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

Final Feasibility Study

Lower Duwamish Waterway

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Volume I - Main Text, Tables, and Figures

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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.

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[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).

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[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

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[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.

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[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.

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[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

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[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

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[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

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[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

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[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

		Recovery Category[a,b]		
		1	2	3
RALs[c]	**Footprint**	**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

		Recovery Category[a,b]		
		1	2	3
RALs[c]	**Footprint**	**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

		Recovery Category[a,b]		
		1	2	3
RALs[c]	**Footprint**	**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

		Recovery Category[a,b]		
		1	2	3
RALs[c]	**Footprint**	**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

<table>
<tr><th rowspan="3">RALs[c]</th><th rowspan="3">Footprint</th><th colspan="3">Recovery Category[a,b]</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><th>Dredge/Cap Viable</th><th>ENR/*in situ* Viable</th><th>MNR Viable</th></tr>
<tr><td>>Alt 2 RALs</td><td rowspan="5">AOPC 1</td><td rowspan="4" colspan="3">Dredge</td></tr>
<tr><td>>Alt 3 RALs</td></tr>
<tr><td>>ENR UL</td></tr>
<tr><td>>Alt 4 Higher RALs</td></tr>
<tr><td>>Alt 4 Lower RALs</td><td colspan="2">Dredge[d]</td><td>MNR(10)[e]</td></tr>
<tr><td>>Alt 6 RALs</td><td>AOPC 2</td><td rowspan="2" colspan="3">Institutional controls, site-wide monitoring, & natural recovery[g]</td></tr>
<tr><td>n/a</td><td>Rest of LDW</td></tr>
</table>

Alternative 4: Combined Technology

<table>
<tr><th rowspan="3">RALs[c]</th><th rowspan="3">Footprint</th><th colspan="3">Recovery Category[a,b]</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><th>Dredge/Cap Viable</th><th>ENR/*in situ* Viable</th><th>MNR Viable</th></tr>
<tr><td>>Alt 2 RALs</td><td rowspan="5">AOPC 1</td><td rowspan="3" colspan="3">Cap/Dredge</td></tr>
<tr><td>> Alt 3 RALs</td></tr>
<tr><td>>ENR UL</td></tr>
<tr><td>>Alt 4 Higher RALs</td><td rowspan="2">Cap/Dredge[d]</td><td colspan="2">ENR/ *in situ*</td></tr>
<tr><td>>Alt 4 Lower RALs</td><td>ENR/ *in situ* [d]</td><td>MNR(10)[e]</td></tr>
<tr><td>>Alt 6 RALs</td><td>AOPC 2</td><td rowspan="2" colspan="3">Institutional controls, site-wide monitoring, & natural recovery[g]</td></tr>
<tr><td>n/a</td><td>Rest of LDW</td></tr>
</table>

Alternative 5: Removal and Alternative 5-Removal with Treatment Emphasis

<table>
<tr><th rowspan="3">RALs[c]</th><th rowspan="3">Footprint</th><th colspan="3">Recovery Category[a,b]</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><th>Dredge/Cap Viable</th><th>ENR/*in situ* Viable</th><th>MNR Viable</th></tr>
<tr><td>>Alt 2 RALs</td><td rowspan="5">AOPC 1</td><td rowspan="5" colspan="3">Dredge</td></tr>
<tr><td>>Alt 3 RALs</td></tr>
<tr><td>> ENR UL</td></tr>
<tr><td>>Alt 4 RALs</td></tr>
<tr><td>>Alt 5 RALs</td></tr>
<tr><td>>Alt 6 RALs</td><td>AOPC 2</td><td rowspan="2" colspan="3">Institutional controls, site-wide monitoring, & natural recovery[g]</td></tr>
<tr><td>n/a</td><td>Rest of LDW</td></tr>
</table>

Alternative 5: Combined Technology

<table>
<tr><th rowspan="3">RALs[c]</th><th rowspan="3">Footprint</th><th colspan="3">Recovery Category[a,b]</th></tr>
<tr><th>1</th><th>2</th><th>3</th></tr>
<tr><th>Dredge/Cap Viable</th><th>ENR/*in situ* Viable</th><th>MNR Viable</th></tr>
<tr><td>>Alt 2 RALs</td><td rowspan="5">AOPC 1</td><td rowspan="3" colspan="3">Cap/Dredge</td></tr>
<tr><td>>Alt 3 RALs</td></tr>
<tr><td>>ENR UL</td></tr>
<tr><td>>Alt 4 RALs</td><td rowspan="2">Cap/Dredge</td><td rowspan="2" colspan="2">ENR/ *in situ*</td></tr>
<tr><td>>Alt 5 RALs</td></tr>
<tr><td>>Alt 6 RALs</td><td>AOPC 2</td><td rowspan="2" colspan="3">Institutional controls, site-wide monitoring, & natural recovery[g]</td></tr>
<tr><td>n/a</td><td>Rest of LDW</td></tr>
</table>

Table 8-5 Conceptual Technology Assignments for Remedial Alternatives (continued)

Alternative 6: 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		
>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	**2**	**3**
		Dredge/Cap Viable	**ENR/*in situ* Viable**	**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**	**Type of MTCA Compliance Monitoring**
	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)	"…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.

