentrations above the Alternative 3 RALs, bathymetric requirements that preclude ENR/*in situ* treatment or capping (such as navigation channel maintenance dredging clearance requirements), and contamination thickness such that partial dredging and capping is not cost effective (e.g., thickness less than 4 ft in habitat areas, see Figure 8-2). Other details are identical to those described for Alternative 2R.

- **Partial dredging and capping:** 8 acres would be partially dredged to the necessary depth based on elevation constraints, and covered with an isolation cap. Partial dredging and capping would occur in areas with surface sediment concentrations above the Alternative 3 RALs, bathymetric requirements that preclude ENR/*in situ* treatment or capping (such as navigation channel maintenance dredging clearance requirements), and contamination thickness such that partial dredging and capping is cost effective (e.g., thickness greater than 4 ft in habitat areas, see Figure 8-2).

- **Capping:** 11 acres of contaminated sediment would be contained with an isolation cap. Capping would occur in areas with contaminant concentrations above the RALs where ENR is precluded by physical (e.g., Recovery Category 1) or contaminant characteristics (e.g., surface sediment concentrations greater than the ENR/*in situ* treatment UL). In addition, all under-pier areas above the RALs are assumed to be capped.

- **ENR/*in situ*:** 10 acres of contaminated sediment would be remediated with a layer of ENR sand (with or without an *in situ* amendment such as activated carbon). ENR/*in situ* would occur in areas with contaminant concentrations above the Alternative 3 RALs where ENR/*in situ* is assumed to be viable based on physical characteristics (e.g., Recovery Category 2 or 3) and contaminant concentrations (e.g., surface sediment concentrations less than the ENR/*in situ* UL). For cost estimating, half of the ENR/*in situ* area is assumed to undergo *in situ* treatment using carbon amendment, and 15% of the ENR/*in situ* area is assumed to need active remediation through dredging due to re-evaluation during remedial design or long-term monitoring.

- **MNR(20):** same area (99 acres) as for Alternative 3R, with recovery predicted within 20 years following a construction time frame of 3 years (as opposed to 6 years).
- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.
- **Institutional controls:** Alternative 3C includes the same institutional controls as described for Alternative 3R, except that proprietary controls and monitoring and notification of waterway users would apply to 19 acres of engineered caps, 10 acres of ENR/*in situ* treatment, 99 acres of MNR, and all unremediated areas where contamination remains. The 29 dredged acres would have fewer controls because less contamination would remain.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes**. These elements would be the same as described for Alternative 3R, except for the following differences:
    - Construction monitoring would apply during the estimated 3 years of construction.
    - O&M monitoring would apply to the estimated 19 acres of engineered caps, 10 acres of ENR/*in situ* treatment, and 99 acres of MNR.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 3C would remove approximately 490,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 270,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, provide cap material, and place ENR/*in situ* material.

The estimated construction time frame is 3 years. The estimated net present value of the cost of Alternative 3C is $200 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.4 Alternatives 4R and 4C

Similar to Alternatives 3R and 3C, Alternatives 4R and 4C are designed, at a minimum, to make progress toward achieving RAO 1 through a combination of active remediation, natural recovery, and institutional controls; achieve cleanup objectives for RAOs 2 and 4 immediately following construction; but achieve cleanup objectives for RAO 3 (i.e., SQS) within 10 years following construction (instead of within 20 years as described for Alternatives 3R and 3C). Areas with potential scour (Recovery Category 1 areas) are actively remediated to the SQS. Long-term model-predicted concentrations are presented in Section 9.

The technology differences between Alternatives 4R and 4C are similar to the technology differences between Alternatives 3R and 3C. Alternative 4R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 4C emphasizes combined technologies where appropriate. Both remedial alternatives have the same active remedial footprint (107 acres) and the same passive remedial technology assignments. The following subsections describe the details of Alternatives 4R and 4C.

8.3.4.1 Alternative 4R – Removal Emphasis with Upland Disposal

Alternative 4R addresses the AOPC 1 footprint (180 acres) by actively remediating 107 acres (in addition to the 29 acres in the EAAs), and passively remediating 73 acres. Figure 8-12 illustrates the areas estimated to be remediated under Alternative 4R and Table 8-11 summarizes the acres managed. The primary elements of Alternative 4R are as follows:

- **Dredging and upland disposal:** 93 acres would be dredged to sufficient depth to remove all contamination above the SQS. Other details are the same as described for Alternative 2R.
- **Partial dredging and capping:** 14 acres of under-pier areas above the SQS would be partially dredged and covered with an isolation cap.
- **MNR(10):** 50 acres are predicted to recover to below the SQS within 10 years following the estimated remedy construction time frame of 11 years. MNR(10) would apply in areas between the upper RALs and the lower RALs (Table 8-1) that are predicted to recover to below the SQS within 10 years following active remediation. These areas are primarily classified as Recovery Category 3. Areas that do not recover to the SQS within 10 years would be subject to active remediation. For cost estimating purposes, 15% of the 50 acres were projected to eventually require active remediation by dredging, based on either re-evaluation during remedial design or long-term monitoring results. Unlike Alternatives 2R, 2R-CAD, 3R, and 3C, Alternative 4R does not include any MNR(20) areas.

- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.
- **Institutional controls:** The types of institutional controls are discussed in Section 7.2. Alternative 4R includes the following:
  - Seafood consumption advisories, public outreach, and education would apply LDW-wide.
  - Proprietary controls and monitoring and notification of waterway users would apply in proportion to the area where contamination remains above levels needed to meet cleanup objectives. The amount of controls needed would be proportionate to the degree and the likelihood of exposure of remaining contamination, including 14 acres of engineered caps, 50 acres of MNR, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 93 dredged acres would have fewer controls because less contamination would remain.
  - The entire LDW would be subject to an institutional controls plan. Any institutional controls approved by EPA for any EAA would be incorporated into the LDW plan. If necessary, institutional controls plans for the EAAs would be modified to be consistent with the plans for the rest of the LDW.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes.** Monitoring and adaptive management are integral components of Alternative 4R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For this alternative, the scope is summarized as:
  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring.
  - Construction monitoring would apply during the estimated 11 years of construction.
  - O&M monitoring would apply to the estimated 14 acres of engineered caps and 50 acres of MNR.
  - Long-term monitoring would apply LDW-wide until EPA and Ecology conclude that remedial action is sufficiently completed and monitoring is no longer required.
  - Natural recovery processes are predicted to improve sediment quality as estimated by long-term modeling. Changes in sediment quality over time will be evaluated by long-term monitoring.

- Adaptive management would apply within the estimated 50 acres of MNR. Based on the monitoring results, additional active remediation would be implemented as needed to achieve the SQS within 10 years following construction.
- Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 4R would remove approximately 1,200,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 430,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material.

The estimated construction time frame is 11 years. The estimated net present value of the cost of Alternative 4R is $360 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.4.2 Alternative 4C – Combined Technology

Similar to Alternative 4R, Alternative 4C addresses the AOPC 1 footprint (180 acres) by actively remediating 107 acres (in addition to the 29 acres in the EAAs) and passively remediating 73 acres. Figure 8-13 illustrates the areas estimated to be remediated under Alternative 4C and Table 8-11 summarizes the acres managed. The primary elements of Alternative 4C are as follows:

- **Dredging and upland disposal:** 50 acres would be dredged to sufficient depth to remove all contamination above the SQS. Other details are the same as described for Alternative 3C.
- **Partial dredging and capping:** 18 acres would be partially dredged to the necessary depth based on elevation constraints and covered with an isolation cap. Other details are the same as described for Alternative 3C.
- **Capping:** 23 acres of contaminated sediment would be contained with an isolation cap. Other details are the same as described for Alternative 3C.
- **ENR/*in situ*:** 16 acres of contaminated sediment would be remediated with a layer of ENR/*in situ* material. Other details are the same as described for Alternative 3C.
- **MNR(10):** Would apply to 50 acres as described for Alternative 4R.
- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.

- **Institutional controls:** Alternative 4C includes the same institutional controls as described for Alternative 4R, except that proprietary controls and monitoring and notification of waterway users would apply to 41 acres of engineered caps, 16 acres of ENR/*in situ* treatment, 50 acres of MNR, and all unremediated areas where contamination remains. The 50 dredged acres would have fewer controls because less contamination would remain.

- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes**. These elements would be the same as described for Alternative 4R, except for the following differences:

  - Construction monitoring would apply during the estimated 6 years of construction.

  - O&M monitoring would apply to the estimated 41 acres of engineered caps and 50 acres of MNR.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 4C would remove approximately 690,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 470,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, provide cap material, and place ENR/*in situ* material.

The estimated construction time frame is 6 years. The estimated net present value of the cost of Alternative 4C is $260 million). See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.5 Alternatives 5R, 5R-Treatment, and 5C

Similar to Alternatives 4R and 4C, Alternatives 5R, 5R-Treatment, and 5C are designed, at a minimum, to: make progress toward achieving RAO 1 through a combination of active remediation, natural recovery, and institutional controls; achieve cleanup objectives for RAOs 2 and 4 immediately following construction; and achieve cleanup objectives for RAO 3 immediately following construction (instead of within 10 years as for Alternatives 4R and 4C). Long-term model-predicted concentrations are presented in Section 9.

The technology differences between Alternatives 5R and 5C are the same as the differences in the technologies between Alternatives 4R and 4C. Alternative 5R-Treatment has the same technology assignments as Alternative 5R, except it includes *ex situ* treatment of sediment from actively remediated areas using soil washing, in addition to upland disposal. Alternatives 5R, 5R-Treatment, and 5C have the same active remedial footprint (157 acres) and the same passive remedial technology assignments. The active remedial footprint represents areas with surface sediment concentrations above the SQS. The following subsections describe the details of Alternatives 5R, 5R-Treatment, and 5C.

8.3.5.1 Alternative 5R – Removal Emphasis with Upland Disposal

Alternative 5R addresses the AOPC 1 footprint (180 acres) by actively remediating 157 acres (in addition to the 29 acres in the EAAs), and passively remediating 23 acres (verification monitoring). Figure 8-14 illustrates the areas estimated to be remediated under Alternative 5R and Table 8-11 summarizes the acres managed. The primary elements of Alternative 5R are as follows:

- **Dredging and upland disposal:** 143 acres would be dredged to sufficient depth to remove all contamination above the SQS. Other details are the same as described for Alternative 2R.
- **Partial dredging and capping:** 14 acres (under-pier areas) would be partially dredged and covered with an isolation cap. Other details are the same as described for Alternative 2R.
- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.
- **Institutional controls:** The types of institutional controls are discussed in Section 7.2. Alternative 5R includes the following:
  - Seafood consumption advisories, public outreach, and education would apply LDW-wide.
  - Proprietary controls and monitoring and notification of waterway users would apply in proportion to the area where contamination remains above levels needed to meet cleanup objectives. The amount of controls needed would be proportionate to the degree and the likelihood of exposure of remaining contamination, including 14 acres of engineered caps and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 143 dredged acres would have fewer controls because less contamination would remain.
  - The entire LDW would be subject to an institutional controls plan. Any institutional controls approved by EPA for any EAA would be incorporated into the LDW plan. If necessary, institutional controls plans for the EAAs would be modified to be consistent with the plans for the rest of the LDW.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes.** Monitoring and adaptive management are

integral components of Alternative 5R. The basic monitoring elements are described in Appendix K and summarized in Section 8.2.4. For Alternative 5R, the scope is summarized as:

- Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring.
- Construction monitoring would apply during the estimated 17 years of construction.
- O&M monitoring would apply to the estimated 14 acres of engineered caps.
- Long-term monitoring would apply LDW-wide until EPA and Ecology conclude that remedial action is sufficiently completed and monitoring is no longer required.
- Natural recovery processes are predicted to improve sediment quality as estimated by long-term modeling. Changes in sediment quality over time will be evaluated by long-term monitoring.
- Adaptive management for all remedial alternatives is described in Section 8.2.5.
- Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 5R would remove approximately 1,600,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS. Partial dredging and capping are assumed under overwater structures. Approximately 590,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and provide cap material.

The estimated construction time frame is 17 years. The estimated net present value of the cost of Alternative 5R is $470 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.5.2 Alternative 5R-Treatment – Removal Emphasis with Soil Washing Treatment

Alternative 5R-Treatment is identical to Alternative 5R in terms of active and passive remedial footprints, monitoring requirements, institutional controls, quantities, and time frames. The only difference between the two alternatives is that Alternative 5R-Treatment includes the construction and use of an *ex situ* soil washing facility that could reduce the quantity of contaminated sediment sent to the landfill. The following provides additional details regarding the soil washing facility for treating dredged material.

Soil Washing Facility Details

The soil washing facility is assumed to be located within a single transloading/ dewatering facility used for all dredged sediment. The soil washing operations are expected to require up to approximately 7 acres and would be sited entirely within an expanded transloading facility footprint.

All dredged/excavated material generated for this alternative would be handled at the transloading/treatment facility. To optimize the effectiveness of soil technology, this alternative would need to be sequenced in a manner that would allow targeted dredging of areas with relatively coarser grained sediments that are more amenable to treatment.

Once the dredged/excavated materials are delivered to the transloading/treatment facility, the soil washing process is as follows:

1) Physically wash the dredged sediment and separate coarse-grained (cleaner sand) from fine particle (contaminated) sediment. As addressed in Section 7.1.2.2, this FS assumes that soil washing is feasible for those areas that contain more than 30% sand. Approximately 800,000 cy of material are assumed to undergo soil washing in Alternative 5R-Treatment, generating approximately 400,000 cy of sand fraction and 400,000 cy of waste fines fraction (filter cake) (see Section 7).

2) Treat the wash water and discharge it to the LDW. The FS assumes the following treatment train will be used: collect and settle, flocculate, filter, analyze, and discharge wastewater. Chemically analyze the water to confirm that pollutant or contaminant concentrations meet discharge limits.

3) Collect and stockpile the cleaner sand fraction in an on-site location. Chemically analyze the sand to confirm whether contaminant concentrations are suitable for beneficial reuse.

4) Transfer the treated sands off site and stockpile for reuse or disposal.

5) Chemically analyze all remaining fine-grained sediment to determine appropriate handling and disposal requirements.

6) Based on the analytical results, treat any excess wastewater and load railcars with remaining sediment for transport to an appropriate Subtitle C or D landfill for disposal.

The potential disposition of the treated sand fraction is uncertain and has considerable implications for implementation and cost, as discussed in Section 7. Four potential outcomes for the treated sand fraction are listed below in order from the least costly to the most costly:

- Meet the applicable chemical and physical requirements for in-water beneficial reuse, and hence be used in the remedial actions as on-site cap or ENR material with potential material cost savings.
- Be suitable for upland use as fill with no associated value or disposal cost.
- Be suitable for open water disposal with a comparatively low disposal cost.
- Require landfill disposal at significant cost.

The FS assumes the treated sand fraction has no associated value or disposal cost (i.e., is cost neutral). Section 9 further explores cost sensitivity analyses for other possible disposal options. The approximate raw material production rate for the soil-washing treatment system is assumed to be 40 to 45 tons per hour. Assuming that only the sand portion of the sediment is recoverable and all other sediment would need to be disposed of in a Subtitle D landfill, approximately 400,000 cy of sediment would be potentially available for beneficial reuse. The remaining 400,000 cy of material would be disposed of in the regional Subtitle D landfill, along with the estimated 800,000 cy of sediment not suitable for treatment because the fines fraction is too high for effective soil-washing. The volume of treated material may require a large temporary storage area until permits for viable reuse are obtained (or equivalency is demonstrated), and viable reuse options are identified. Soil washing is estimated to result in a maximum reduction of about 25% of the material otherwise destined for the landfill.

Estimated Quantities, Construction Time Frame, and Cost

Alternative 5R-Treatment is assumed to have the same volume of sediment removed, volume of material placed, and construction time frame as Alternative 5R.

The estimated net present value of the cost of Alternative 5R-Treatment is $510 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.5.3 Alternative 5C – Combined Technology

Similar to Alternative 5R, Alternative 5C addresses the AOPC 1 footprint (180 acres) by actively remediating 157 acres (in addition to the 29 acres in the EAAs) and passively remediating 23 acres (verification monitoring). Figure 8-15 illustrates the areas estimated to be remediated under Alternative 5C and Table 8-11 summarizes the acres managed. The primary elements of Alternative 5C are as follows:

- **Dredging and upland disposal:** 57 acres would be dredged to sufficient depth to remove all contamination above the SQS. Other details are the same as described for Alternative 3C.
- **Partial dredging and capping:** 23 acres would be partially dredged to the necessary depth based on elevation constraints and covered with an isolation cap. Other details are the same as described for Alternative 3C.

- **Capping:** 24 acres of contaminated sediment would be contained with an isolation cap. Other details are the same as described for Alternative 3C.
- **ENR/*in situ*:** 53 acres of contaminated sediment would be remediated with a layer of ENR/*in situ* material. Other details are the same as described for Alternative 3C.
- **Verification monitoring:** Would apply to the same 23 acres as described for Alternative 2R.
- **Institutional controls:** Alternative 5C includes the same institutional controls as described for Alternative 5R, except proprietary controls and monitoring and notification of waterway users would apply to 47 acres of engineered caps, 53 acres of ENR/*in situ* treatment, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 57 dredged acres would have fewer controls because less contamination would remain.
- **LDW-wide monitoring, adaptive management, periodic reviews, and natural recovery processes**. These elements would be the same as described for Alternative 5R, except for the following differences:
  - Construction monitoring would apply during the estimated 7 years of construction
  - O&M monitoring would apply to the estimated 47 acres of engineered caps and 53 acres of ENR/*in situ* treatment.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 5C would remove approximately 750,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the SQS, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 580,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR/*in situ* material.

The estimated construction time frame is 7 years. The estimated net present value of the cost of Alternative 5C is $290 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.6 Alternatives 6R and 6C

Alternatives 6R and 6C are designed to achieve cleanup objectives for RAOs 1, 2, 3, and 4 immediately following construction. In addition, Alternatives 6R and 6C are designed to achieve the range of long-term model-predicted concentrations immediately following construction. Long-term model-predicted concentrations of the human health risk drivers are presented in Section 9.

The technology differences between Alternatives 6R and 6C are the same as the differences in technology assignments between Alternatives 5R and 5C. Alternative 6R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 6C emphasizes using combined technologies when applicable. Alternatives 6R and 6C have the same active remedial footprint (302 acres, AOPCs 1 and 2 combined). The active remedial footprint represents areas with surface sediment concentrations above the Alternative 6 RALs. The following subsections describe the details of Alternatives 6R and 6C.

8.3.6.1 Alternative 6R – Removal Emphasis with Upland Disposal

Alternative 6R addresses the AOPC 2 footprint (122 acres) and all of AOPC 1 (180 acres). This remedial alternative actively remediates the entire footprint of 302 acres (in addition to the 29 acres in the EAAs) and is estimated to achieve the long-term model-predicted concentrations of the human health risk drivers immediately following construction. The 23 acres assigned to verification monitoring areas for Alternatives 2 through 5 are actively remediated in Alternative 6. Figure 8-16 illustrates the areas estimated to be remediated under Alternative 6R and Table 8-11 summarizes the acres managed. The primary elements of Alternative 6R are as follows:

- **Dredging and upland disposal:** 274 acres would be dredged to sufficient depth to remove all contamination above the Alternative 6 RALs. In dredged areas, residuals management would be used as needed to achieve a final surface below the Alternative 6 RALs, and areas with existing depths shallower than -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 28 acres (under-pier areas) would be partially dredged and finished with an isolation cap.
- **Institutional controls:** Alternative 6R includes:
  - Seafood consumption advisories, public outreach, and education would apply LDW-wide.
  - Proprietary controls and monitoring and notification of waterway users would apply in proportion to the area where contamination remains above levels needed to meet cleanup objectives. The amount of controls needed would be proportionate to the degree and the likelihood of exposure of remaining contamination, including 28 acres of engineered caps and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 274 dredged acres would have fewer controls because less contamination would remain.

  - The entire LDW would be subject to an institutional controls plan. Any institutional controls approved by EPA for any EAA would be incorporated into the LDW plan. If necessary, institutional controls plans for the EAAs would be modified to be consistent with the plans for the rest of the LDW.