▨ 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.

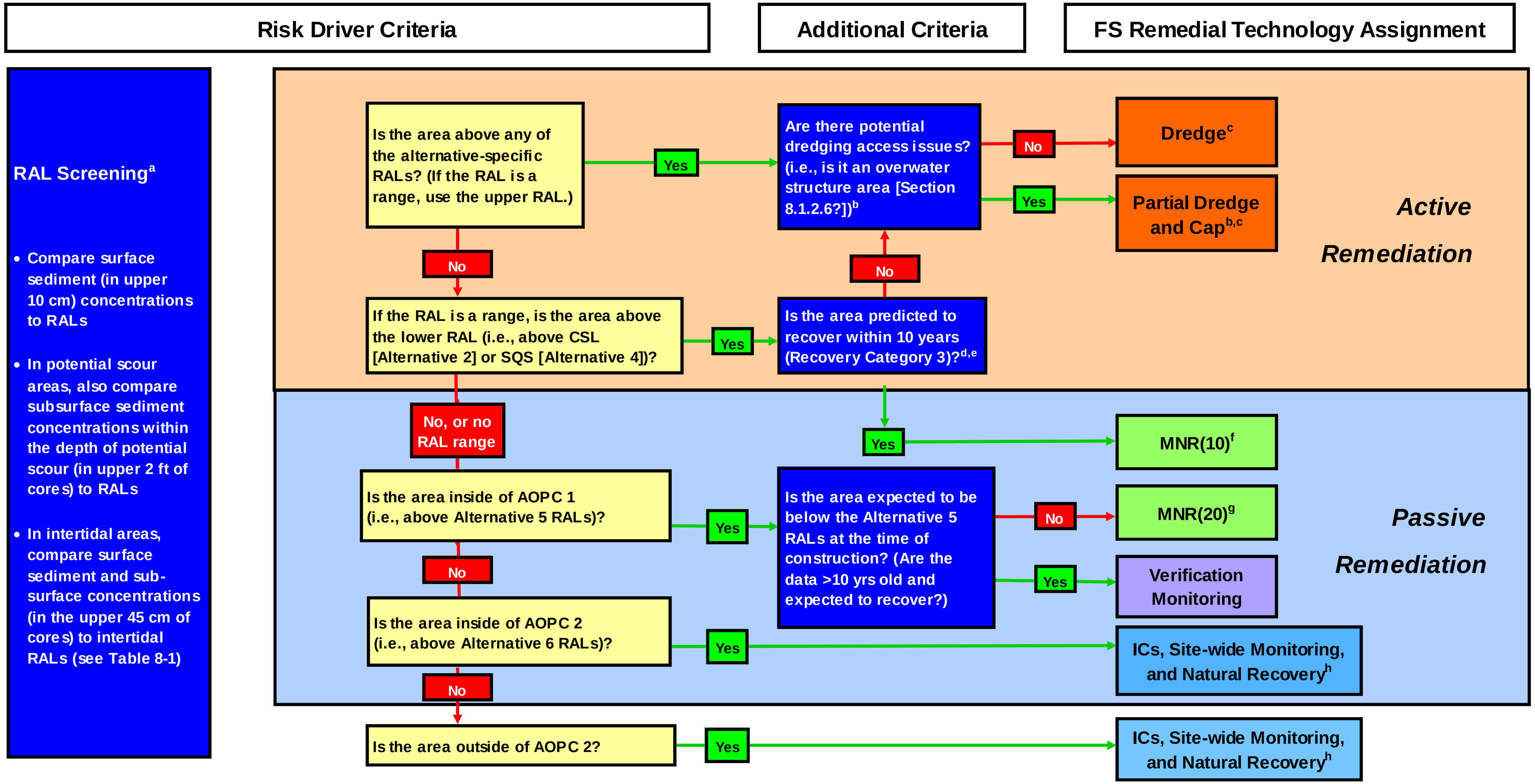
h. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting and do not include operation and maintenance. The capital costs of cleanup actions in the EAAs are estimated at approximately $95 million.

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.

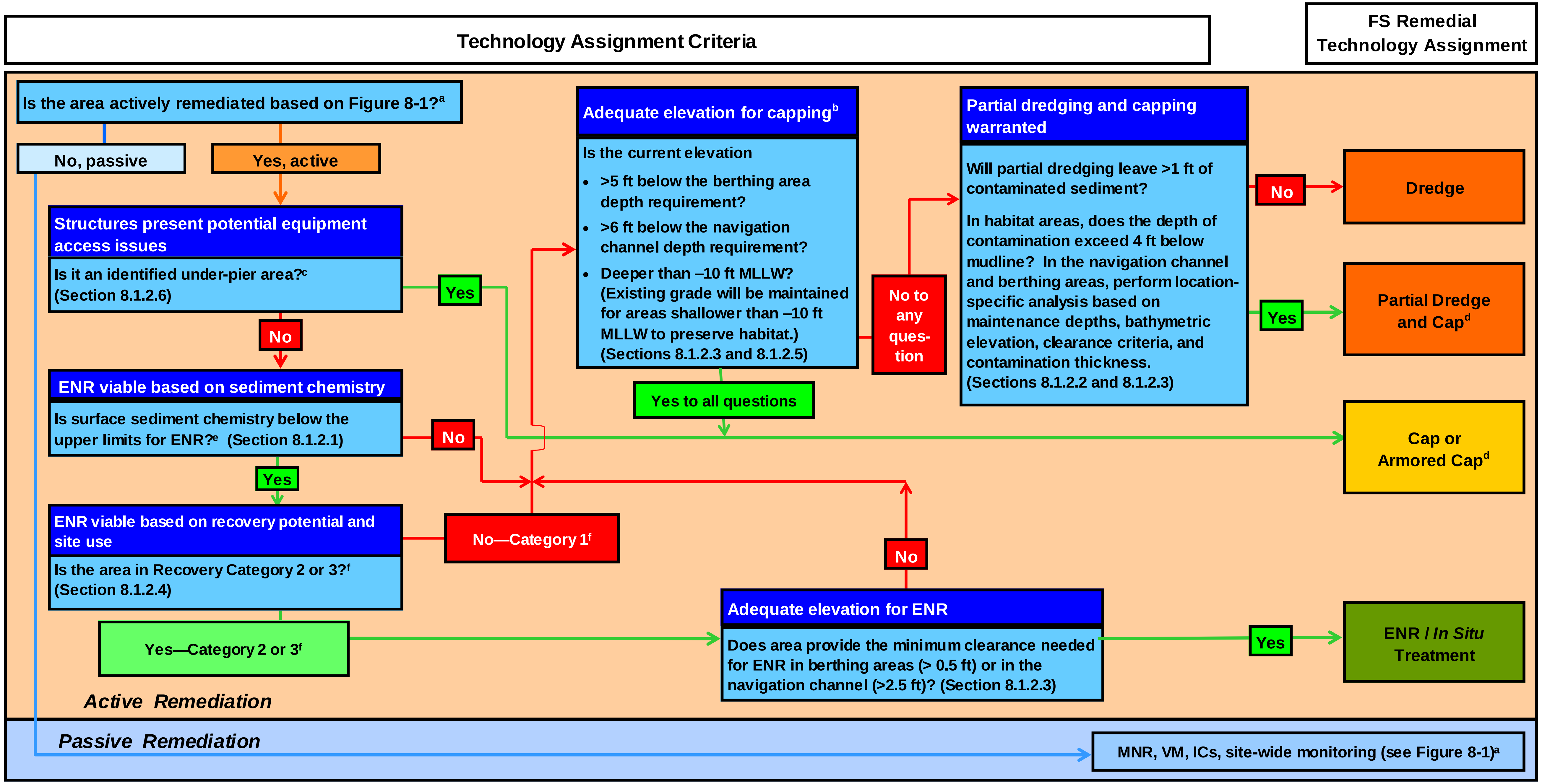
f. MNR(10) refers to monitoring to achieve alternative-specific target concentrations within 10 years following construction (i.e., the CSL for Alternatives 2R and 2R-CAD and the SQS for Alternatives 4R and 4C) .

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.