- **LDW-wide monitoring, adaptive management, and periodic reviews.** For Alternative 6R, the scope is summarized as:

  - Baseline monitoring would occur site-wide concurrently with remedial design investigations and verification monitoring.
  - Construction monitoring would apply during the estimated 42 years of construction.
  - O&M monitoring would apply to the estimated 28 acres of engineered caps.
  - Long-term monitoring would apply LDW-wide until EPA and Ecology conclude that remedial action is sufficiently completed and monitoring is no longer required.
  - Adaptive management for all alternatives is described in Section 8.2.5.
  - Periodic reviews would be the same as described for Alternative 2R.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 6R would remove approximately 3,900,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the Alternative 6 RALs. Partial dredging and capping are assumed under overwater structures. Approximately 1,200,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, and for partial dredging and capping.

The estimated construction time frame is 42 years. The estimated net present value of the cost of Alternative 6R is $810 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.3.6.2 Alternative 6C – Combined Technology

Similar to Alternative 6R, Alternative 6C addresses the AOPC 2 footprint (122 acres) and all of AOPC 1 (180 acres). This remedial alternative actively remediates the entire footprint of 302 acres (in addition to the 29 acres in the EAAs) and is predicted to achieve long-term model-predicted concentrations immediately following construction. Figure 8-17 illustrates the estimated areas to be remediated under Alternative 6C and Table 8-11 summarizes the acres managed. The primary elements of Alternative 6C are as follows:

- **Dredging and upland disposal:** 108 acres would be dredged to sufficient depth to remove all contamination above the Alternative 6 RALs. In dredged areas, residuals management would be used as needed to achieve a final surface below the Alternative 6 RALs, and areas with existing depths shallower than -10 ft MLLW would be backfilled to grade.
- **Partial dredging and capping:** 42 acres would be partially dredged to the necessary depth based on elevation constraints, and finished with an isolation cap.
- **Capping:** 51 acres of contaminated sediment would be isolation capped.
- **ENR/*in situ*:** 101 acres of contaminated sediment would be remediated with a layer of ENR/*in situ* material. Other details are the same as described for Alternative 3C.
- **Institutional controls:** Alternative 6C includes the same institutional controls as described for Alternative 6R, except that proprietary controls and monitoring and notification of waterway users would apply to 93 acres of engineered caps, 101 acres of ENR/*in situ* treatment, and all unremediated areas where contamination remains above levels needed to meet cleanup objectives. The 108 dredged acres would have fewer controls because less contamination would remain.
- **LDW-wide monitoring, adaptive management, and periodic reviews:** These elements would be the same as described for Alternative 6R, except for the following differences:
    - Construction monitoring would apply during the estimated 16 years of construction.
    - O&M monitoring would apply to the estimated 93 acres of engineered caps and 101 acres of ENR/*in situ* treatment.

Estimated Quantities, Construction Time Frame, and Cost

As shown in Table 8-11, Alternative 6C would remove approximately 1,600,000 cy of contaminated sediment (not including the EAAs) by dredging and excavation, assuming dredging to the extent of the active footprint and vertically to the depth of contamination above the Alternative 6 RALs, and partial dredging and capping to the depth necessary based on elevation constraints. Approximately 1,100,000 cy of sand, gravel, and rock would be needed to manage dredge residuals, restore habitat areas to grade, cap, and place ENR/*in situ* material.

The estimated construction time frame is 16 years. The estimated net present value of the cost of Alternative 6C is $530 million. See Appendix I for cost estimate details and cost sensitivity analyses.

8.4 Uncertainties

Sufficient data collection and analyses have been completed to develop and evaluate the LDW conceptual site model and remedial alternatives presented therein. Overall, the remedial alternatives are sufficiently defined to allow a detailed evaluation against the CERCLA criteria (Section 9), to perform a comparative analysis in accordance with CERCLA criteria (Section 10), to perform a disproportionate cost analysis in accordance with the MTCA criteria (Section 11), and to support remedial decision-making. However, inherent in the conceptual nature of the FS process, key uncertainties remain regarding certain assumptions made in development of the remedial alternatives. These uncertainties include, but are not limited to, the following:

- Adequacy and timing of source control
- Volume estimates
- Remedial technology assignments and expected performance
- Extent and rate of ongoing natural recovery processes
- Considerations of other technologies
- Future land and waterway uses
- Cost estimates.

These uncertainties are discussed below.

8.4.1 Adequacy and Timing of Source Control

Ecology is the lead agency for managing source control in the LDW and works in cooperation with local jurisdictions and EPA to create and implement source control strategy and action plans and to prioritize upland cleanup efforts in the LDW. Since 2002, the Source Control Work Group has identified 24 source control areas (SCAs), which are generally based on stormwater and combined sewer overflow infrastructure and drainage to the LDW study area (see Figure 2-22). As of July 2011, Ecology had published Source Control Action Plans (SCAPs) for 18 of the 24 SCAs. Ecology is currently working with its consultants to develop data gap reports and SCAPs for the remaining SCAs. Section 2 provides a more detailed discussion of these SCAs.

In accordance with EPA guidance and prudent practice, remedial actions generally should not commence until appropriate source control measures have been implemented and their performance verified. Remedial actions need to be carefully coordinated with source control work and SCAPs. In certain cases, source control may be the limiting factor in scheduling in-water cleanup. Unfortunately, the discovery of new information or sampling data about a source may increase uncertainty about the potential for recontamination. Therefore, working cooperatively to identify and characterize suspected sources/pathways early with respect to proposed sediment cleanup is critical to keep source control and sediment cleanup schedules synchronized to the extent practical. The success of sediment cleanup is dependent upon addressing ongoing sources and their pathways, such as contaminated upland sites, stormwater, and combined sewer overflow discharges. This is especially important for sources adjacent to the LDW. A number of the currently identified high-priority source control actions are currently being conducted by LDWG parties in conjunction with sediment remediation, including managing time lines for source control and sediment remedies (e.g., Boeing/Thompson-Isaacson, Terminal 115N, Slip 4, North Boeing Field/Georgetown Steam Plant, Terminal 117).

Significant effort has been invested in regulating and reducing discharges to the LDW. Nevertheless, uncertainty remains as to whether these and planned future source control actions will be completed prior to implementing the selected remedy, and whether these actions will be sufficiently protective to prevent recontamination of LDW sediment. These uncertainties were not addressed in estimates of construction time frames for the remedial alternatives, except that Alternatives 2 through 6 are not initiated until five years after issuance of the ROD to allow sufficient time for progress in source control efforts. During this five-year period, baseline sampling and remedial design sampling will also occur; results should help determine when source control is sufficient to commence remediation of contaminated sediment in a given area.

Following remediation, the effectiveness of source control will continue to be assessed. Based on these assessments, additional source control (or other actions) may be performed as needed under an adaptive management approach.

8.4.2 Volume Estimates

The horizontal and vertical extent of sediment concentrations exceeding RALs is a key uncertainty in this FS, and the key sensitivity parameter for the cost and duration of remedial actions (see Appendix I). Uncertainty in FS sediment characterization stems from the age of some data and the spatial coverage of sampling, especially in the subsurface. This uncertainty is accounted for with a dredge volume adjustment factor of 50%, which is added to the FS neat-line volume. This value was empirically determined based on the volume increase from FS to implementation for 19 large sediment remediation projects nationwide (Palermo 2009, Anchor QEA and ARCADIS 2010). “Volume creep” commonly results from additional dredging resulting from the design of constructible dredge prisms with flat box cuts and side slopes, overdredging, additional characterization of sediments, and management of dredge residuals. In addition, Appendix E (volume estimates) calculates a conservative volume beyond the measured depth of contamination, down to the native alluvium. This native stratum was used as the basis to develop a reasonable upper limit for the volume estimates used in the FS cost estimates.

Remedial design sampling will refine the estimated extent of contaminated sediment and confirm or modify the technology assignments identified in the FS. The assumptions used to define the remedial areas and volumes set forth in this section are reasonable and appropriate for an FS-level alternatives development process.

8.4.3 Remedial Technologies Assignments and Expected Performance

The remedial alternatives have been assembled using a set of assumptions about the applicability and effectiveness of remedial technologies (Section 8.1). Some of these are rather straight-forward, such as the assumption that capping is not applicable in the navigation channel without enough post-construction vertical clearance to allow for future maintenance dredging. Other criteria are based on general assumptions that require confirmation during remedial design.

In addition, some location-specific attributes of the LDW were not used for technology assignments in assembling site-wide remedial alternatives. For example, shoreline structures such as pilings and riprap will affect the viability of full removal of contaminated sediment; therefore, partial dredging and capping may be necessary in more places than indicated in these alternatives. In total, all of these assessments could result in refinements and changes to the mix of technologies during remedial design. Similar sources of uncertainty exist for all remedial technologies; see below for examples.

8.4.3.1 Capping, ENR/*In Situ* Treatment, and MNR Uncertainties

The effectiveness of capping is uncertain with respect to waterway conditions. This uncertainty was addressed through contaminant transport modeling in Appendix C, and by a cost contingency for capping areas reverting to dredging. Uncertainty regarding the long-term stability of cap material was addressed by including an additional cost for maintenance and repair of sediment caps.

The assumption that ENR/*in situ* treatment is viable in Recovery Category 2 and 3 areas but not viable in Recovery Category 1 areas is appropriate for FS-level analysis, but would require re-evaluation during remedial design. The recovery categories are based on a set of assumptions about the conditions of the waterway (e.g., that the STM base-case accurately represents conditions in the waterway), and about how these conditions relate to the applicability of ENR/*in situ* treatment (e.g., that more than 10 cm of scour during a high-flow event would preclude effective ENR/*in situ* treatment, but less than 10 cm of scour would not). Both of these sets of assumptions would be revisited and refined during remedial design. This could involve empirical studies of the use of ENR/*in situ* treatment in the LDW or other waterways, bathymetric surveying, additional modeling, location-specific scour modeling or measurement, and others.

The effectiveness of MNR is a key uncertainty for Alternatives 2 through 4. Uncertainty in the rate of natural recovery is discussed in Section 8.4.4. Like ENR/*in situ* treatment, MNR uncertainty was accounted for by limiting MNR based on a set of assumptions (e.g., no MNR(10) in Recovery Categories 1 or 2), and by assuming that a percentage of the MNR areas will require contingency actions. Time-trend analysis and adaptive management would account for this uncertainty during remedy implementation.

These sources of uncertainty were accounted for in the FS by incorporating adaptive management components into the cost estimate. For example, these sources of uncertainty for ENR/*in situ* treatment were addressed by assuming that 15% of the ENR/*in situ* area will be re-assigned to dredging following construction based on adaptive management activities. Similar adjustments are made for capping and MNR (see Appendix I for details). These adjustments account for changes in remedy implementation triggered by new information gathered during remedial design, construction, and following construction. Alternatives 1 through 5 also rely to varying degrees on natural recovery in areas outside those designated for MNR and active remediation to achieve cleanup objectives. The FS does not account for specific adaptive management or contingencies for these areas. However, site-wide monitoring should, in practice, provide information from which adaptive management or contingency decisions can be made, if necessary.

8.4.3.2 Treatment Uncertainty

Significant uncertainty exists with the *ex situ* treatment option, soil washing. If soil washing is employed, bench-and pilot-scale testing would be needed to confirm the assumption that sand-size material from the LDW can be treated to an acceptable level for beneficial reuse, if a suitable and allowable use can be found. If there is no acceptable beneficial reuse of the sand, it may require landfill disposal along with the untreated sediments, greatly increasing the cost of Alternative 5R-Treatment and diminishing the potential benefit of treatment. Compliance with water quality criteria may also require additional water treatment.

Uncertainties also exist for *in situ* treatment technologies (i.e., carbon or treated clays amendment). Several laboratory and field demonstration projects using carbon amendments around the country have had promising results, providing proof-of-concept that the bioavailability of contaminant concentrations in surface sediment can be significantly reduced. ENR applications have had similar success, but both applications rely on stability of the sediment bed to resist scour and substantial loss of material. Location-specific studies, including possible field demonstrations, may be necessary to assess both the implementation methods and performance of ENR/*in situ* treatment. In particular, demonstrations/analyses could evaluate ENR/*in situ* treatment in scour areas and intertidal areas. Results from this evaluation would be used to guide the final technology assignments for the selected remedy and establish performance metrics for ENR with *in situ* treatment.

8.4.3.3 Dredging Uncertainty

When dredging is employed, potential sediment resuspension and plume migration will need to be understood to develop an effective residual management plan. The management of dredge residuals is an uncertain activity in practice. Based on empirical data cited by the National Resource Council (NRC 2007), 13 out of 14 sites could not account for all the mass of contaminated sediment, which may have been lost to the waterway as dredge residuals. The NRC document also states (p. 164):

> *"Dredging alone is unlikely to be effective in reaching short-term or long-term goals where sites exhibit one of more unfavorable conditions. Where unfavorable conditions exist, increased contaminant resuspension, release, and residuals will tend to limit ability to meet cleanup levels and delay the achievement of remedial action objectives unless managed through a combination of remedies or alternative remedies."*

The unfavorable site conditions often include: presence of debris, bedrock, or other physical obstructions that prevent full removal; side slopes; piers and other obstacles; strong currents; scour potential; and ongoing sources. Some of these are also unfavorable conditions for effective implementation of other technologies assessed in this FS, such as capping, ENR/*in situ*, and MNR. Pilot studies, experienced contractors, best management practices, a monitoring program, and a good understanding of site conditions and associated limitations, can help improve the likelihood that dredging will be successful. However, there is a "*general lack of evidence that dredging projects have led to the achievement of long-term remedial success and did so within the expected time frames*" (NRC 2007, p. 90). Of the 21 dredging projects reviewed in that report, about half of the projects have not achieved their RAOs or did not have adequate monitoring to evaluate success. Insufficient time has elapsed at another 25% of the sites. The expected performance of dredging as a remedial alternative has its limitations in reaching long-term RAOs. These sources of uncertainty are accounted for in the FS by incorporating contingency actions into the remedial alternatives.

In summary, uncertainties are inevitable and must be managed appropriately. Many short-term uncertainties will be addressed during remedial design and implementation; however, long-term uncertainties will remain following completion of the selected remedial actions. Collectively, these uncertainties will be addressed through the use of long-term monitoring and adaptive management to ensure protectiveness of the selected remedial actions.

8.4.4 Extent and Level of Ongoing Natural Recovery Processes

Natural recovery is believed to be occurring within portions of the LDW, based on empirical data and sediment transport modeling calibrated to the LDW system, but the extent and level of recovery is uncertain, in large part because of the lack of time-trend data and the difficulty in predicting future conditions. Natural recovery predictions have uncertainty associated with: contaminant concentrations of particles entering the

LDW from upstream, sedimentation rates, resuspension rates, scour depth, dispersion rates, groundwater flow rates, degree of contaminant mobility, degree of source control, and the amount of subsurface contamination exposed by natural and anthropogenic disturbances (see additional discussions of uncertainty in Section 9). Empirical time trends can be confounded by spatial heterogeneity and variations in the behavior or degree of source control for various contaminants.

For the FS, the rate of natural recovery was predicted using the BCM (Section 5) and empirical time trend data (Section 6). To address concerns of the possibility that the BCM may overestimate rates of natural recovery and miss some key parameters affecting natural recovery (for example, vessel scour), the recovery categories were constructed to conservatively identify areas of the LDW with higher or lower potential for natural recovery (Section 6). These were compared with empirical data in an attempt to improve natural recovery predictions. Appendix F includes specific examples of empirical time trend data used to evaluate natural recovery in the LDW.

The BCM was conservatively employed in the assembly of remedial alternatives in two ways. First, by including any location that exceeded the relevant contaminant concentrations within the AOPC boundary, regardless of the date the location was sampled, natural recovery was not incorporated into that delineation. While this is a conservative approach to ensure adequate remediation of those locations, it may overestimate risk-driver concentrations because it does not take into account recovery from the time the sediment was sampled to the time that active remediation begins. Second, the MNR predictions for the development of remedial alternatives did not assume any natural recovery occurs until the end of construction. Therefore, they did not account for natural recovery occurring from the time of sampling through remedial design and construction. Section 9 accounts for this uncertainty by assuming that natural recovery occurs concurrently with active remediation.

To summarize, these uncertainties are managed by calibrating the STM and BCM, using empirical trends where available, and using conservative technology assignment assumptions. In total, while uncertainty exists, the conceptual recovery model for the LDW is based on all the lines of evidence in Appendix F and represents the best estimate of conditions in the LDW. In addition, considerably less uncertainty exists in site-wide analysis of the LDW than in smaller scale analysis of specific locations within the LDW (see Appendix J).

The best way to assess risk-driver contaminant trends is through direct measurement. Therefore, remedial design sampling (including verification monitoring), MNR monitoring, site-wide monitoring, and long-term monitoring, combined with adaptive management, are crucial to the long-term success and effectiveness of remediation of the LDW.

8.4.5 Consideration of Other Technologies

The alternatives presented in this FS use technologies that, with the exception of soil washing, are common to most sediment remediation projects undertaken worldwide. Investigation and development of new technologies for sediment cleanup continues within the sediment management practice. The FS recognizes that new technologies should not be discounted for consideration in the cleanup of the LDW. In part, this recognition is because of the very real potential that complete cleanup of the LDW could potentially span an appreciable period of time (e.g., approximately 20 to 40 or more years from the date of this document).

Advances in dredging and cap amendments have the potential to improve cleanup of the LDW and should be considered at the remedial design stage.

Although not retained in the development of site-wide alternatives, other on-site options (e.g., nearshore CAD, upland landfill within the project boundary) are potentially viable options for disposal of dredged material. Although these disposal options are not considered to be LDW-wide options because of insufficient capacity, lack of available land, and anticipated difficulties in meeting substantive legal requirements including possible mitigation, these options may be determined to be viable and reasonable on a location-specific basis during remedial design. Depending on the specifics of such a proposal, a ROD Amendment or Explanation of Significant Differences and associated public process may be required for these disposal options to be included in a location-specific design.

8.4.6 Future Land and Waterway Uses

Future changes in upland land use or changes to in-water uses of the LDW have the potential to impact remedial design decisions. To identify and evaluate potential future use changes, existing zoning and ongoing planning activities for future uses were investigated in this FS. Findings are summarized below.

8.4.6.1 Land Uses

Land bordering the majority of the LDW is zoned for industrial/manufacturing uses. Three local jurisdictions border the LDW: the City of Seattle, the City of Tukwila, and King County. These jurisdictions have established planning priorities and goals for the LDW that are described in the following planning documents:

- City of Seattle Comprehensive Plan 2012 http://www.seattle.gov/DPD/Planning/Seattle_s_Comprehensive_Plan/Overview/
- City of Seattle Shoreline Master Program Updates 2012 http://www.seattle.gov/dpd/Planning/ShorelineMasterProgramUpdate/Overview/

- City of Tukwila Comprehensive Plan 2009 http://www.ci.tukwila.wa.us/dcd/dcdcompplan.html
- City of Tukwila Shoreline Master Program Update 2010 http://www.ci.tukwila.wa.us/dcd/shoreline.html
- King County Comprehensive Plan 2008 http://www.kingcounty.gov/property/permits/codes/growth/CompPlan.aspx
- King County Shoreline Master Program Update 2010 http://www.kingcounty.gov/environment/waterandland/shorelines/program-update.aspx

In general, these documents call for land surrounding the LDW to remain zoned primarily for industrial and manufacturing activities into the future. Existing neighborhoods adjacent to the LDW are zoned residential and are also expected to remain as such. These plans have a universal goal to improve the habitat value of the LDW corridor and to increase public access. Where technically feasible and consistent with current property use, additional public access and shoreline/habitat restoration is encouraged through these municipal planning priorities.

The City of Seattle Shoreline Master Program Updates establish policies and regulations that govern development and uses of adjoining shorelines. An overarching objective of the updates is natural resource protection with the adopted standard of preventing any net loss of environmental function. A component of the updates is a restoration plan that identifies specific habitat restoration opportunities along the Lower Duwamish Waterway. The updates are scheduled to be adopted by the Seattle City Council in 2012, and adopted by Ecology thereafter. In this context, it should be noted that zoning is always subject to variance and changes by local zoning authorities, as is local planning, because the priorities of succeeding elected officials and governing bodies change over time.