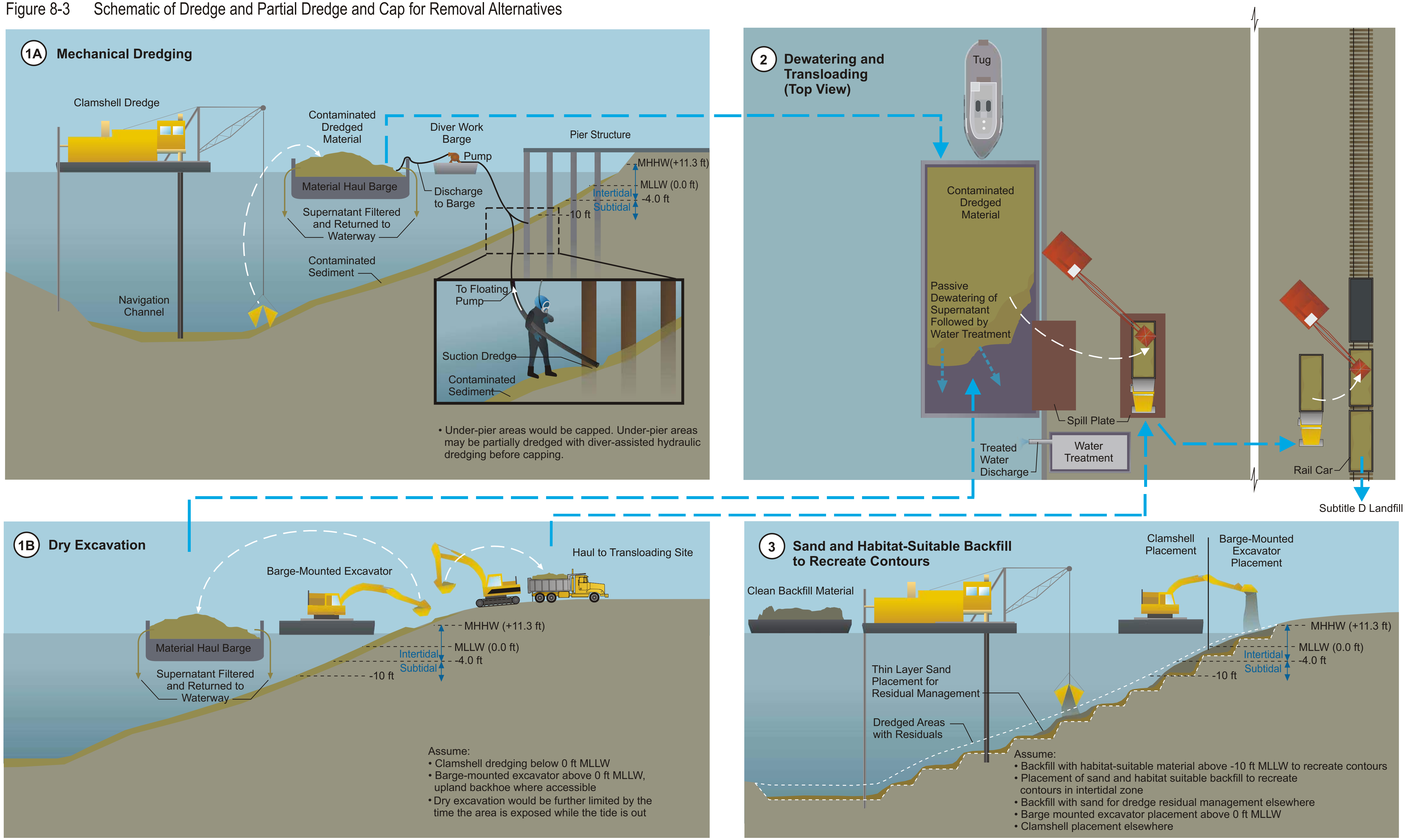
d. Armor capping is assumed to be necessary in potential scour areas.

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



- Under-pier areas would be capped. Under-pier areas may be partially dredged with diver-assisted hydraulic dredging before capping.