8.4.6.2 Waterway Uses

The National Oceanic and Atmospheric Administration (NOAA) and the Lower Duwamish River Natural Resource Trustees prepared the *Lower Duwamish River Draft Restoration Plan and Programmatic Environmental Impact Statement* (RP/PEIS; NOAA 2009) to identify general types of restoration projects that will be used to compensate for natural resource damage. The plan also considers the unique characteristics of different segments of the river and how they influence the restoration strategy. The Draft RP/PEIS was released for public comment on May 22, 2009.

A community planning project to create a long-range vision for the Duwamish River and its surroundings was led and recently completed by the Duwamish River Cleanup Coalition (DRCC). The project was a comprehensive, community-based, visioning endeavor involving workshops, mapping, and interviews, engaging people who live in, work in, or visit the Duwamish Valley. The project compiled the community's ideas, concerns, and visions of the future Duwamish Valley into a comprehensive map and report (DRCC 2009, available online at www.duwamishcleanup.org). The DRCC is the formal community advisory group recognized by EPA for this project.

Figure 2-4 shows existing shoreline restoration areas and public access points along the LDW. Specific land and waterway uses or practices may be expected to change over time. Land or waterway changes that physically alter a remedy component (e.g., construction in the location of an existing sediment cap) would need to consider the remedial component during planning and construction. Under these circumstances, it would be the responsibility of the project sponsor to design and construct the remedial action in a manner that is generally acceptable to EPA and Ecology. The sponsor would need to appropriately manage contaminated material encountered during construction, and comply with all required post-construction maintenance and monitoring.

The LDW is also one of the locations of the Muckleshoot Tribe's commercial, ceremonial, and subsistence fishery for salmon. The Suquamish Tribe actively manages aquatic resources north of the Spokane Street Bridge, located just north of the LDW. The Duwamish Tribe uses Herring's House Park and other parks along the Duwamish for cultural gatherings.

On July 7, 2009, the Port of Seattle Commission adopted the Lower Duwamish River Habitat Restoration Plan (Port of Seattle 2009), which establishes a long-range framework to guide restoration of aquatic and riparian habitat on Port property along the shoreline. The plan identifies sites where natural habitat can be enhanced or restored to coexist with commerce that relies on the LDW for navigation. Prior to adoption of the plan, the Port undertook a comprehensive outreach process that engaged numerous stakeholders, including area businesses, community and environmental groups, Native American tribes, and key public agencies.

At present, the Port of Seattle does not forecast a change in the vessel draft or authorized navigation channel depths in the LDW in the foreseeable future (Hotchkiss 2010). The existing ship and vessel traffic usage is expected to remain unchanged, and any changes to these assumptions will be addressed during remedial design or in the future. Currently, vessel speed regulations are in force to reduce personal injuries and property damage. The speed limit for vessels is 5 knots within the navigation channel of the LDW (Windward and QEA 2008, QEA 2008). Because of congestion, vessel speeds are often much slower.

In general, existing zoning and habitat enhancement planning activities are not expected to conflict with potential active and passive remediation activities on a site-wide basis. However, any potential conflicts will be addressed during remedial design.

8.4.7 Cost Estimates

Table 8-11 presents best-estimate total costs for the remedial alternatives. These costs were developed in accordance with applicable EPA guidance (EPA 2000a) and are presented in detail in Appendix I. It is important to acknowledge uncertainty in the accuracy of these cost estimates. Several factors can influence the accuracy of estimated remedial alternative costs at the FS level. In particular, as discussed in Appendix I, the costs are very sensitive to the estimated dredge removal volume. Modest changes in the estimated dredge removal volume can significantly impact costs. Other factors, such as fuel and labor, can also significantly impact costs. The FS cost estimates are best estimates based on present day costs, projected into the future. Future economic conditions are difficult to predict. For this reason, the relative accuracy of the cost estimates is likely better for alternatives with shorter durations than for those with longer durations. Overall, the cost sensitivity values fall close to or within the cost accuracy range of -30 to +50 percent expected by EPA for FS-level estimates (EPA 2000a).

In accordance with EPA guidance (EPA 2000a), the best-estimate costs are reported in terms of their net present values. Net present value analysis is a standard method used to express expenditures that occur over different time periods on a common basis. A discount rate is applied to represent the difference between the rate of return on investments and the rate of inflation. EPA (2000a) guidance recommends using a discount rate of 7% in calculating net present value for non-federal sites. The guidance recommends using discount rates published in Appendix C of Office of Management and Budget Circular A-94 for federal projects. This FS uses a discount rate of 2.3% based on the 30-year real (i.e., inflation-adjusted) discount rate published in the 2011 revisions of Appendix C to the OMB Circular. This rate was used, in part, because three of the four entities that prepared this FS and that will be involved in cleanup of the LDW are in the public sector.[20]

A discount rate of 2.3% suggests that, in the future, investments would yield an average of 2.3% above the rate of inflation. The net present value is the amount of money that would need to be invested now to ensure that funds for implementing a remedial alternative are available in the future, taking into account an assumed annual inflation rate in those costs. Given that the return on investments is assumed to be greater than the rate of inflation, the net effect of the net present value analysis is to make costs incurred far in the future smaller relative to the cost of implementation at present. While useful for comparing remedial alternatives, the discounted costs may not be meaningful projections for the parties contributing money to cleanup of the LDW. Certain parties (public, public-private entities) may not be able to invest sufficient funds

[20] See Appendix I for additional details on selection of discount rate. Net present value costs using a 7% discount rate were also calculated for the remedial alternatives and provided to EPA/Ecology in a separate memorandum.

(without incurring additional costs of bonding or borrowing) before remediation starts, and will therefore not be able to take advantage of the interest accumulation assumption implied by the net present value calculation. Of course, projecting both the rate of return on investments and the rate of inflation far into the future has considerable uncertainty in itself. If, for example, the rate of inflation happened to be greater than the rate of return on investments, the future costs would be greater than if the costs were incurred today. Therefore, non-discounted costs have also been provided in Appendix I (Table I-51) to exhibit the sensitivity of the discount rate on estimated costs.

Table 8-1 Remedial Alternatives and Associated Remedial Technologies, Remedial Action Levels, and Actively Remediated Acres

Remedial Alternatives and Technologies[a]	Brief Description and Expected Outcomes	Remedial Action Levels for Risk Drivers[b]					Actively Remediated Area (Acres)
		Total PCBs (µg/kg dw)[c]	Arsenic (mg/kg dw)	Dioxins/ Furans (ng TEQ/kg dw)	cPAHs (µg TEQ/kg dw)[d]	Benthic SMS (41 Contaminants)[e]	
Alternative 1 No Further Action after removal or capping of Early Action Areas	CERCLA baseline alternative used for comparison to other alternatives.	n/a	n/a	n/a	n/a	n/a	29 acres
Alternative 2 (2R) – dredge emphasis with upland disposal/MNR Alternative 2 with CAD (2R-CAD) – dredge emphasis with contained aquatic disposal/MNR	Actively remediate hotspots and other areas to achieve the CSL, total 1 × 10^{-5} direct contact excess cancer risks, HQ <1 for direct contact non-cancer hazards, and HQ <1 for risks to river otters within 10 years following construction. Achieve the CSL immediately following active remediation in areas not predicted to recover naturally (Categories 1 and 2). MNR to achieve the SQS in a greater than 10-year time frame. More reliance on MNR to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption. Additional actions will be taken if SQS not achieved within 20 years following construction.	1,300[c] to 2,200[c]; 10-yr post-construction target: 1,300[c]	93	50	5,500	CSL to 3 × CSL[d] 10-yr post-construction target: CSL	32 acres (plus 29 acres EAAs)
Alternative 3 removal (3R) – dredge emphasis with upland disposal/MNR Alternative 3 combined technologies (3C) – ENR/*in situ* /cap/MNR where appropriate, otherwise dredge with upland disposal	Actively remediate areas to achieve the CSL, total 1 × 10^{-5} direct contact excess cancer risks, individual risk drivers in the 10^{-5} or 10^{-6} magnitude direct contact excess cancer risk[f], HQ <1 for direct contact non-cancer hazards, and HQ <1 for risks to river otters immediately following construction. Use MNR to achieve SQS in a greater than 10-year time frame. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative. Additional actions will be taken if SQS not achieved within 20 years following construction.	1,300[bc]	93 (site-wide) 28 (intertidal)	35 (site-wide) 28 (intertidal)	3,800 (site-wide) 900 (intertidal)	CSL toxicity or chemistry	58 acres (plus 29 acres EAAs)
Alternative 4 removal (4R) – dredge emphasis with upland disposal/MNR Alternative 4 combined technologies (4C) – ENR/*in situ* /cap/MNR where appropriate, otherwise dredge with upland disposal	Actively remediate areas to achieve the SQS within 10 years following construction and incremental reduction in the site-side SWAC for total PCBs (RAO 1). Achieve the SQS immediately following active remediation in areas not predicted to recover naturally (Categories 1 and 2). Use MNR in other areas to achieve the SQS within 10 years following construction. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative. Additional actions will be taken if SQS not achieved within 10 years following construction.	240[c] to 700[c]; 10-yr post-construction target: 240[c]	57 (site-wide) 28 (intertidal)	25 (site-wide) 28 (intertidal)	1,000 (site-wide) 900 (intertidal)	SQS to CSL[d] 10-yr post-construction target: SQS	107 acres (plus 29 acres EAAs)
Alternative 5 removal (5R) – dredge emphasis with upland disposal Alternative 5 removal with treatment (5R-T) – dredge with soil washing treatment and disposal/re-use[g] Alternative 5 combined technologies (5C) – ENR/*in situ* /cap where appropriate, otherwise dredge with upland disposal	Active remediate areas to achieve the SQS and incremental reduction in the site-wide SWAC for total PCBs (RAO 1) immediately following construction. More reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption than previous alternative	240[c]	57 (site-wide) 28 (intertidal)	25 (site-wide) 28 (intertidal)	1,000 (site-wide) 900 (intertidal)	SQS toxicity or chemistry	157 acres (plus 29 acres EAAs)
Alternative 6 removal (6R) – dredge emphasis with upland disposal Alternative 6 combined technologies (6C) – ENR/*in situ* /cap where appropriate, otherwise dredge with upland disposal	Reduction in PCB SWAC to achieve approximate range of long-term model-predicted concentrations immediately following construction. Most reliance on active remediation to reduce risk-driver concentrations associated with human health risks attributable to seafood consumption.	100[c]	15 (site-wide) 28 (intertidal)	15 (site-wide) 28 (intertidal)	1,000 (site-wide) 900 (intertidal)	SQS toxicity or chemistry	302 acres (plus 29 acres EAAs)

Notes:

a. Alternatives 2 through 6 include institutional controls and site-wide monitoring.

b. Site-wide remedial action levels are applied to concentrations in the upper 10 cm of sediment throughout the LDW and in the upper 60 cm in Recovery Category 1 areas. Intertidal remedial action levels are applied to concentrations in the upper 45 cm of sediment in intertidal areas (above -4 ft MLLW).

c. Total PCBs concentrations of 1,300 µg/kg dw and 240 µg/kg dw are dry weight approximations of the 65 mg/kg oc (CSL) and 12 mg/kg oc (SQS) values assuming 2% TOC. Compliance with SMS (RAO 3) will be evaluated using carbon normalized data as appropriate. The RALs for PCBs are a range for Alternatives 2 and 4. The upper RALs are used where conditions for recovery are predicted within 10 years (Recovery Category 3); the lower RALs are used where conditions for recovery are predicted to be limited or less certain (Recovery Categories 1 or 2), or where the BCM does not predict recovery to the 10-yr post-construction target concentration. An intertidal RAL for PCBs in the upper 45 cm of sediment was not developed because the PRGs for direct contact scenarios are achieved after remediation of the EAAs and other hot-spot areas (using the Alternative 2 RALs).

d. Individual cPAH compounds are also incorporated in benthic RALs.

e. The RALs for SMS contaminants (excluding arsenic) are a range for Alternatives 2 and 4. The upper RALs are used where conditions for recovery are predicted to be more favorable (Recovery Category 3); the lower RALs are used where conditions for recovery are predicted to be limited or less certain (Recovery Categories 1 or 2), or where the BCM does not predict recovery to the 10-yr post-construction target concentration.

f. Direct contact excess cancer risks attributable to individual contaminants are less than 1 × 10^{-6} for cPAHs, PCBs, and dioxins/furans, and less than 1 × 10^{-5} for arsenic (1 × 10^{-6} excess cancer risk levels are below natural background for arsenic).

g. Treatment technology could be used in conjunction with any alternative. Treatment unit costs are presented in Section 11.

AOPC = area of potential concern; BCM = bed composition model; C = combined technology; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cm = centimeters; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; HQ = hazard quotient; kg = kilograms; µg = micrograms; mg = milligrams; MNR = monitored natural recovery; n/a = not applicable; ng = nanograms; oc = organic carbon; PCB = polychlorinated biphenyl; R = removal emphasis; RAL = remedial action level; RAO = remedial action objective; R-T = removal with physical treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration TBD = to be determined; TEQ = toxic equivalent; TOC = total organic carbon; yr = year

Table 8-2 Technology Applicability Assumptions for the FS

Technology[a, b]	Active or Passive Technology[c]	Sediment Contaminant Concentration[d]	Physical Conditions (Scour, Berthing, Sedimentation Rate, Under Piers, Slope Stability)	Elevation Requirements (Habitat, Navigation Channel, Berthing Areas)[e]
Removal	Active	No upper concentration limit. Vertical extent is to the depth of SQS exceedances (Alternatives 2 through 5) or the depth of Alternative 6 RAL exceedances (Alternative 6). A 50% volume adjustment factor is added to the neat volume for all alternatives. Manage post-dredge residuals in all dredge areas with 6 inches of thin-layer sand placement.	Removal Alternatives: partially viable under piers. In those areas, assume partial dredging and capping under piers. Applicable in all other areas.	Habitat areas: (i.e., depths shallower than -10 ft MLLW), assume backfill to grade to maintain habitat. Dry excavate depths shallower than -2 ft MLLW. Navigation channel and berthing areas: no restrictions.
Partial Dredging and Capping	Active	No upper concentration limit. If <1 foot of contamination is predicted to remain below the cap, assume complete removal (e.g., if contaminant thickness is <4 ft for a 3-ft removal). Dredge vertically to the depth necessary to fit a 3-ft cap and comply with post-construction elevation assumptions.	Applicable in all areas. Engineered capping as necessary in scour areas, berthing areas, under piers, and in areas with >20 degree slopes (greater than 2.7:1 slopes). Partial dredging and capping is the default active technology under piers for the removal-emphasis alternatives.	Habitat areas: partial dredge 3 ft and cap to grade. Finish with habitat suitable substrate. Navigation channel and berthing areas: partial dredge to provide 3 ft and 2 ft clearance respectively post-construction.
Capping	Active	No upper concentration limit.	Applicable in all areas. Engineered capping as necessary in scour areas, berthing areas, under piers, and in areas with >20 degree slopes. Capping is the default active technology under piers for the combined-technology alternatives.	Habitat areas: partial dredge and cap (see above). Navigation channel and berthing areas: Applicable in areas with >6 ft and >5 ft preconstruction clearance respectively (depth necessary to fit a 3-ft cap).
ENR/*in situ*	Active	Concentration upper limit for ENR/*in situ* is 3 x the site-wide RAL for all risk drivers, and 1.5 x the intertidal RAL for three of the human health risk drivers (arsenic, cPAHs and dioxins/furans) in the intertidal areas. See Table 8-3.	Not applicable in Recovery Category 1 areas (Table 8-4).	Habitat area: ENR/*in situ* is not restricted based on habitat. Navigation and berthing areas: ENR/*in situ* is viable if >2 ft and >0 ft preconstruction clearance, respectively.[f]
MNR(10).[g,h]	Passive	Concentration upper limit for MNR(10) is RAL by definition. Applicable in areas above the 10-year post-construction target for only Alternatives 2R and 2R-CAD (CSL) and 4R and 4C (SQS).	Not applicable in Recovery Category 1 and 2 areas (Table 8-4).	Not restricted based on habitat.

Table 8-2 Technology Applicability Assumptions for the FS (continued)

Technology[a, b]	Active or Passive Technology[c]	Sediment Contaminant Concentration[d]	Physical Conditions (Scour, Berthing, Sedimentation Rate, Under Piers, Slope Stability)	Elevation Requirements (Habitat, Navigation Channel, Berthing Areas)[e]
MNR(20)[i]	Passive	MNR(20) applies to areas below the RALs.	Applies to all areas of the LDW. Assume areas adaptively managed using monitoring to achieve long-term targets.	Not restricted based on habitat.
Verification Monitoring	Passive	Areas with concentrations >Alternative 5 RALs (as bounded by AOPC 1), but at concentrations predicted to be below the Alternative 5 RALs by the time of construction based on recovery potential, empirical trends, and age of data.	Not applicable in Recovery Category 1 and 2 areas (Table 8-4).	Not applicable in Recovery Category 1 and 2 areas (Table 8-4).
Institutional Controls, Site-wide Monitoring, & Natural Recovery Processes[j]	Passive	Apply to all areas of the LDW.	Apply to all areas of the LDW.	Apply to all areas of the LDW.

Notes:

a. Criteria and assumptions are for the FS and may be changed during remedial design.
b. Capping and ENR/*in situ* are applicable only to the combined technology alternatives.
c. Active technology applicable above the RALs. Passive technologies are applicable below the RALs.
d. Sediment concentration in the upper 10 cm is compared to alternative specific RALs throughout the site. In intertidal areas, the RALs for human health risk drivers are compared to both surface sediment and to the vertical average of the upper 45 cm in intertidal areas. In scour areas (areas with observed vessel scour of >10 cm scour during high-flow events), alternative-specific RALs are compared to both surface sediment and the maximum concentration in the upper 2 ft of cores.
e. Habitat areas are defined as nearshore areas with bathymetric depths shallower than -10 ft MLLW. Navigational channel and berthing areas have water depth requirements to ensure safe passage of vessels.
f. As a conservative assumption, the assignment of ENR/*in situ* was limited based on similar navigation channel and berthing area clearance requirements as for capping. However, ENR/*in situ* may not have clearance requirements in the navigation channel or berthing areas.
g. Active remediation (dredging, capping, ENR/*in situ*, or a combination) is required for Alternatives 2 and 4 in areas not predicted to recover to below the 10-year post construction target concentration (i.e., the lower RAL).
h. MNR(10) is monitoring to achieve the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4).
i. MNR(20) is monitoring to achieve PRGs for RAOs 2 through 4 within 20 years after construction is complete. MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance. Recovery categories are likely to change based on additional information during monitoring. The time to achieve PRGs for RAOs 2 through 4 may be considerably less than 20 years; see Section 9 for predicted outcomes. Natural recovery processes are predicted to improve surface sediment quality over time (and achieve long-term model-predicted concentrations for Alternatives 2 through 5).
j. Institutional controls in the form of seafood consumption advisories apply site-wide for all alternatives. Ranges of institutional controls and monitoring apply to specific actions and areas, such as areas where subsurface contamination is contained on site. Site-wide monitoring will assess long-term progress toward the remedial action objectives for all alternatives.