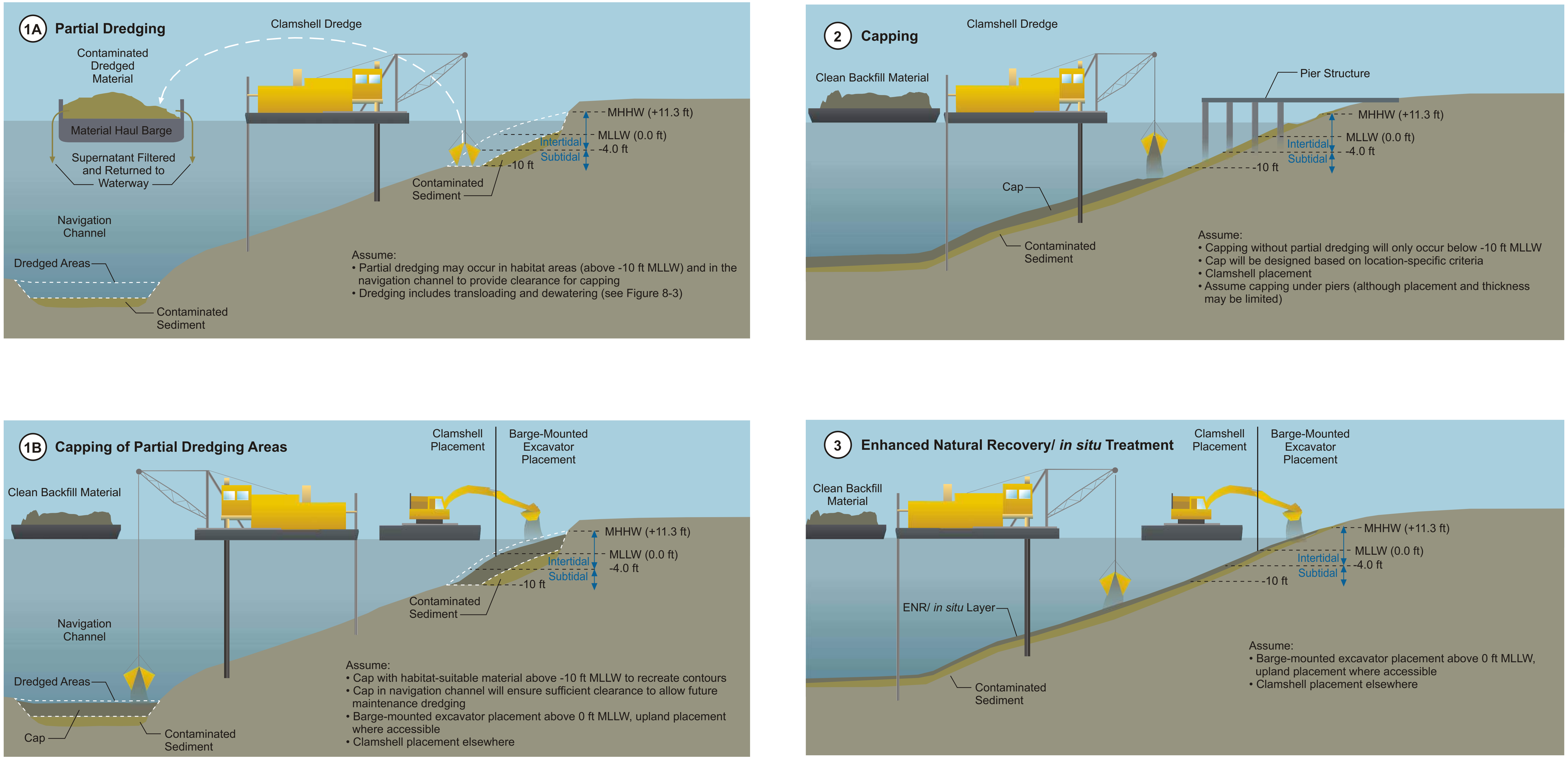
Assume:
- Clamshell dredging below 0 ft MLLW
- Barge-mounted excavator above 0 ft MLLW, upland backhoe where accessible
- Dry excavation would be further limited by the time the area is exposed while the tide is out

Assume:
- Backfill with habitat-suitable material above -10 ft MLLW to recreate contours
- Placement of sand and habitat suitable backfill to recreate contours in intertidal zone
- Backfill with sand for dredge residual management elsewhere
- Barge mounted excavator placement above 0 ft MLLW
- Clamshell placement elsewhere

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



Assume:
- Partial dredging may occur in habitat areas (above -10 ft MLLW) and in the navigation channel to provide clearance for capping
- Dredging includes transloading and dewatering (see Figure 8-3)

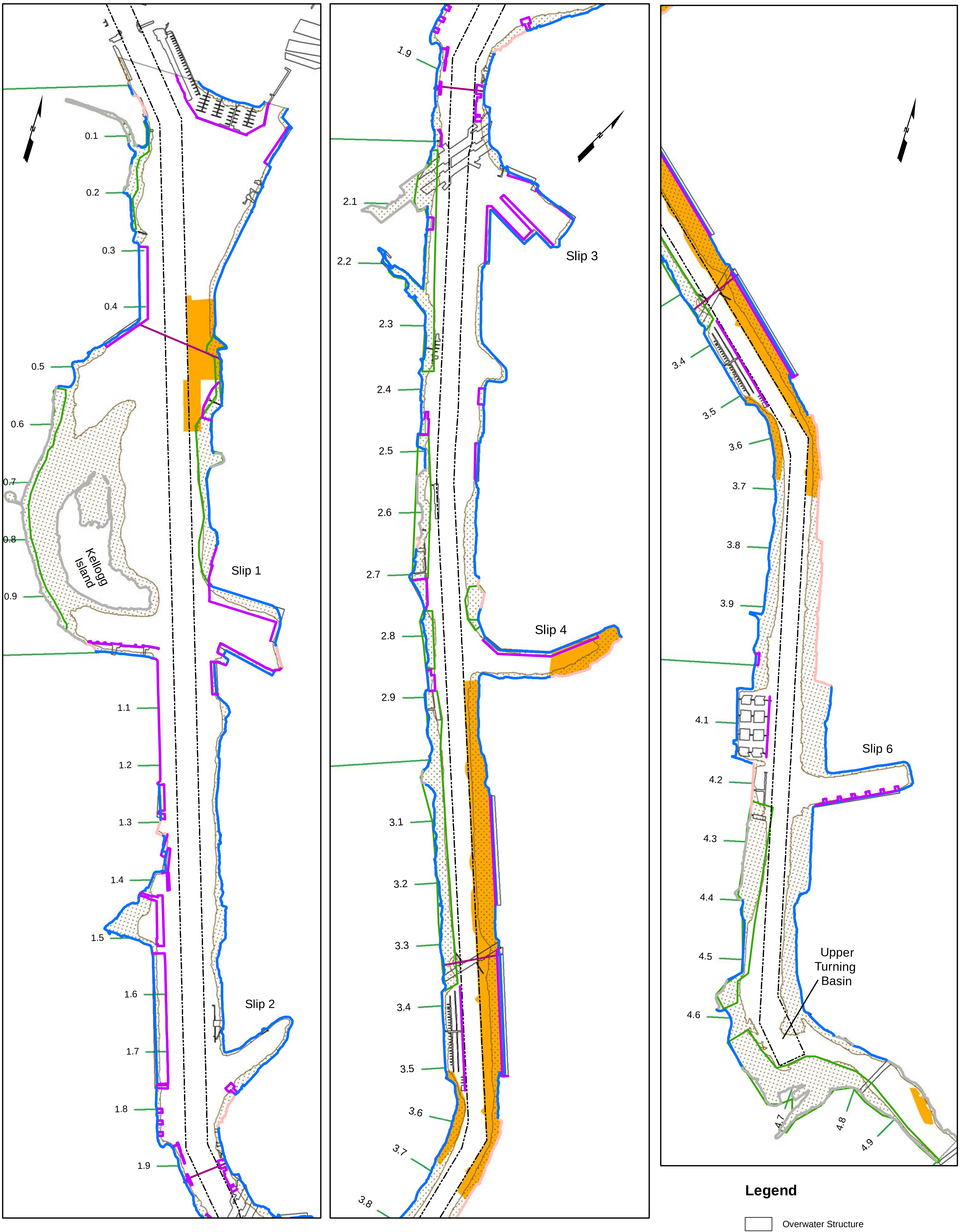
Assume:
- Capping without partial dredging will only occur below -10 ft MLLW
- Cap will be designed based on location-specific criteria
- Clamshell placement
- Assume capping under piers (although placement and thickness may be limited)

Assume:
- Cap with habitat-suitable material above -10 ft MLLW to recreate contours
- Cap in navigation channel will ensure sufficient clearance to allow future maintenance dredging
- Barge-mounted excavator placement above 0 ft MLLW, upland placement where accessible
- Clamshell placement elsewhere

Assume:
- Barge-mounted excavator placement above 0 ft MLLW, upland placement where accessible
- Clamshell placement elsewhere

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.

Technology Assignment

🟧 Dredge, Cap, or Partial Dredge and Cap (Early Action Areas: 29 acres)

☐ Remaining Study Area (412 acres)

Legend

☐ 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

Feet
0 200 400 800

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Alternative 1 No Further Action

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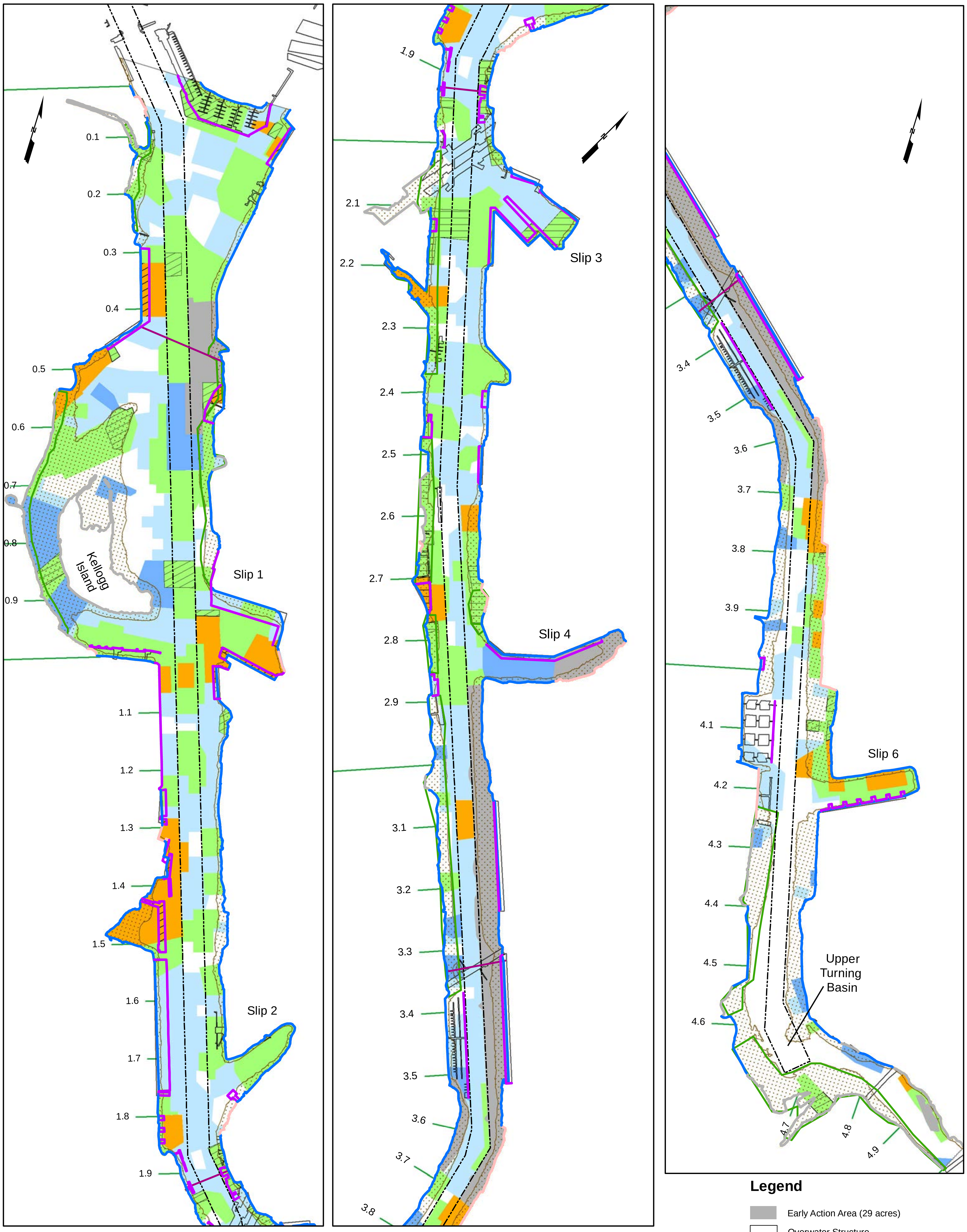
FIGURE 8-5