AOPC = area of potential concern; C = combined technology; CAD = contained aquatic disposal; CSL = cleanup screening level; ENR = enhanced natural recovery; ft = foot; FS = feasibility study; LDW = Lower Duwamish Waterway; MLLW = mean lower low water; MNR = monitored natural recovery; PRG = preliminary remediation goal; R = removal emphasis; RAL = remedial action level; RAO = remedial action objective; SQS = sediment quality standard

Table 8-3 Concentration Upper Limit for ENR/*In Situ* Treatment in Site-wide/Intertidal Areas for Alternatives 3C through 6C

Risk Driver	Concentration Limits for Enhanced Natural Recovery/*in situ* [a, b, c, d] (site-wide/intertidal)			
	Alternative 3C	Alternative 4C	Alternative 5C	Alternative 6C
PCBs (µg/kg dw)	3,900	2,100	720	300
Arsenic (mg/kg dw)	279/42	171/42	171/42	45/42
cPAHs (µg TEQ/kg dw)	11,400/1,350	3,000/1,350	3,000/1,350	3,000/1,350
Dioxins/Furans (ng TEQ/kg dw)	105/42	75/42	75/42	45/42
SMS Contaminants	3 × CSL	3 × CSL	3 × SQS	3 × SQS

Notes:

a. The upper limit for ENR/ *in situ* is based on 3 times the site-wide RAL, and 1.5 times the intertidal RAL in intertidal areas (for arsenic, cPAHs, and dioxins/furans). The concentration in the upper 10 cm of sediment is compared to the site-wide upper limit, and the concentration in the upper 45 cm of sediment in intertidal areas is compared to the intertidal upper limit (where applicable).

b. The removal-emphasis alternatives do not include ENR/ *in situ*.

c. All concentration upper limits are site-wide unless two upper limits are presented for site-wide/intertidal areas.

d. The ENR upper limits apply only to areas assigned to Recovery Categories 2 and 3; this feasibility study assumes that no ENR/ *in situ* will be applied in areas assigned to Recovery Category 1. *In situ* treatment is assumed viable in all ENR/*in situ* areas.

C = combined technology; cm = centimeters; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; ENR = enhanced natural recovery; *in situ* = *in situ* treatment; kg = kilograms; µg = micrograms; mg = milligrams; ng = nanograms; PCB = polychlorinated biphenyl; RAL = remedial action level; SMS = Sediment Management Standards; SQS = sediment quality standard; TEQ = toxic equivalent

Table 8-4 Recovery Categories and Technology Assignment Assumptions

Feasibility Study Technology	Recovery Categories[a]		
	Category 1[b] Recovery Is Presumed to be Limited	Category 2[c] Recovery Less Certain	Category 3[d] Predicted to Recover
Dredging	Applicable	Applicable	Applicable
Capping	Applicable	Applicable	Applicable
ENR/*in situ*	Not Applicable	Applicable	Applicable
MNR(10)[e]	Not Applicable	Not Applicable	Applicable
MNR(20)[f]	Applicable	Applicable	Applicable
Institutional Controls, Site-wide Monitoring, & Natural Recovery	Applicable	Applicable	Applicable

Notes:

a. Recovery categories represent areas with similar predicted rates of chemical natural recovery and similar characteristics with regard to predicted remedial technology effectiveness. See Section 6 and Table 6-3 for definitions.

b. Recovery Category 1 – Recovery Is Presumed to be Limited: Potential sediment instability attributable to maintenance dredging, flow scour, or vessel scour; potentially slow recovery attributable to low sedimentation; or empirical chemical evidence for no natural recovery attributable to sediment instability.

c. Recovery Category 2 – Recovery Less Certain: Sediment may be stable, but recovery may be slow because of low sedimentation rates, berthing areas without vessel scour or net flood scour; or empirical chemical evidence for slow natural recovery (or source-control related).

d. Recovery Category 3 –Predicted to Recover: Sediment is stable and naturally recovering based on available evidence.

e. MNR(10) is monitoring to achieve the 10-year post-construction target concentrations (applicable to Alternatives 2 and 4). Includes verification monitoring areas.

f. MNR(20) is monitoring to achieve SQS and PRGs for RAOs 2 through 4 within AOPC 1 within 20 years (applicable to Alternatives 2R, 2R-CAD, 3R, and 3C). MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance, and recovery categories are likely to change based on additional information during monitoring.

AOPC = area of potential concern; C = combined technology; CAD = contained aquatic disposal; ENR = enhanced natural recovery; *in situ* = *in situ* treatment; MNR = monitored natural recovery; PRG = preliminary remediation goal; R = removal emphasis; RAO = remedial action objective; SQS = sediment quality standard

Table 8-5 Technology Assignments for Remedial Alternatives

Alternative 2: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b]		
		1	**2**	**3**
		Dredge/Cap Viable	**ENR/*in situ* Viable**	**MNR Viable**
>Alt 2 Upper RALs	AOPC 1	Dredge		
>Alt 2 Lower RALs		Dredge[d]	Dredge[d]	MNR(10)[e]
>Alt 3 RALs		MNR(20)[f]		
>Alt 4 RALs				
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 2: Removal with CAD

RALs[c]	Footprint	Recovery Category[a,b]		
		1	**2**	**3**
		Dredge/Cap Viable	**ENR/*in situ* Viable**	**MNR Viable**
>Alt 2 Higher RALs	AOPC 1	Dredge		
>Alt 2 Lower RALs		Dredge[d]	Dredge[d]	MNR(10)[e]
>Alt 3 RALs		MNR(20)[f]		
>Alt 4 RALs				
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 3: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b]		
		1	**2**	**3**
		Dredge/Cap Viable	**ENR/*in situ* Viable**	**MNR Viable**
>Alt 2 RALs	AOPC 1	Dredge		
>ENR UL				
>Alt 3 RALs				
>Alt 4 RALs		MNR(20)[f]		
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 3: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b]		
		1	**2**	**3**
		Dredge/Cap Viable	**ENR/*in situ* Viable**	**MNR Viable**
>Alt 2 RALs	AOPC 1	Cap/Dredge		
>ENR UL				
>Alt 3 RALs		Cap/Dredge	ENR/ *in situ*	
>Alt 4 RALs		MNR(20)[f]		
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Table 8-5 Conceptual Technology Assignments for Remedial Alternatives (continued)

Alternative 4: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR/*in situ* Viable	3 MNR Viable
>Alt 2 RALs	AOPC 1	Dredge		
>Alt 3 RALs				
>ENR UL				
>Alt 4 Higher RALs				
>Alt 4 Lower RALs		Dredge[d]		MNR(10)[e]
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 4: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR/*in situ* Viable	3 MNR Viable
>Alt 2 RALs	AOPC 1	Cap/Dredge		
> Alt 3 RALs				
>ENR UL				
>Alt 4 Higher RALs		Cap/Dredge[d]	ENR/ *in situ*	
>Alt 4 Lower RALs			ENR/ *in situ* [d]	MNR(10)[e]
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 5: Removal and Alternative 5-Removal with Treatment Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR/*in situ* Viable	3 MNR Viable
>Alt 2 RALs	AOPC 1	Dredge		
>Alt 3 RALs				
> ENR UL				
>Alt 4 RALs				
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Alternative 5: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1 Dredge/Cap Viable	2 ENR/*in situ* Viable	3 MNR Viable
>Alt 2 RALs	AOPC 1	Cap/Dredge		
>Alt 3 RALs				
>ENR UL				
>Alt 4 RALs		Cap/Dredge	ENR/ *in situ*	
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2	Institutional controls, site-wide monitoring, & natural recovery[g]		
n/a	Rest of LDW			

Table 8-5 Conceptual Technology Assignments for Remedial Alternatives (continued)

Alternative 6: Removal Emphasis

RALs[c]	Footprint	Recovery Category[a,b] 1: Dredge/Cap Viable	2: ENR/*in situ* Viable	3: MNR Viable
>Alt 2 RALs	AOPC 1	Dredge		
>Alt 3 RALs				
>Alt 4 RALs				
>ENR UL				
>Alt 5 RALs				
>Alt 6 RALs	AOPC 2			
n/a	Rest of LDW	Institutional controls, site-wide monitoring, & natural recovery[g]		

Alternative 6: Combined Technology

RALs[c]	Footprint	Recovery Category[a,b] 1: Dredge/Cap Viable	2: ENR/*in situ* Viable	3: MNR Viable
>Alt 2 RALs	AOPC 1	Cap/Dredge		
>Alt 3 RALs				
>Alt 4 RALs				
>ENR UL				
>Alt 5 RALs		Cap/Dredge	ENR/ *in situ*	
>Alt 6 RALs	AOPC 2			
n/a	Rest of LDW	Institutional controls, site-wide monitoring, & natural recovery[g]		

Notes:

a. Based on new data collected during remedial design, the technology assignments made during remedial design may differ from those assumed in the FS. See Section 6 for a description of recovery categories.

b. The tables provide a conceptual schematic of the remedial alternatives. Additional details are used to make location-specific technology assignments. For example, removal alternatives include partial dredge and cap in difficult-to-access areas such as overwater structures. The alternative-specific maps (Figures 8-6 through 8-17) illustrate these details.

c. RALs in red font show all concentrations above which active remediation occurs. Alternative 2 and 4 RALs for Recovery Category 3 areas are predicted by the BCM to achieve the stated CSL or SQS within the specified recovery time frame (see Table 8-1).

d. Active remediation to the lower RALs to achieve the target concentrations within 10 years following construction in areas not predicted to recover naturally (Recovery Categories 1 and 2).

e. MNR(10) is monitoring to achieve target concentrations within 10 years following construction (applicable to Alternatives 2 and 4).

f. MNR(20) is monitoring to achieve the SQS within 20 years after construction (applicable to Alternatives 2R, 2R-CAD, 3R, and 3C). MNR(20) is applicable in all recovery categories because these areas are adaptively managed for long-term compliance, and recovery categories may change based on additional information during remedial design and monitoring.

g. Also includes natural recovery processes that are predicted to improve surface sediment quality over time and eventually reach long-term model-predicted concentrations site-wide.

AOPC = area of potential concern; BCM = bed composition model; CAD = contained aquatic disposal; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; n/a = not applicable; RAL = remedial action level; SQS = sediment quality standard; UL = upper limit

Table 8-6 Summary of Seismic Design Parameters and Analyses from Previous Reports and Remedial Designs

Study and Site	Analysis Type	Analysis Parameters	Note	Result
Sediment Sites Downstream of the LDW / Near Elliott Bay				
Tetra Tech 2011. *Appendix H to the Lockheed West Feasibility Study*	Liquefaction potential	108-year, PGA of 0.176g	a,b	Liquefaction predicted in top 20 ft below ground surface; lower bound FOS 0.4-0.72 across alternatives
		475-year, PGA of 0.378g		As above; lower bound FOS 0.18-0.24 across alternatives
		2,475-year, PGA of 0.754g		As above; lower bound FOS 0.08-0.16 across alternatives
	Lateral spreading	108-year, PGA of 0.176g		Lower/Upper bounds of spreading: 0.62-5.08 ft
		475-year, PGA of 0.378g		Lower/Upper bounds of spreading: 1.79-8.41 ft
		2,475-year, PGA of 0.754g		Lower/Upper bounds of spreading: 4.16-8.5 ft
	Slope stability following liquefaction	Evaluated several profiles through capped and ENR areas, using one-half of above PGAs for evaluation)		FOS > 1 in 108-year event, but < 1 in 475-year and 2,475-year events; in the two latter cases, a flow slide is predicted
Enviros 1990. *Lockheed Shipyard No. 2 Sediment Characterization and Geotechnical Study*	Liquefaction potential	M7.5, PGA 0.32g	a	Liquefaction expected. Report recommended vibro-emplaced rock columns to stabilize berm for Port development
Hart Crowser 1995. *Geotechnical Engineering Design Study for Southwest Harbor Project Terminal 5 Expansion*	Liquefaction potential	M6.5, PGA 0.15g or 0.17g	a	Liquefaction expected 10-40 ft bgs
		M7.5, PGA 0.27		Liquefaction to > 50 ft bgs
	Seismic slope stability	M6.5, PGA 0.1 (Olympia 1949 event)	a	FOS > 1 - 1 ft lateral displacement
		M7.5, PGA 0.12		FOS < 1 - flow slide predicted
Hart Crowser 2003. *Final 100% Remedial Design Submittal. Sediment Remediation. Lockheed Shipyard No. 1, Sediment Operable Unit, Seattle WA, Attachment B-1.*	Liquefaction potential	475-year, PGA of 0.32g	a	Predicted lateral spreading of 1 to 5 ft
		2,475-year, PGA of 0.5g		Predicted lateral spreading of 0.15 ft
	Seismic slope stability	475-year, PGA of 0.16g		FOS ranged from 0.89-1.49
URS 2003. *Final Design for the Pacific Sound Resources Superfund Site Marine Operable Unit.* Prepared for U.S. Environmental Protection Agency Region 10.	Liquefaction potential	100-year, M6.8, PGA of 0.13g	a	Liquefaction expected on subtidal slopes of 4.5H:1V to 2H:1V to depth of 30-50 ft bgs
	Seismic slope stability	100-year, M6.8, PGA of 0.065		FOS: 0.78-1.30; noted that no liquefaction was observed following Nisqually quake, but that prior large, submarine landslides had occurred in the area
McCabe, WM. 2004. *Seismic Stability of a Sloping Cap.* Proceedings of Ports 2004, Port Development in the Changing World, American Society of Civil Engineers	Liquefaction potential	M6.8, PGA of 0.22g (Nisqually 2001 earthquake)	a	Stated liquefaction expected in the URS design (cited above) was not observed following Nisqually earthquake, and ascribed this to a higher percentage of low plasticity fines than used in design
Palmer et al., 2004. *Liquefaction Susceptibility and Site Class Maps of Washington State by County.* Washington Division of Geology and Earth Resources, Washington State Department of Natural Resources.	Liquefaction susceptibility	M7.3, PGA of 0.15g and 0.3g	a	Class E soils in LDW and deeper bedrock magnify effects; liquefaction expected in area of LDW
Sediment Sites within the LDW				
AMEC Geomatrix, Dalton, Olmstead and Fugelvand, and Floyd|Snider 2011. *Geotechnical Engineering Report, Duwamish Sediment Other Area and Southwest Bank Corrective Measure and Habitat Project, Boeing Plant 2, Seattle/Tukwila Washington* (Appendix E in 90% Design Report).	Liquefaction potential	100-year, M6.0, PGA of 0.32g	b	Liquefaction not expected due to shallow depth of soil subject to this
		475-year, M7.5, PGA of 0.367g		Liquefaction expected near base of riverward slope in zone of soil 5-10 ft thick; upland subsidence of 1-2 inches; liquefaction not expected in offshore dredge/fill area following construction
	Lateral spreading	100-year, M6.0, PGA of 0.32g	b	Little or no lateral spreading predicted due in part to presence of densification of slope with pilings
		475-year, M7.5, PGA of 0.367g		Little or no lateral spreading predicted due in part to presence of densification of slope with pilings; text mentions 1 ft lateral spread 200 ft from shoreline
	Slope stability following liquefaction	100-year, M6.0, PGA of 0.32g	b	For slopes of 4H:1V and 3H:1V, FOS greater than USACE-recommended FOS throughout site; lateral deflection of < 1 in; no slope failure predicted
		475-year, M7.5, PGA of 0.367g		For slopes of 4H:1V and 3H:1V, acceptable FOS greater than 1.2 throughout site; lateral deflection of ≤ 1.7 in; no slope failure predicted

Notes:

a. Table format and information adapted from Appendix H of the *Lockheed West Feasibility Study* (Tetra Tech 2011).

b. Minimum FOS are from USACE 2000, *Design and Construction of Levees*. They include: End of Construction (1.3), Long-term or Steady Seepage (1.4), Rapid Drawdown (1.0-1.2). As noted in AMEC et al. (2011), a USACE Engineering Manual is currently in preparation to address seismic evaluations.

bgs = below ground surface; FOS = factor of safety (factors of safety of <1 are generally considered hazards for ground movement; however, see note b above for additional post-construction context); ft = feet; H:V = horizontal:vertical; g = acceleration of gravity (980 centimeters/second); in = inches; LDW = Lower Duwamish Waterway; M = magnitude; PGA = peak ground acceleration (gravities); USACE = U.S. Army Corps of Engineers

Table 8-7 Area-specific Construction Assumptions for the FS Summarized from Appendix I

Elevation or Geographic Limits[a]	Applicable Active Remedial Technologies[b]	Volume Estimating Assumptions and Construction Assumptions
Native or Eroding Banks; MHHW to -2 ft MLLW	Excavate using land-based or barge-mounted excavator, cap, ENR/*in situ*	For cost estimating, excavation, capping, and ENR/*in situ* are performed by barge-mounted precision excavator. Excavation is performed to a stable slope vertically to the depth of contamination above the SQS. Excavation areas are restored to original grade with sand and habitat substrate.[c] Capping areas are assumed to be partially dredged to 3 ft below mudline and capped to grade with sand habitat substrate. ENR/*in situ* areas are assumed to be covered with 9 inches of sand or amended sand to achieve a 6-in ENR/*in situ* layer , and habitat substrate without partial removal. During design, additional engineering considerations in native or eroding bank areas could include the use of land-based excavation and placement applied with a 25-ft maximum lateral reach from top of bank,[d] the use of thicker or thinner caps or the use of capping materials other than sand, and additional considerations to account for bank stability.
Engineered Banks; MHHW to -2 ft MLLW	Excavate using barge-mounted excavator, cap, ENR/*in situ*	For cost estimating purposes, engineered banks are assumed to have the same removal, backfill, capping, and ENR/*in situ* volume assumptions as native or eroding banks (see above). Additional engineering considerations for engineered banks are incorporated into the cost estimate as a 10% contingency for areas with additional engineering challenges. During design, additional considerations will be necessary for engineered banks that will ensure the structural integrity of the bank. Engineered surface (e.g., riprap or bulkhead) will remain during removal; partial removal with capping may be necessary. Removal adjacent to vertical sheet pile may not be feasible because of geotechnical stability; partial removal with capping may be necessary. Land-based excavation and placement may be applicable with a 25-ft maximum lateral reach from top of bank.[c]
Under Piers and Overwater Structures	Partial dredge using diver-assisted hydraulic dredge, cap	For cost estimating purposes, partial dredging and capping is assigned in the active remedial footprint for the removal-emphasis alternatives and capping is assigned in the active remedial footprint for the combined technology alternatives. Removal is assumed to be 1 ft and capping is assumed to be 3 ft after partial removal. Removal is assumed to occur at a much lower rate and by different methods than open water dredging (such as diver-assisted dredging), and capping is assumed to occur by casting material laterally under the structure. The remediation of under-pier areas is assumed to occur concurrently with open water remediation. During design, many additional engineering considerations will need to be addressed, including the use of specialized equipment for dredging or capping, partial demolition and replacement of structures, slope stability improvements, casting of cap material, structural or utility work, and additional logistical and access constraints, such as temporary relocation of moorage/marina facilities. Caps thinner than 3 ft and use of ENR/*in situ* may also be considered during design.
-2 ft MLLW to -10 ft MLLW	Dredge or partial dredge and cap, ENR/*in situ*	For cost estimating purposes, habitat areas are assumed to be shallower than -10 ft MLLW. Removal and placement would occur via barge-mounted precision excavator. Habitat would be maintained by conserving bathymetric elevation, and appropriate habitat substrate would be used. During design, additional options for improving habitat may be considered.

Table 8-7 Area-specific Construction Assumptions for the FS Summarized from Appendix I (continued)

Elevation or Geographic Limits[a]	Applicable Active Remedial Technologies[b]	Volume Estimating Assumptions and Construction Assumptions
Deeper than -10 ft MLLW	Dredge or partial dredge and cap, cap, ENR/*in situ*	For cost estimating purposes, removal and placement are performed via barge-mounted precision excavator. Capping requires armoring in high-flow event scour or vessel scour areas. For the FS, the cost for armoring is assumed to be the same as a full sand cap. Active remediation adjacent to the navigation channel is assumed to account for USACE maintenance dredge tolerance and sloping from the navigation channel. During design, additional considerations include the use of capping materials other than sand, and additional elevation considerations in the navigation channel or berthing areas.
Additional site-wide assumptions	Removal	For cost estimating purposes, 9 inches of sand is assumed to achieve a 6-in thin sand layer in all dredge areas to manage residuals. For the base case, the dredge-cut prism volume equals the neat-line volume to remove sediment >SQS, plus 50% volume to account for overdredge, side slopes, box cuts (i.e., design of constructible dredge prisms), and additional characterization, and more removal in intertidal areas. For Alternative 6, the dredge-cut prism volume equals the neat-line volume >SQS plus 34% to account for the lower RAL for Alternative 6 (plus the additional 50% to arrive at the dredge-cut volume). Production rate assumed to be 1,600 tons/day (1,000 cy/day). Debris removal is factored into FS costing by assuming a reduced dredging rate for 10% of dredging areas, and is incorporated into the production rate. Debris removal includes side-scan survey and debris disposal at a construction debris landfill. See Appendix I for cost details.
	Capping/ENR/*in situ*	For cost estimating purposes, 3.5 ft of capping material is assumed to achieve a goal of a minimum 3-ft cap, and 9 inches of sand is assumed to achieve a 6-in ENR layer. Additional material (10%) is assumed to be necessary to account for material required in steep slope areas (>20 degree slopes) to address slope stability. Debris sweep is assumed for all capping and ENR/*in situ* areas on a cost-per-acres basis. Cap and ENR/*in situ* maintenance is included on a cost-per-acre basis. See Appendix I for cost details.

Notes:

a. FS assumed intertidal and habitat range extends from -10 ft MLLW to the approximate MHHW elevation. -2 ft MLLW is the approximate lowest elevation considered to be practical for excavation using land-based equipment.

b. The process options listed in this table are primary options with site-wide applicability. Other options discussed in Section 7 may also be appropriate, as determined on a location-specific basis at the time of remedial design.

c. Backfill and restoration to original grade are assumed for all removal actions between MHHW and -10 ft MLLW. ENR/*in situ* does not require restoration to original grade.

d. Longer reaches than 25 ft are possible but bucket size diminishes with longer reach equipment. Also, some areas may be sufficiently accessible by water for nearshore removal operations.

cy = cubic yards; ENR = enhanced natural recovery; FS = feasibility study; ft = foot: MHHW = mean higher high water; MLLW = mean lower low water; RAL = remedial action level; SQS = sediment quality standard; USACE = U.S. Army Corps of Engineers

Table 8-8 Assumptions for Dredge Production Rate Estimates Summarized from Appendix I

Parameter	Derrick Barge/Clamshell (Deep Water)	Barge-mounted Precision Excavator (Deep Water)	Barge-mounted Precision Excavator (Shallow Water)
24 Hours/Day, 6 Days/Week			
Cycle Time (min)	3.5	3	2.5
Bucket Capacity (cy)	6	5	3
Effective Bucket Capacity (at 55%; cy)[a]	3.3	2.8	1.7
Operating Day (hours/day)	24	24	24
Weekly Operating Days (days/week)	6	6	6
Operating Efficiency (%)[b]	60%	60%	60%
Daily Average Dredge Production (cy/day)	820	790	570
Daily Average Dredge Production (tons/day)[c]	1,200	1,200	830
12 Hours/Day, 5 Days/Week			
Cycle Time (min)	3.5	3	2.5
Bucket Capacity (cy)	6	5	3
Effective Bucket Capacity (at 55%; cy)[a]	3.3	2.8	1.7
Operating Day (hours/day)	12	12	12
Weekly Operating Days (days/week)	5	5	5
Operating Efficiency (%)[b]	60%	60%	60%
Daily Average Dredge Production (cy/day)	400	390	280
Daily Average Dredge Production (tons/day)[c]	590	580	420

Notes:

1. Both 24 hours/day and 12 hours/day dredge operations were assumed to accommodate a range of project sizes, duration, complexity, and tribal and community concerns (e.g., noise, lights).
2. Values in table are rounded for presentation. Unrounded values used in the cost estimate are presented in Appendix I, Table I-5.

a. USACE 2008d. *Technical Guidelines for Environmental Dredging of Contaminated Sediments*. ERDC/EL TR-08-29.
b. *ibid*. Operating efficiency includes allowance for non-production activities such as equipment maintenance/repair, water quality management, navigation systems, agency inspections, waiting for test results, moving dredges/barges, traffic, standby for navigation, and refueling.
c. Assumes average sediment bulk density of 1.5 tons/cy. See Table 8-9 for the blended average production rate estimates used in this FS.

cy = cubic yards; FS = feasibility study; min = minutes; USACE = U.S. Army Corps of Engineers

Table 8-9 Recommended Open Water Dredge/Excavation Scenario and Net Annual Production Rate Estimate

Item	Value(s)	Notes
No. of dredges/excavators operating simultaneously	2	One open water dredge/precision excavator and one shallow-water excavator
Dredge operating regimes	50% of construction weeks @ 24 hours/day, 6 days/week 50% of construction weeks @ 12 hours/day, 5 days/week	Operations during the construction window average an equal split between 24 hours/day, 6 days/week and 12 hours/day, 5 days/week equipment operations. Both operating regimes are typical for projects in the Puget Sound region and depend on project size, duration, complexity, and tribal and community concerns (e.g., noise, light).
In-water construction window	Oct. 1 to Feb. 15	USACE Seattle District
Total number of calendar days in construction window	138	
Holidays (days)	5	Thanksgiving (2 days), Christmas (2 days), and New Year's Day
Other dredging downtime (days)	15	Accounts for dredging downtime or slowed production to accommodate debris sweep, ancillary construction (e.g., piling/dolphin, bulkhead, pier/dock related work), tribal fishing delays, weather and water quality related delays, and a dredging-free period near the end of the construction window for finishing residuals management, ENR/*in situ*, and capping.
Net dredging days per season (days)	49 @ 24 hours/day; 39 @ 12 hours/day	Total net dredging days split between 24 hours/day, 6 days/week and 12 hours/day, 5 days/week operations
Net annual production rate (tons/year)	140,000	Equates to approximately 1,600 tons/day average blended dredge production rate over the 88 net days of dredging (equates to approximately 92,000 cy/year). See Appendix I for cost estimating details.

Notes:

See Appendix I for cost estimating details.

cy = cubic yards; ENR = enhanced natural recovery; USACE = U.S. Army Corps of Engineers

Table 8-10 Comparison of Monitoring Criteria and Terminologies Used for Sediment Sites

Monitoring Objective	Type of Monitoring Included in FS The selected monitoring type is based, in part, on EPA contaminated sediment remediation guidance for hazardous wastes sites (EPA 2005b) and EPA guidance for monitoring at hazardous waste sites: framework for monitoring plan development and implementation (EPA 2004)	Type of MTCA Compliance Monitoring "…shall be required until residual hazardous substances concentrations no longer exceed site cleanup levels established under WAC 173-340 through 173-340-760" [173-340-410][a]
Establish baseline conditions for future compliance monitoring	Baseline monitoring	n/a
Refine the nature and extent of contaminated areas after the FS; confirm recovery processes	Remedial design sampling and verification monitoring[b]	n/a
Protect human health and the environment during construction	Construction monitoring (short-term monitoring during construction)	Protection monitoring
Verify that remedial action levels or remediation levels have been achieved before demobilizing from the site	Post-construction performance monitoring	Performance monitoring
Confirm that natural recovery processes are occurring as predicted to achieve cleanup goals	O&M monitoring	Performance monitoring
Monitor the stability of a cap or ENR/*in situ* area to ensure isolation and containment	O&M monitoring	Confirmational monitoring
Monitor surface sediments over time for potential recontamination	Long-term monitoring	Confirmational monitoring
Monitor tissues over time to evaluate risk reduction	Long-term monitoring	Confirmational monitoring
Determine how ongoing sources at or near a site may affect the success of active cleanup and/or natural recovery	Source control evaluation – in parallel to baseline, remedial design, and long-term monitoring. Not part of the CERCLA remedy.	Source control monitoring (not a component of compliance monitoring)

Notes:

a. Demonstrating the ability to meet cleanup standards involves the point of compliance, how long it takes to meet cleanup levels (restoration time frame), and monitoring to ensure that cleanup standards have been met and will continue to be met in the future [WAC 173-340-700]

b. These are not identified as separate costs but are included in the general scope of remedial design costs, which are 20% of the total project cost.

(Shaded) Included in FS cost estimates for monitoring in Appendix I. Remedial design and verification sampling included in the capital costs of each alternative.

CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; ENR = enhanced natural recovery; EPA = U.S. Environmental Protection Agency; FS = feasibility study; MTCA = Model Toxics Control Act; O&M = operation & maintenance; WAC = Washington Administrative Code

Table 8-11 Remedial Alternative Areas and Volumes

	Remedial Alternative Technology and Areas																	Cost ($MM Net Present Value)		
Site-wide Remedial Alternative	EAAs (acres)	Dredge (acres)	Partial Dredge and Cap (acres)	Cap (acres)	ENR/ *in situ* (acres)	MNR(10)[a] (acres)	MNR(20)[b] (acres)	VM (acres)	Institutional Controls, Site-wide Monitoring, & Natural Recovery (AOPC 2) (acres)	Site-wide Monitoring, & Natural Recovery (Rest of LDW) (acres)	Total Active (acres)	Total Study Area (acres)	Dredge-cut Prism Volume (cy)[c]	Performance contingency Volume (cy)[d]	Total Dredge Volume (cy)[e]	Total Placement Volume (Capping, ENR/*in situ*, Dredge Residuals, Habitat) (cy)	Construction Time Frame (years)[f]	Low Sensitivity[g]	Best Estimate[g]	High Sensitivity[g]
1 No Further Action (EAAs)	29	0	0	0	0	0	0	0	0	412	0	441	n/a	n/a	n/a	n/a	n/a	n/a	$9[h]	n/a
2 Removal	29	29	3	0	0	19	106	23	122	110	32	441	370,000	210,000	580,000	120,000	4	$140	$220	$260
2 Removal with CAD[i]	29	29	3	0	0	19	106	23	122	110	32	441	370,000	210,000	580,000	200,000	4	$120	$200	$250
3 Removal	29	50	8	0	0	0	99	23	122	110	58	441	590,000	180,000	760,000	260,000	6	$200	$270	$340
3 Combined Technology	29	29	8	11	10	0	99	23	122	110	58	441	300,000	190,000	490,000	270,000	3	$140	$200	$270
4 Removal	29	93	14	0	0	50	0	23	122	110	107	441	1,000,000	110,000	1,200,000	430,000	11	$320	$360	$450
4 Combined Technology	29	50	18	23	16	50	0	23	122	110	107	441	560,000	130,000	690,000	470,000	6	$210	$260	$320
5 Removal[j]	29	143	14	0	0	0	0	23	122	110	157	441	1,600,000	34,000	1,600,000	590,000	17	$410	$470	$570
5 Removal with Treatment[j]	29	143	14	0	0	0	0	23	122	110	157	441	1,600,000	34,000	1,600,000	590,000	17	$440	$510	$670
5 Combined Technology	29	57	23	24	53	0	0	23	122	110	157	441	640,000	110,000	750,000	580,000	7	$240	$290	$360
6 Removal	29	274	28	0	0	0	0	0	0	110	302	441	3,900,000	0	3,900,000	1,200,000	42	$730	$810	$850
6 Combined Technology	29	108	42	51	101	0	0	0	0	110	302	441	1,500,000	150,000	1,600,000	1,100,000	16	$450	$530	$580

Notes:

1. Areas are rounded to the nearest acre as shown. Volumes in this table are rounded to two significant figures. Volumes are calculated in a spreadsheet prior to rounding; therefore, hand-calculated values may differ slightly from those shown. Acres and volumes shown for Alternatives 2 through 6 do not include the EAAs.

a. MNR(10) is monitoring designed to achieve the 10-year post-construction target concentrations within 10 years (applicable to Alternatives 2 and 4).

b. MNR(20) is monitoring to achieve SQS within 20 years after construction is complete (applicable to Alternatives 2R, 2R-CAD, 3R, and 3C).

c. The dredge-cut prism volume estimate is the neat-line volume to the maximum depth of SQS plus an additional 50% for Alternatives 2 through 5 to account for overdredging, additional sediment characterization, cleanup passes for residuals management, and additional volumes for constructability (e.g., stable side slopes). For Alternative 6, 34% was first added to the depth of SQS to account for the lower RALs, an additional 50% volume was added for construction factors. These volumes are used to calculate the construction time frame.

d. Performance contingency volumes account for changes in technology assignment and performance-based contingency assumptions (e.g., 15% of ENR/*in situ*, MNR, and verification monitoring areas are assumed to require dredging based on long-term monitoring results). These volumes were used to calculate total costs.

e. Total dredge volume equals dredge-cut prism volume plus the performance contingency volume. Rounded values are shown in the table. Cost calculations are performed on unrounded values.

f. Construction time frame estimated based on open water dredge-cut prism volumes.

g. Net present value costs are calculated assuming a discount rate of 2.3% on both capital and monitoring costs starting at the beginning of construction. Best estimate cost assumptions are considered accurate to +50% and -30%. See Appendix I for cost estimate assumptions.

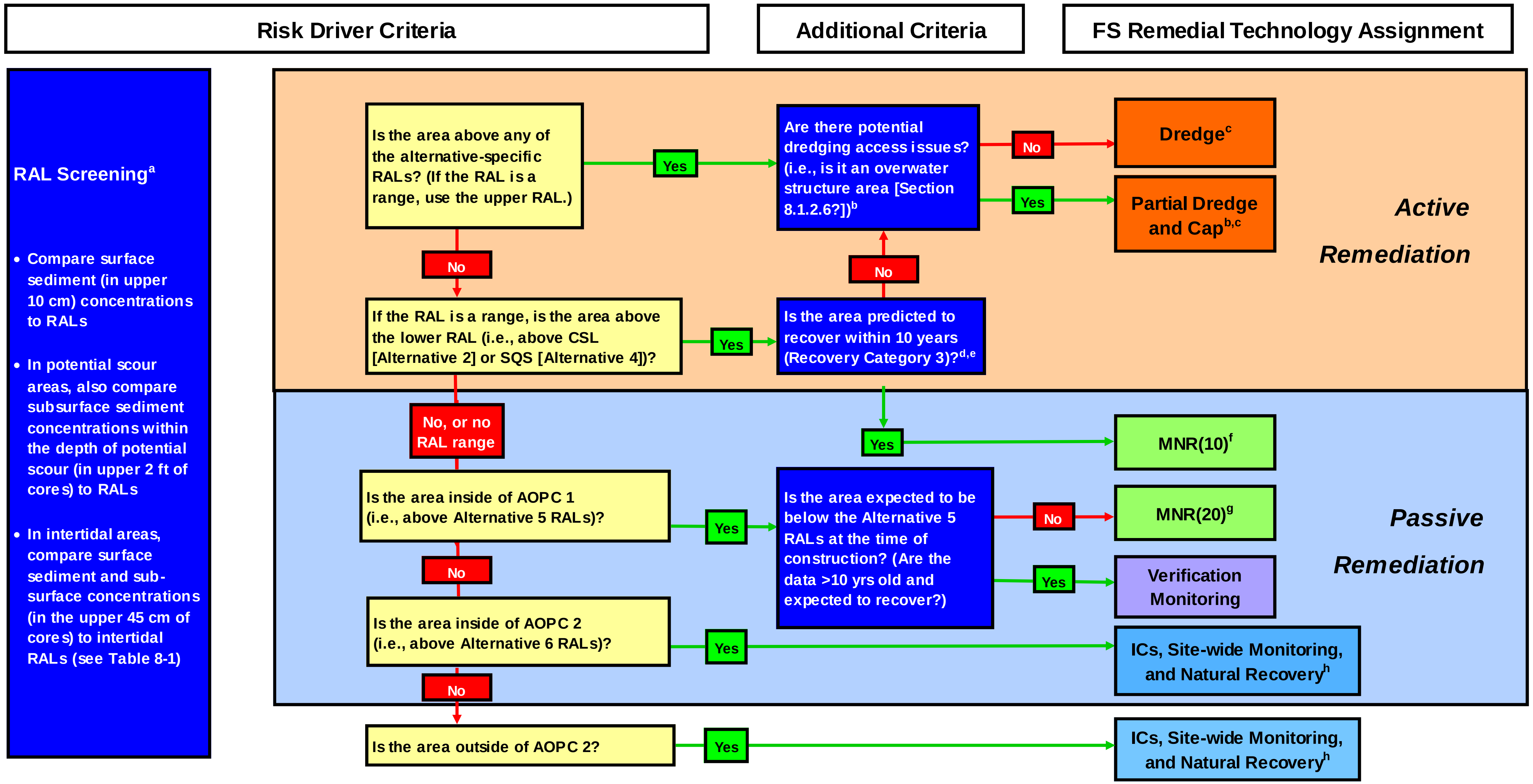
h. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting and do not include operation and maintenance. The capital costs of cleanup actions in the EAAs are estimated at approximately $95 million.

i The removal with CAD alternative has the same areas/dredge volumes as the removal with upland disposal alternative. This alternative also has 23 acres of engineered caps (the CAD areas) that are not shown as active remediation within the footprint on this table, but which are accounted for in the cost and placement volumes.

j. The removal with upland disposal alternative has same the areas/dredge volumes as the removal with treatment alternative.

AOPC = area of potential concern; C = combined technology; CAD = contained aquatic disposal; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MM = million; MNR = monitored natural recovery; n/a = not applicable; R = removal emphasis; RAL= remediation action level; SQS = sediment quality standard; VM = verification monitoring

Figure 8-1 Flow Chart for Technology Assignments for Removal-Emphasis Alternatives (Alternatives 2R, 2R-CAD, 3R, 4R, 5R, 5R-T, 6R)



Notes:

Technology assumptions are only for the FS and may change during remedial design. Some areas of the LDW (outside AOPCs) do not require remediation but are still subject to ICs and site-wide monitoring.

a. See Section 8.1.1 for additional details. See Table 8-1 for the array of RALs for each alternative. All RAL screening bullets apply to all yellow boxes.

b. Under-pier areas are assigned partial dredging and capping for the R alternatives for cost estimating purposes; however, these areas have engineering challenges that require location-specific analysis. Various remedial technologies may be employed during remedial design.

c. The spatial extent of the remedial footprints is slightly modified in the FS for constructability considerations and detailed interpretation of the chemical data and trends (see Appendix D).

d. Recovery Category 1—Recovery presumed to be limited; Recovery Category 2—Recovery less certain; Recovery Category 3—Predicted to recover.

e. Recovery criteria are based on recovery categories and BCM predictions. For this analysis, "No" means Recovery Categories 1 or 2 , OR areas where the BCM does not predict recovery within 10 years following construction to concentrations below the CSL (Alternative 2) or SQS (Alternative 4). "Yes" means Recovery Category 3 AND areas where BCM predicts recovery to below the CSL or SQS within 10 years.

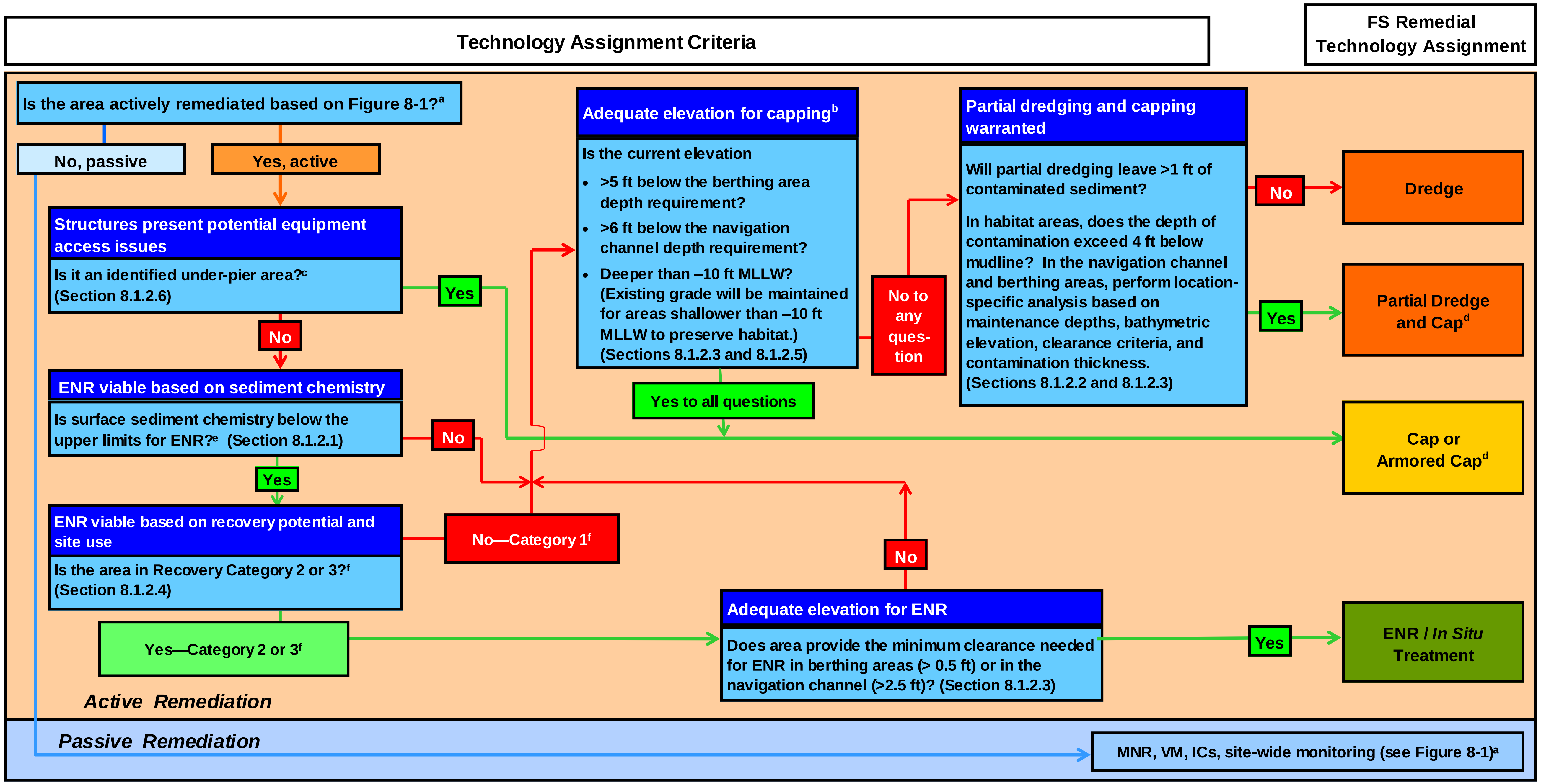
f. MNR(10) refers to monitoring to achieve alternative-specific target concentrations within 10 years following construction (i.e., the CSL for Alternatives 2R and 2R-CAD and the SQS for Alternatives 4R and 4C) .

g. MNR(20) refers to monitoring to achieve the SQS within 20 years following construction (applicable to Alternatives 2R, 2R-CAD, 3R and 3C in areas below RALs but above the SQS).

h. Natural recovery processes continue to improve surface sediment quality over time, and eventually achieve long-term model-predicted concentrations site-wide.