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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Alternative 2 Removal
Technology Assignments

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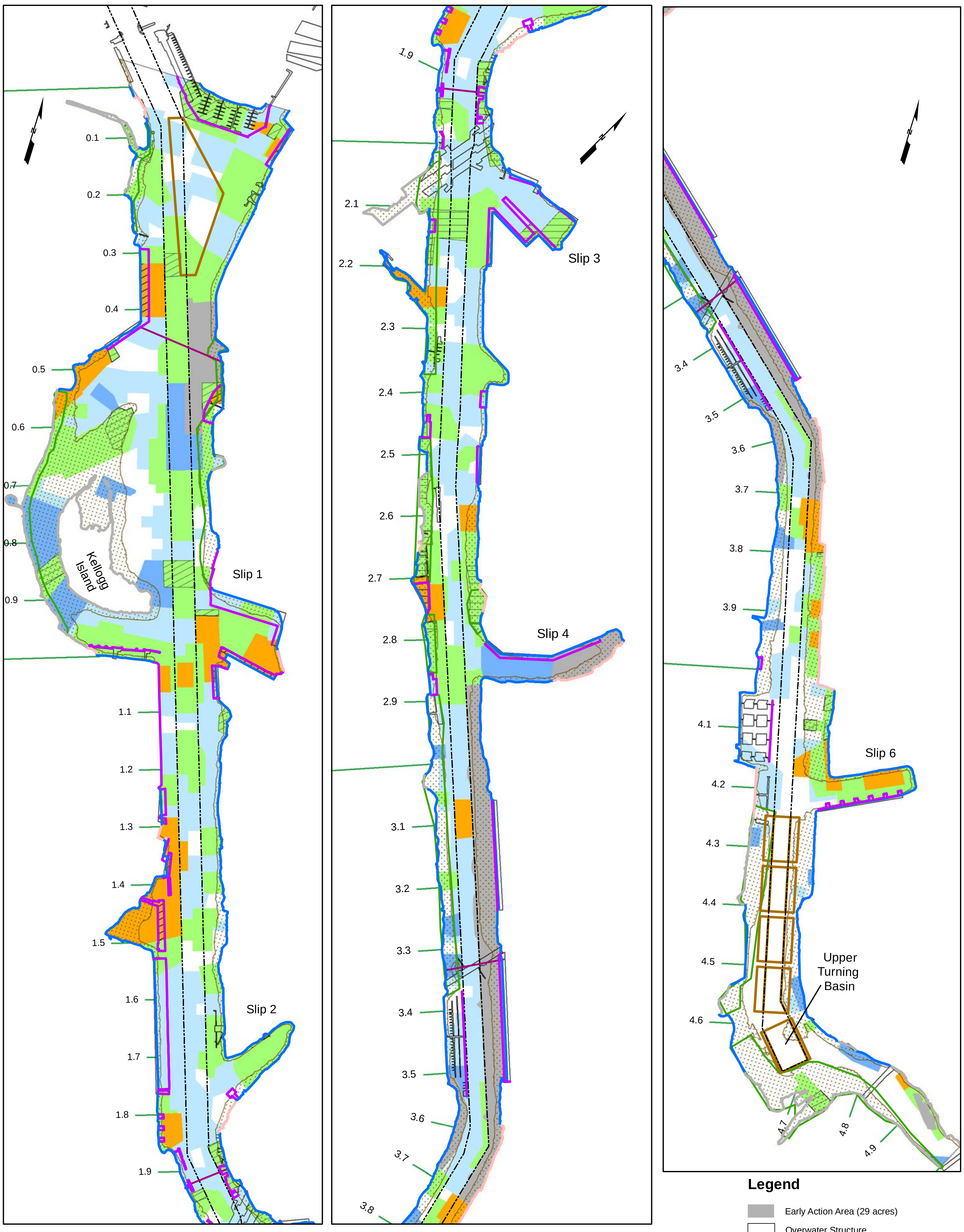