AOPC = area of potential concern; BCM = bed composition model; C = combined technology alternative; CAD = confined aquatic disposal; CSL = cleanup screening level; FS = feasibility study; ICs = institutional controls; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; R = removal emphasis alternative; RALs = remedial action levels; SQS = sediment quality standards; T = *ex situ* treatment alternative

Figure 8-2 Flow Chart for Technology Assignments for Combined-Technology Alternatives (Alternatives 3C, 4C, 5C, 6C)



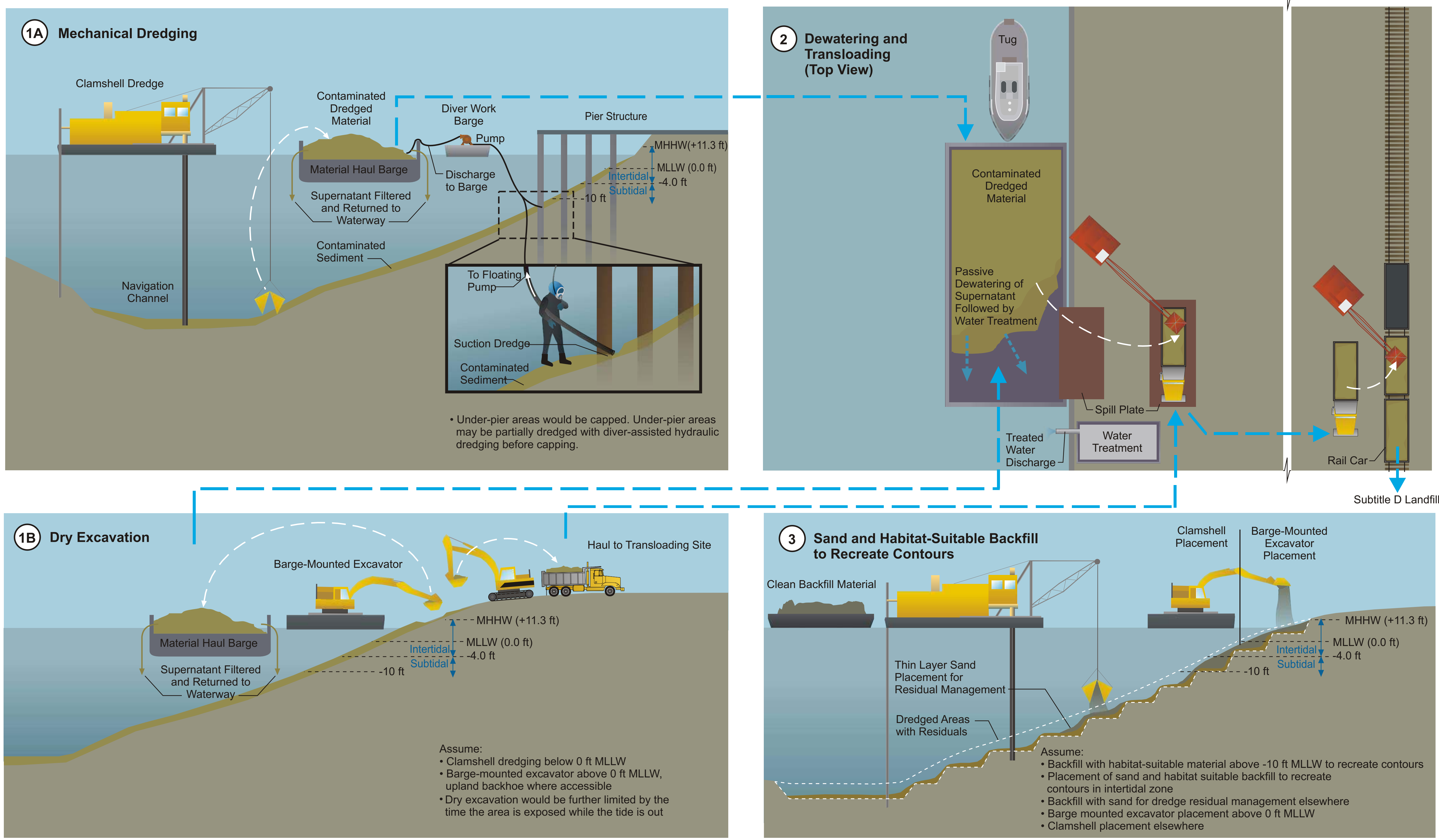
Notes:

Technology assumptions are only for the FS and may change during remedial design. Some areas of the Lower Duwamish Waterway (outside of the areas of potential concern) do not require remediation but are still subject to ICs and site-wide monitoring.

a. See Figure 8-1 for details on the RAL screening and passive remedial technologies.
b. The construction of a cap thicker or thinner than 3 ft would change the elevation requirement shown.
c. Under-pier areas are assigned capping for the R alternatives for cost estimating purposes; however, these areas have engineering challenges that require location-specific analysis. Various remedial technologies may be employed during remedial design.
d. Armor capping is assumed to be necessary in potential scour areas.
e. Upper concentration limit is 3 times the alternative-specific RALs site-wide (all RAOs) and 1.5 times the alternative-specific intertidal RALs in intertidal areas for protection from direct contact (RAO 2; for arsenic, cPAHs, and dioxins/furans). See Table 8-3 for upper concentration limits.
f. Recovery Category 1—Recovery presumed to be limited; Recovery Category 2—Recovery less certain; Recovery Category 3—Predicted to recover. For the FS, enhanced natural recovery (ENR) is assumed to be viable in Recovery Categories 2 and 3, but ENR viability may be re-evaluated during remedial design.

C = combined technology alternative; cPAH = carcinogenic polycyclic aromatic hydrocarbons; ENR = enhanced natural recovery; ft = feet; FS = feasibility study; ICs = institutional controls; MLLW = mean lower low water; MNR = monitored natural recovery; R = removal; RAL = remedial action level; RAO = remedial action objective; VM = verification monitoring

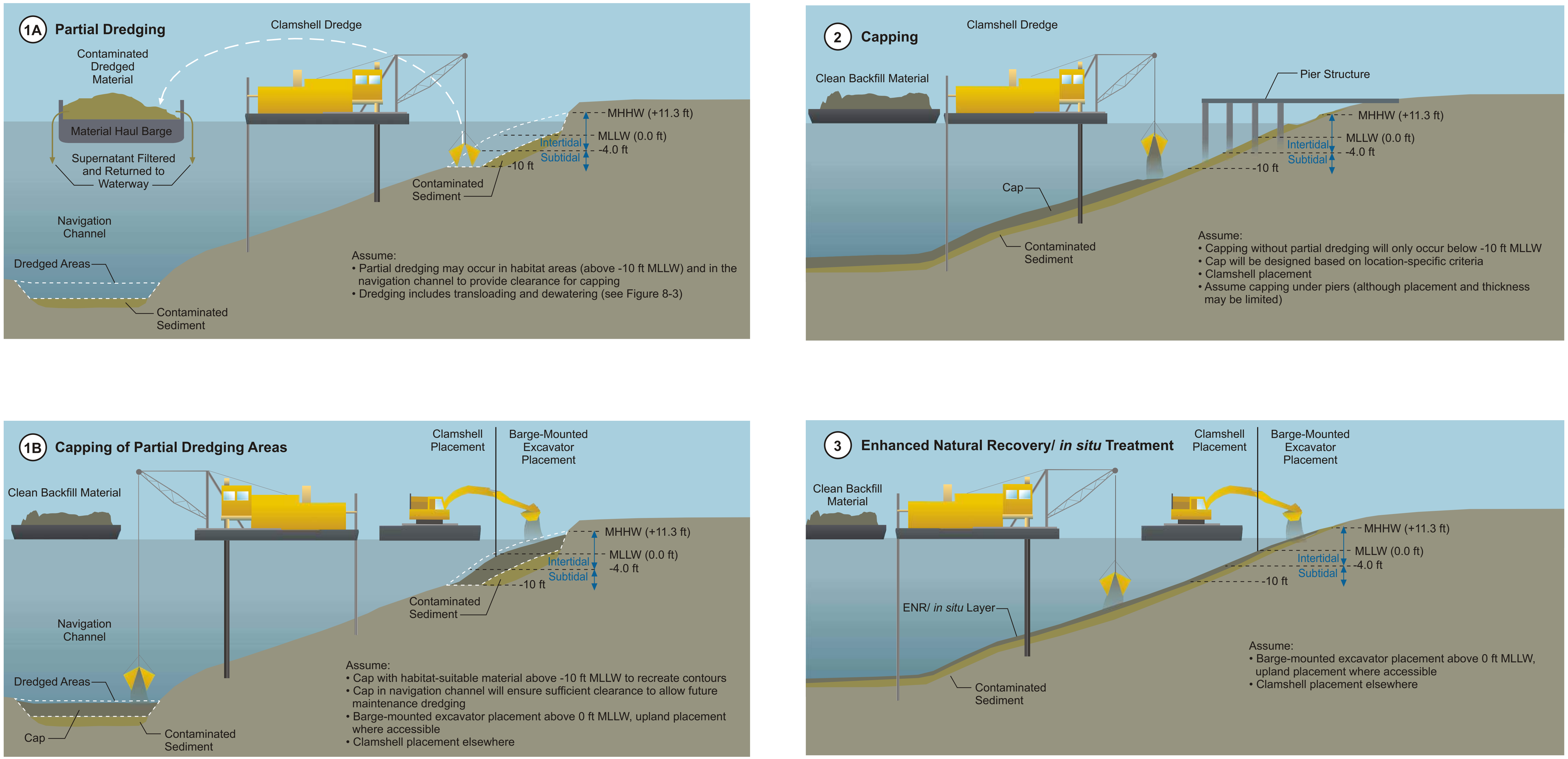
Figure 8-3 Schematic of Dredge and Partial Dredge and Cap for Removal Alternatives



Note:
1. Use of upland backhoe and excavation equipment may be possible in localized areas, but not assumed for this FS. Nearshore intertidal areas will be accessed from in-water barges.

FS = feasibility study; ft = feet; MHHW = mean higher high water; MLLW = mean lower low water

Figure 8-4 Schematic of Partial Dredge and Cap, Cap, and ENR for Combined Alternatives



Note:
1. Use of upland backhoe and excavation equipment may be possible in localized areas, but not assumed for this FS. Nearshore intertidal activities will be accessed from in-water barges.

FS = feasibility study; ft = feet; MHHW = mean higher high water; MLLW = mean lower low water

Notes:
1. Alternative 1, No Further Action, is the CERCLA baseline alternative used for comparison to other alternatives.

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Lower Duwamish Waterway Final Feasibility Study 60150279-14.41			**Alternative 1 No Further Action**
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-5**

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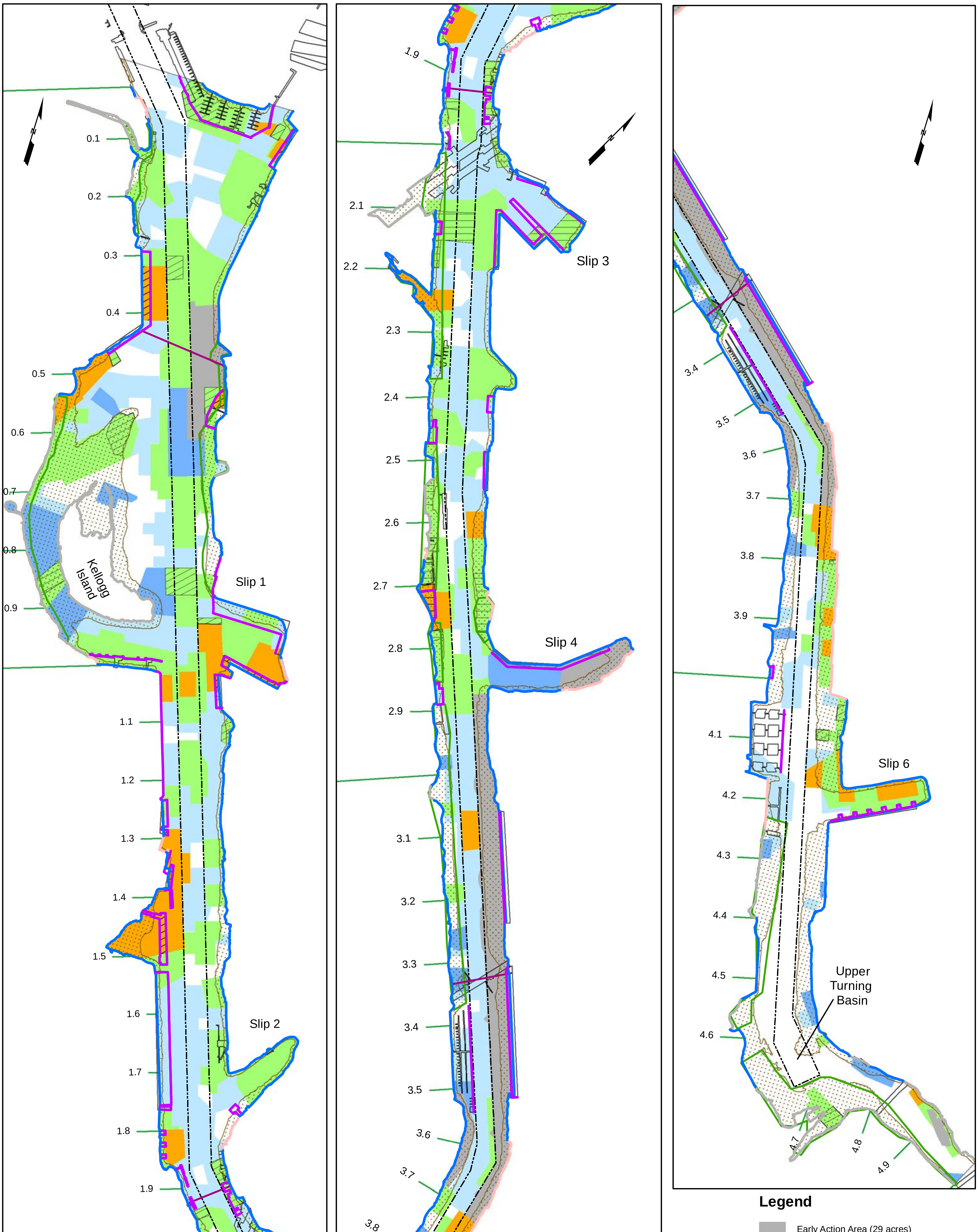

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1:
- Dredge (29 acres)
- Partial Dredge and Cap (3 acres)
- Cap (0 acres)
- ENR/*in situ* Treatment (0 acres)
- Monitored Natural Recovery (10) (19 acres)
- Monitored Natural Recovery (20) (106 acres)

- Verification Monitoring Area (23 acres)
- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

0 200 400 800 Feet

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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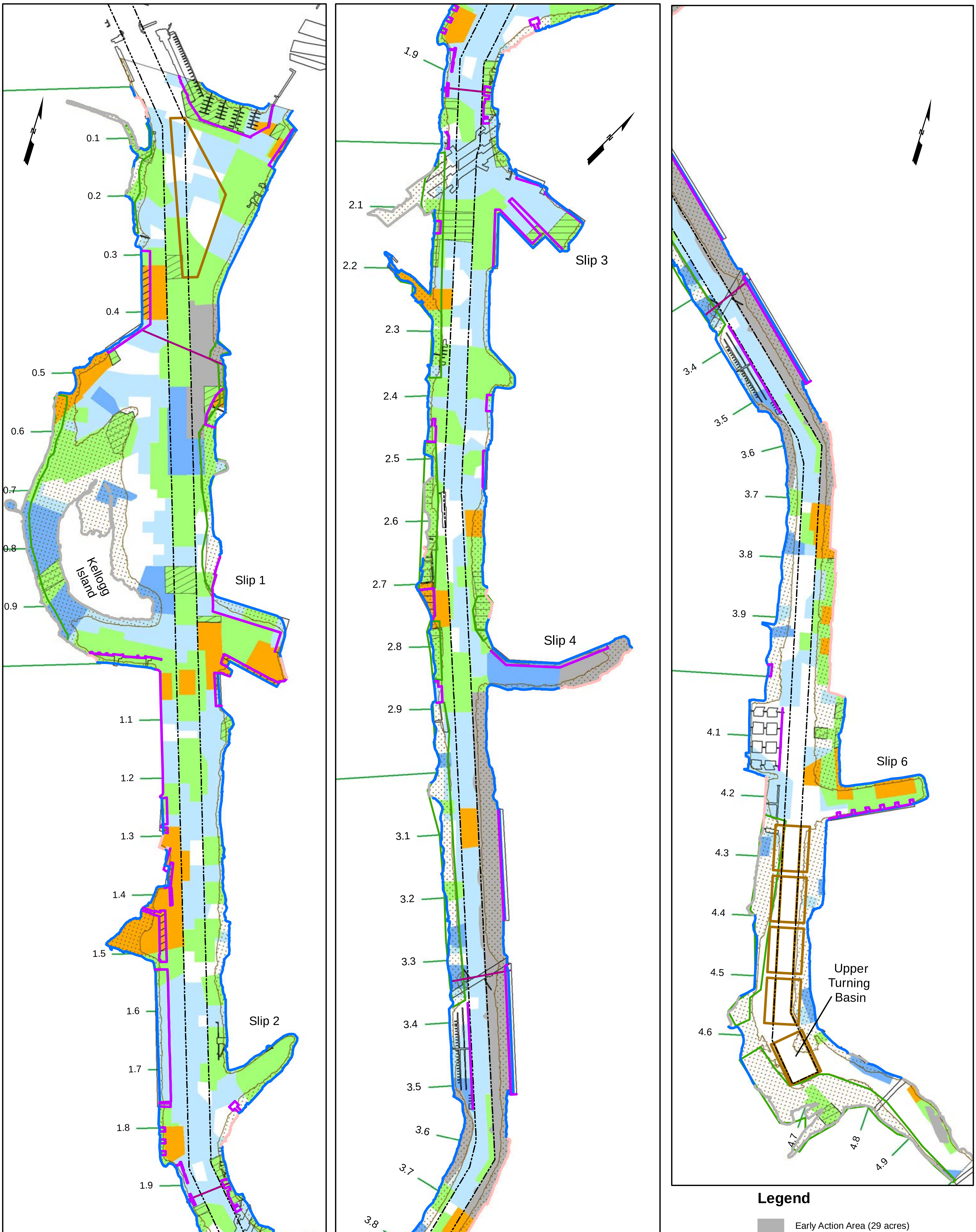
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-6**



Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW
- Contained Aquatic Disposal Area

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

Technology Assignment

- Dredge (29 acres)
- AOPC 1:
  - Partial Dredge and Cap (3 acres)
  - Cap (0 acres)
  - ENR/*in situ* Treatment (0 acres)
  - Monitored Natural Recovery (10) (19 acres)
  - Monitored Natural Recovery (20) (106 acres)
- Verification Monitoring Area (23 acres)
- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

0 200 400 800 Feet

Notes:
1. Northern CAD area is expected to hold 210,000 cubic yards of contaminated sediment. The southern CAD areas are expected to hold 100,000 cubic yards of contaminated sediment.
2. Technology assignments are for the FS and may change based on additional data.
3. AOPC 1 represents the area > Alternative 5 RALs
4. AOPC 2 represents the area > Alternative 6 RALs
5. The total FS study area is 441 acres.
6. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
7. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
8. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

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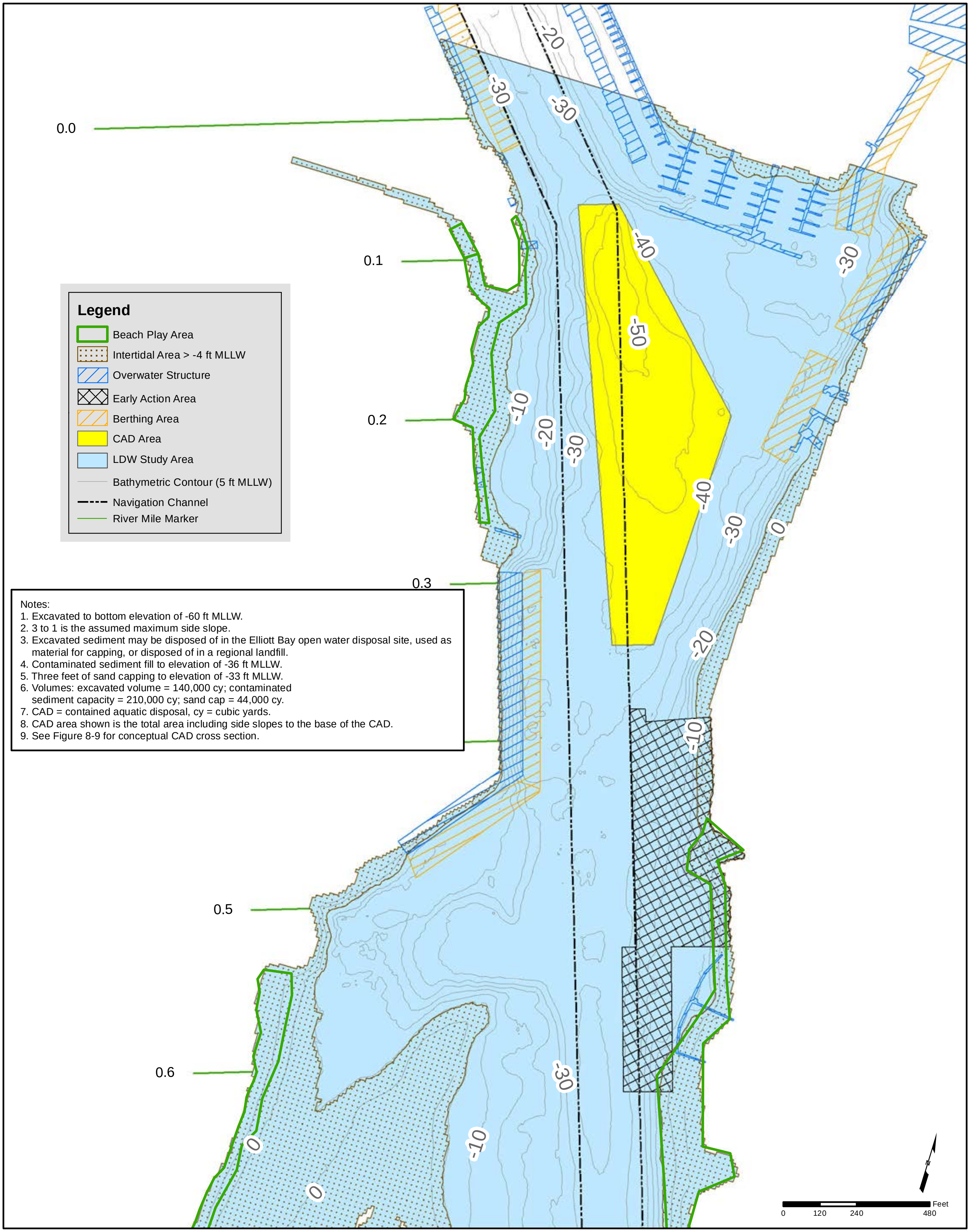
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-7**



Notes:
1. Excavated to bottom elevation of -60 ft MLLW.
2. 3 to 1 is the assumed maximum side slope.
3. Excavated sediment may be disposed of in the Elliott Bay open water disposal site, used as material for capping, or disposed of in a regional landfill.
4. Contaminated sediment fill to elevation of -36 ft MLLW.
5. Three feet of sand capping to elevation of -33 ft MLLW.
6. Volumes: excavated volume = 140,000 cy; contaminated sediment capacity = 210,000 cy; sand cap = 44,000 cy.
7. CAD = contained aquatic disposal, cy = cubic yards.
8. CAD area shown is the total area including side slopes to the base of the CAD.
9. See Figure 8-9 for conceptual CAD cross section.

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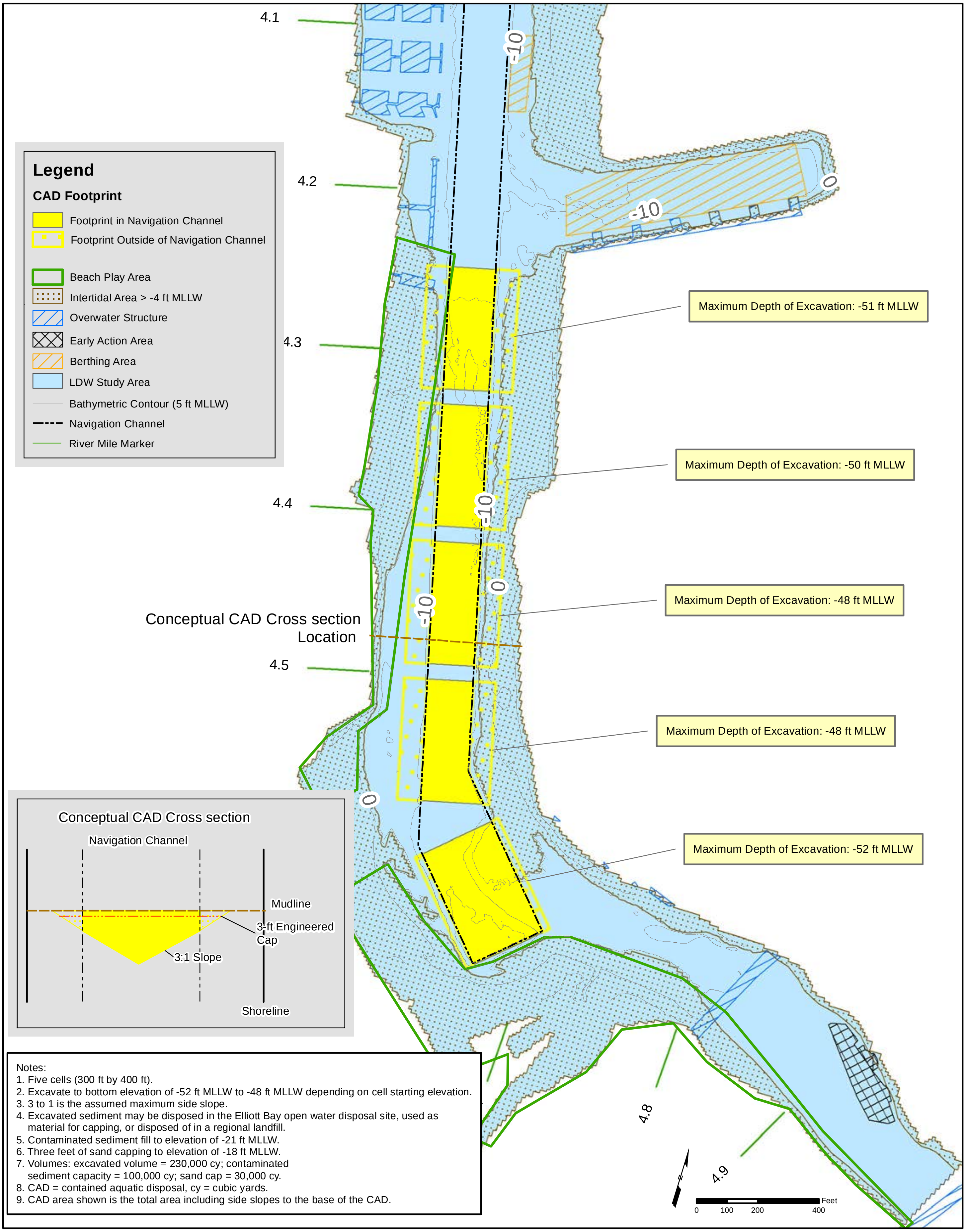
Lower Duwamish Waterway Final Feasibility Study 60150279-14.41	**Alternative 2** **Northern CAD Area**
DATE: 10/31/12 · DWRN:MVI/sea · Revision: 0	**FIGURE 8-8**



Notes:
1. Five cells (300 ft by 400 ft).
2. Excavate to bottom elevation of -52 ft MLLW to -48 ft MLLW depending on cell starting elevation.
3. 3 to 1 is the assumed maximum side slope.
4. Excavated sediment may be disposed in the Elliott Bay open water disposal site, used as material for capping, or disposed of in a regional landfill.
5. Contaminated sediment fill to elevation of -21 ft MLLW.
6. Three feet of sand capping to elevation of -18 ft MLLW.
7. Volumes: excavated volume = 230,000 cy; contaminated sediment capacity = 100,000 cy; sand cap = 30,000 cy.
8. CAD = contained aquatic disposal, cy = cubic yards.
9. CAD area shown is the total area including side slopes to the base of the CAD.

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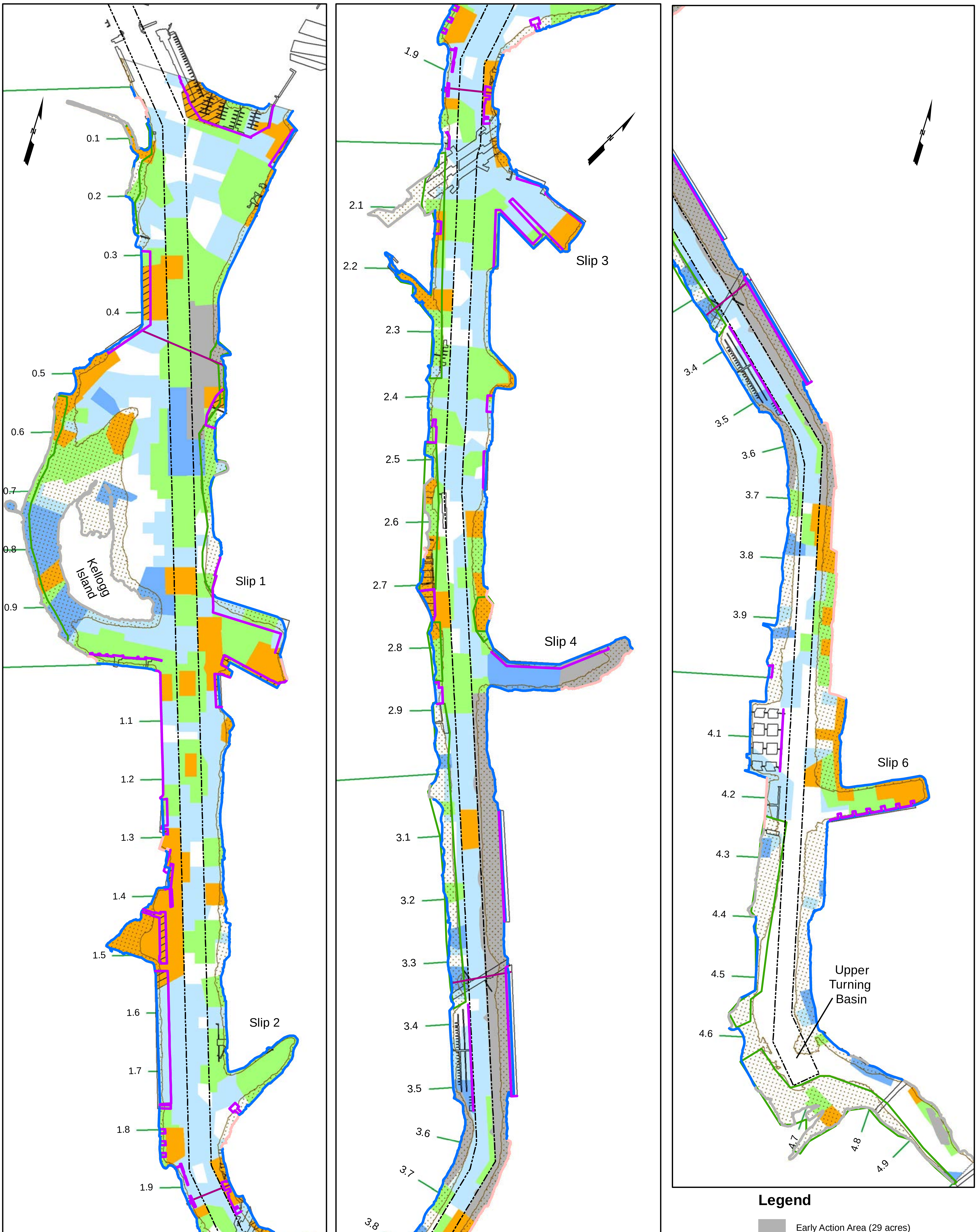
Alternative 2
Southern CAD Areas

FIGURE 8-9



Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (50 acres)
- Partial Dredge and Cap (8 acres)
- Cap (0 acres)
- ENR/*in situ* Treatment (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (99 acres)
- Verification Monitoring Area (23 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

Feet
0 200 400 800

Legend
- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure
- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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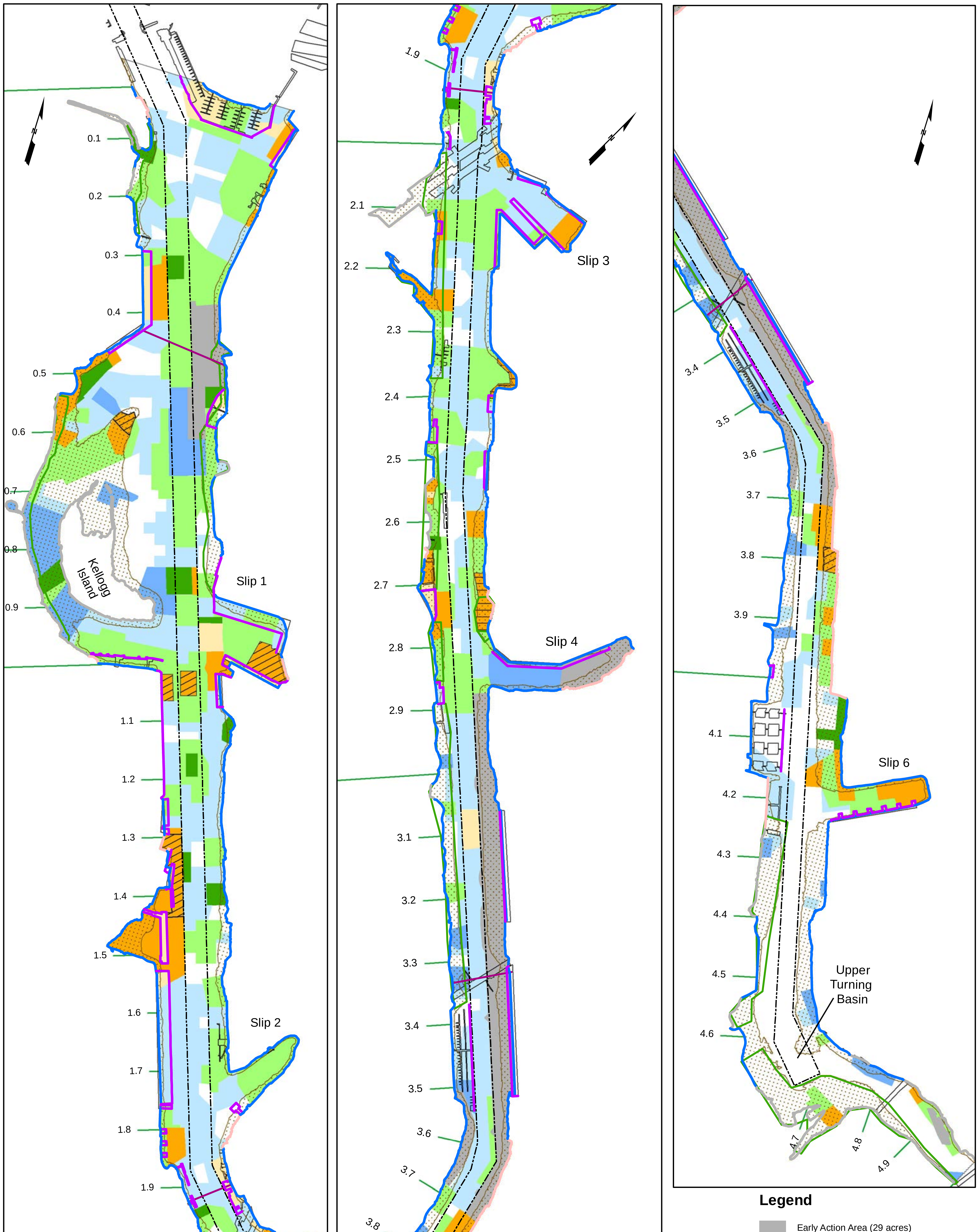
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-10**



Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1:
- Dredge (29 acres)
- Partial Dredge and Cap (8 acres)
- Cap (11 acres)
- ENR/*in situ* Treatment (10 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (99 acres)
- Verification Monitoring Area (23 acres)

- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

Feet
0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-11**

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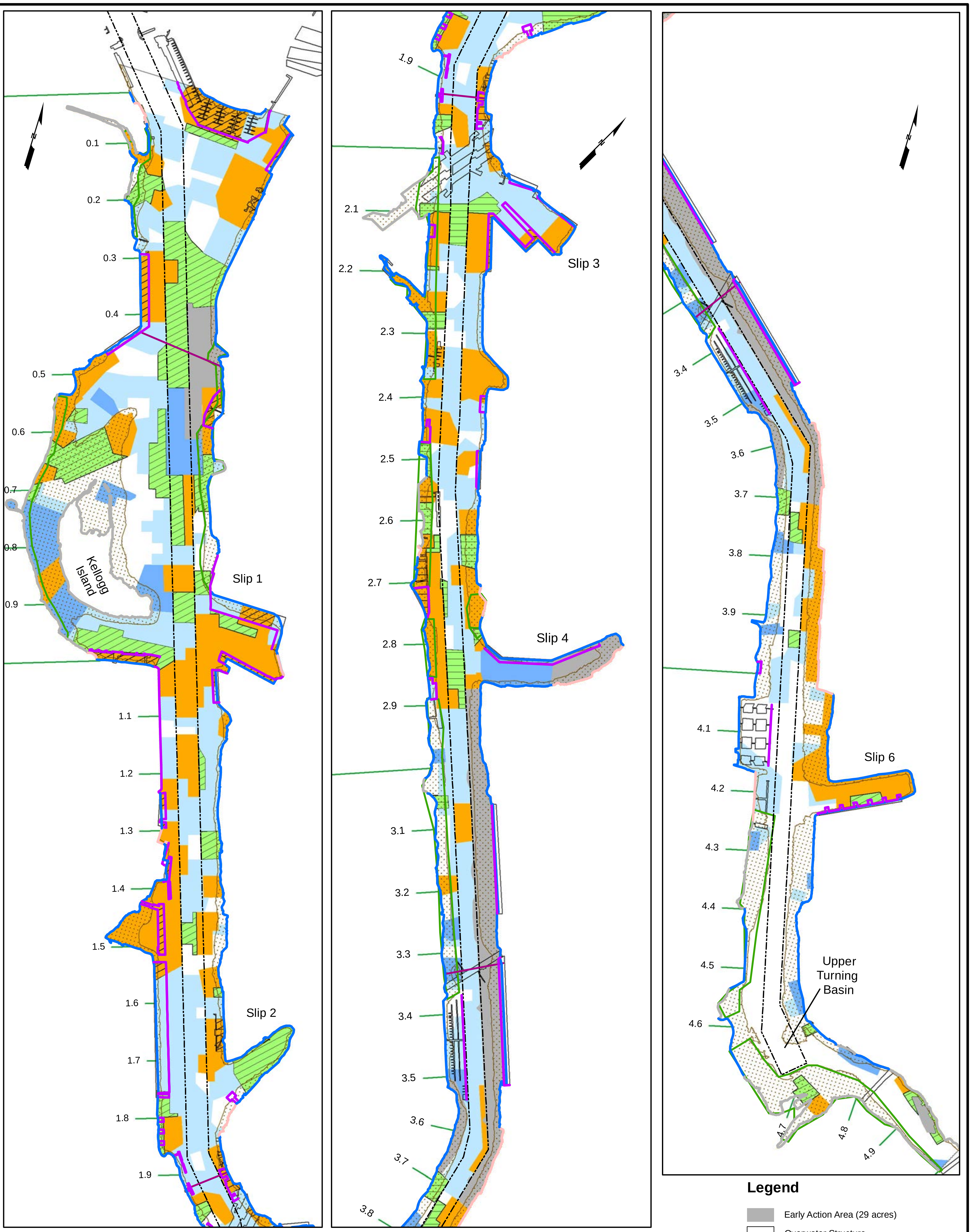

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1:
- Dredge (93 acres)
- Partial Dredge and Cap (14 acres)
- Cap (0 acres)
- ENR/*in situ* Treatment (0 acres)
- Monitored Natural Recovery (10) (50 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (23 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

0 200 400 800 Feet

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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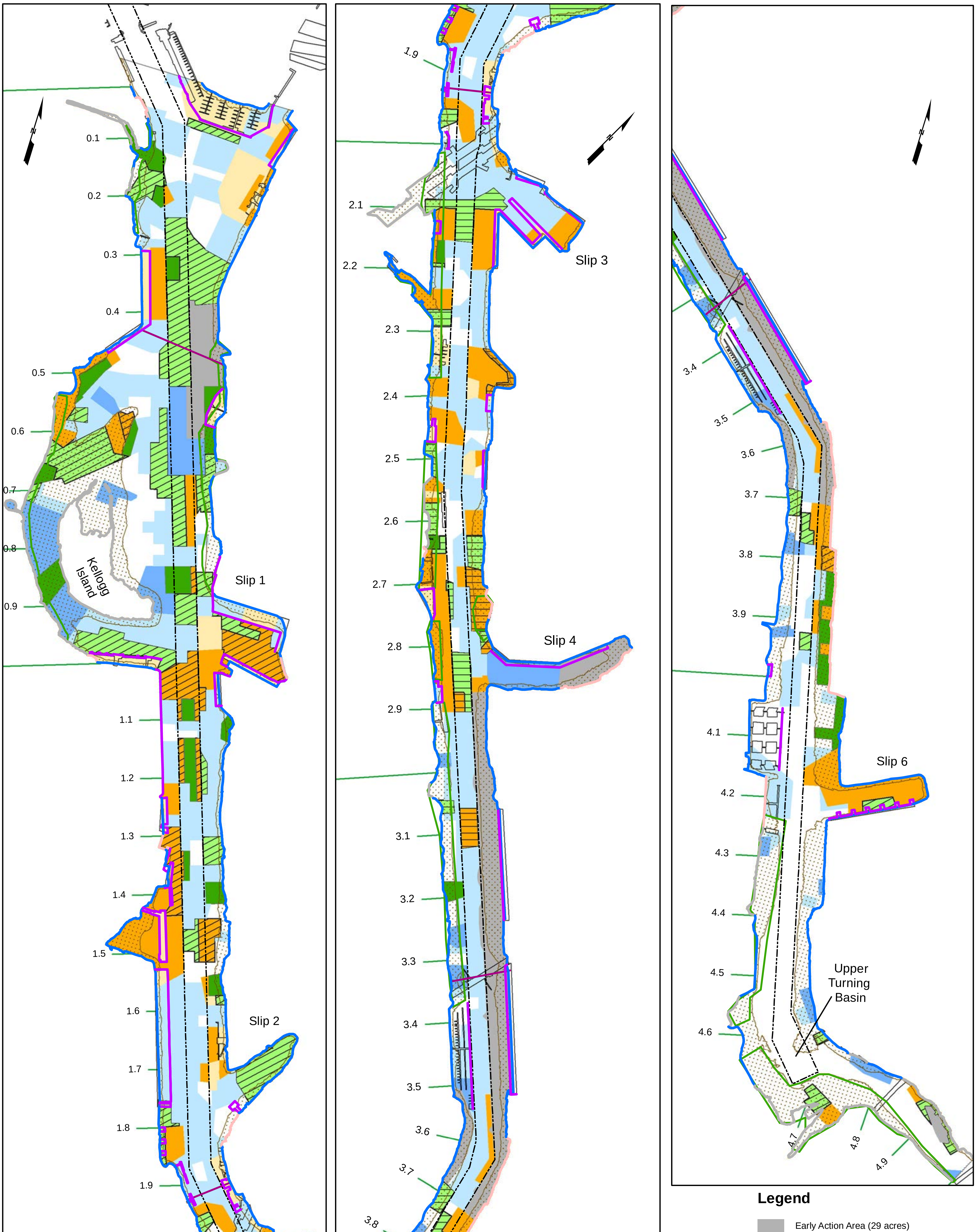
DATE: 10/31/12	DWRN:MVI/sea	Revision: 0	**FIGURE 8-12**



Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1:
- Dredge (50 acres)
- Partial Dredge and Cap (18 acres)
- Cap (23 acres)
- ENR/*in situ* Treatment (16 acres)
- Monitored Natural Recovery (10) (50 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (23 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

Feet: 0 200 400 800

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 4 Combined Technology Assignments

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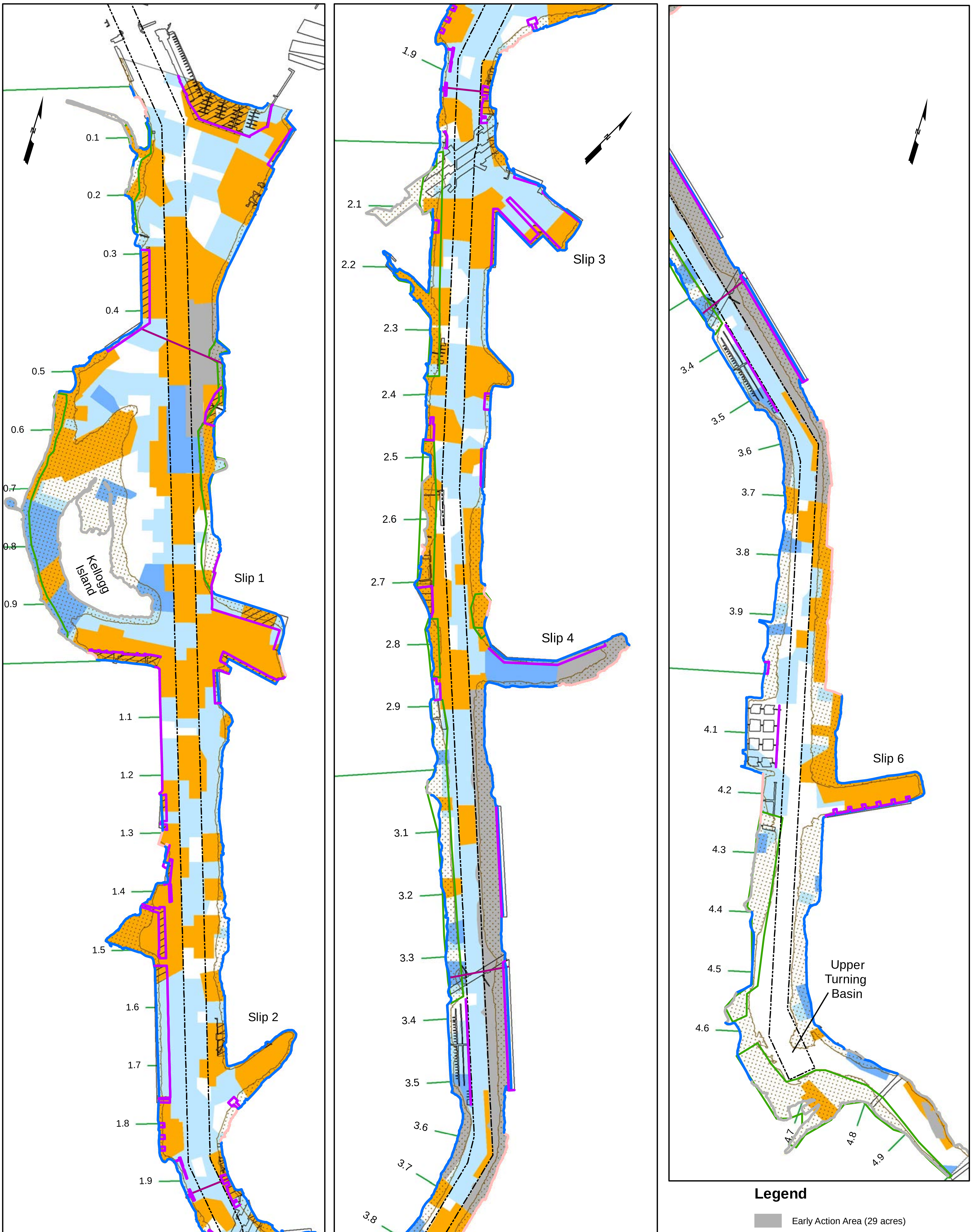

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1
- Dredge (143 acres)
- Partial Dredge and Cap (14 acres)
- Cap (0 acres)
- ENR/*in situ* Treatment (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (23 acres)

- AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)
- Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

Feet
0 200 400 800

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Alternative 5 Removal and Alternative 5 Removal with Treatment Technology Assignments

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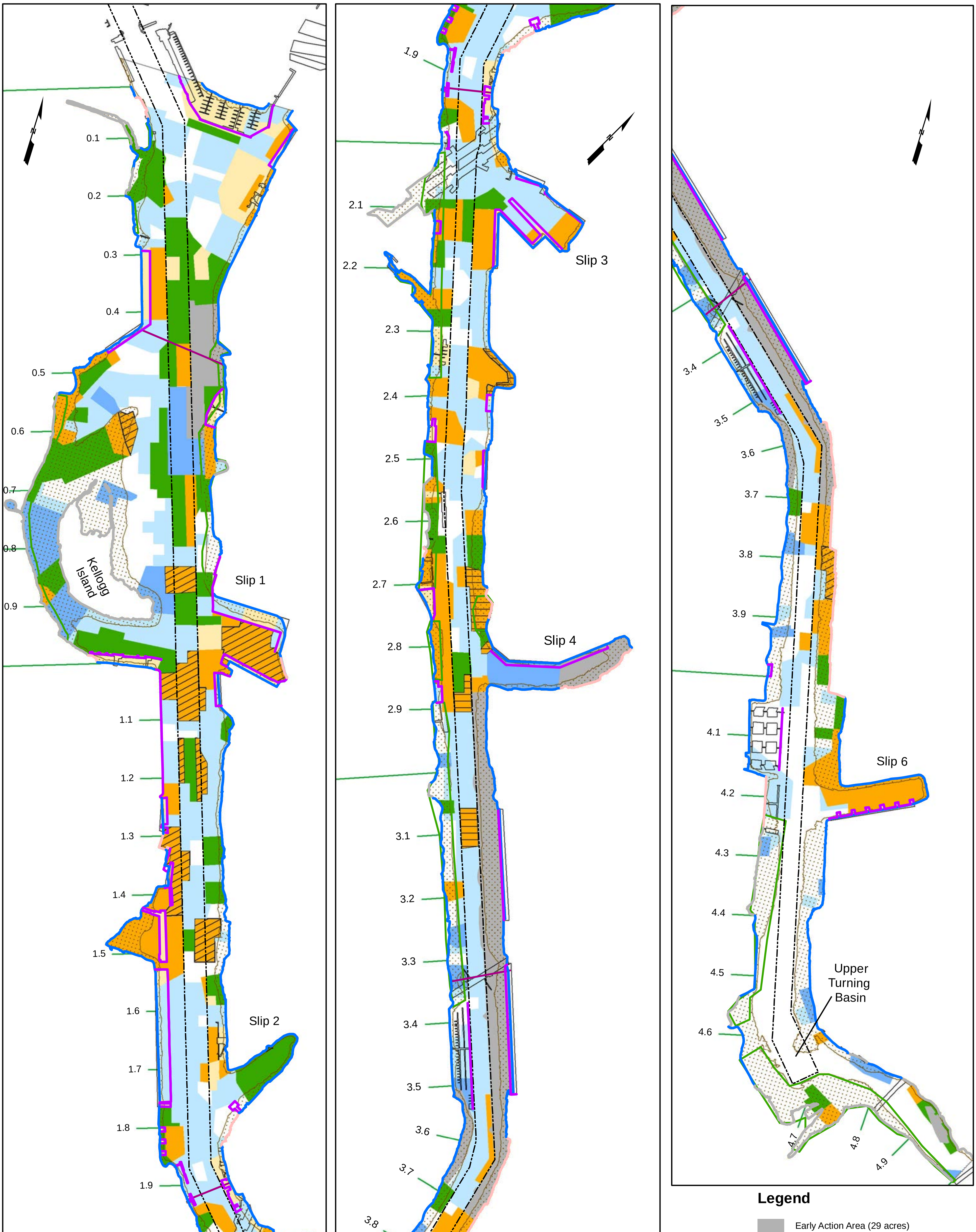
FIGURE 8-14



Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 1:
- Dredge (57 acres)
- Partial Dredge and Cap (23 acres)
- Cap (24 acres)
- ENR/*in situ* Treatment (53 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (23 acres)

AOPC 2 Outside of AOPC 1 (Institutional Controls and Site-wide Monitoring) (122 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

0 200 400 800 Feet

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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Alternative 5 Combined Technology Assignments

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FIGURE 8-15

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure

- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 2
- Dredge (274 acres)
- Partial Dredge and Cap (28 acres)
- Cap (0 acres)
- ENR/*in situ* Treatment (0 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (0 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

Feet: 0 200 400 800

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Alternative 6 Removal Technology Assignments

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FIGURE 8-16

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (CSL for Alternative 2, SQS for Alternative 4) through natural recovery within 10 years.
6. MNR(20) is the area predicted to achieve the SQS through natural recovery within 20 years.
7. Verification monitoring areas will be confirmed during remedial design and are expected to be below the SQS (Alternative 5 RALs).

Technology Assignment

AOPC 2
- Dredge (108 acres)
- Partial Dredge and Cap (42 acres)
- Cap (51 acres)
- ENR/*in situ* Treatment (101 acres)
- Monitored Natural Recovery (10) (0 acres)
- Monitored Natural Recovery (20) (0 acres)
- Verification Monitoring Area (0 acres)

Remaining Study Area (Institutional Controls and Site-wide Monitoring) (110 acres)

0 200 400 800 Feet

Legend

- Early Action Area (29 acres)
- Overwater Structure
- Beach Play Area
- Intertidal Area > -4 ft MLLW

Shoreline Structure
- Armored Slope (10.1 miles)
- Vertical Bulkhead (1.0 miles)
- Exposed Bank (3.7 miles)
- Dock Face (4.9 miles)
- Underwater Utility
- Navigation Channel
- River Mile Marker

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AECOM

Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company

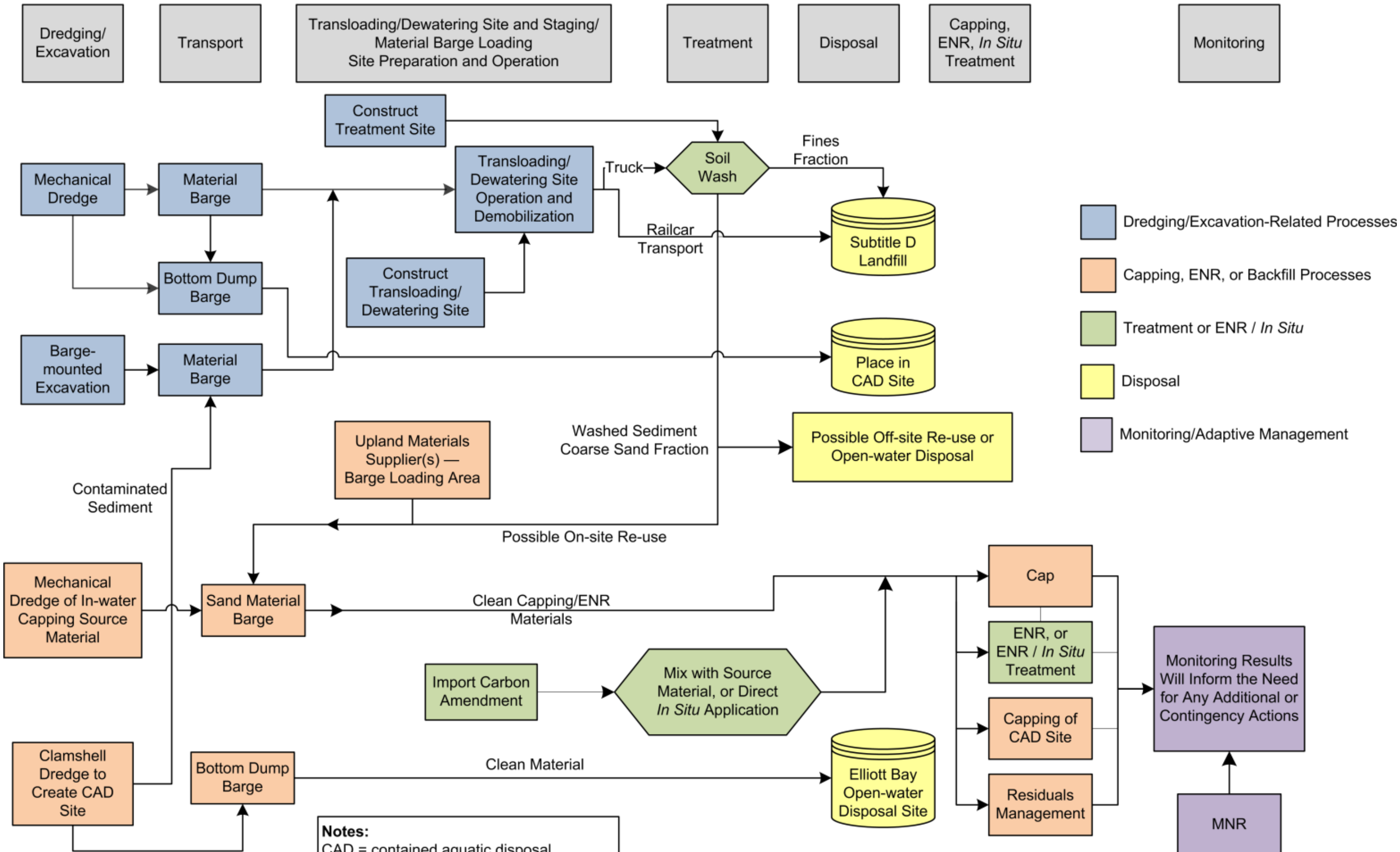
Lower Duwamish Waterway
Final Feasibility Study
60150279-14.41

Alternative 6 Combined Technology Assignments

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 0

FIGURE 8-17

Figure 8-18 Generalized Process Flow Diagram of Active Remedy Elements



Notes:
CAD = contained aquatic disposal
ENR = enhanced natural recovery
MNR = monitored natural recovery