Notes:

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).

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)

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

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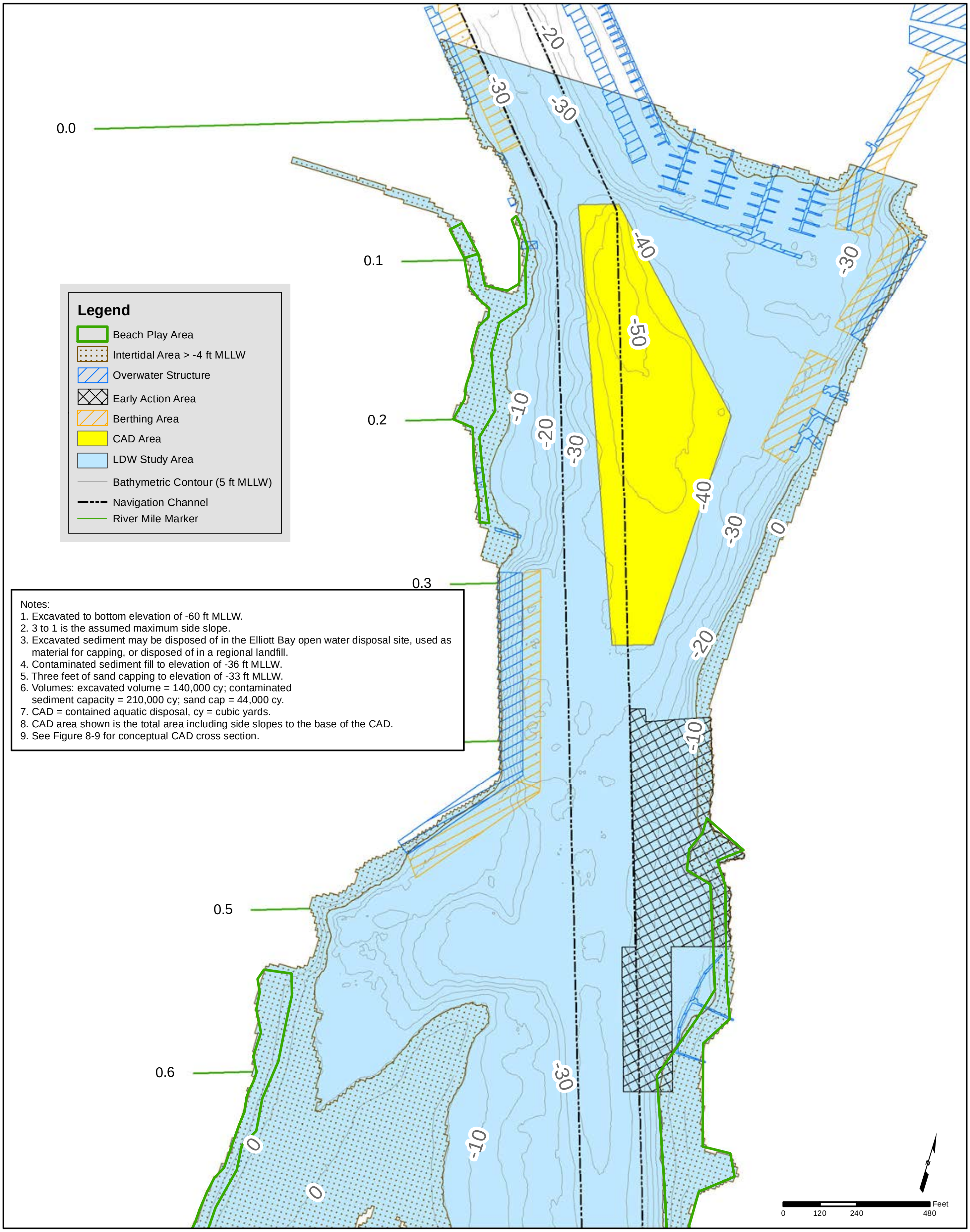
Alternative 2 Removal With CAD Technology Assignments

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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Alternative 2
Northern CAD Area

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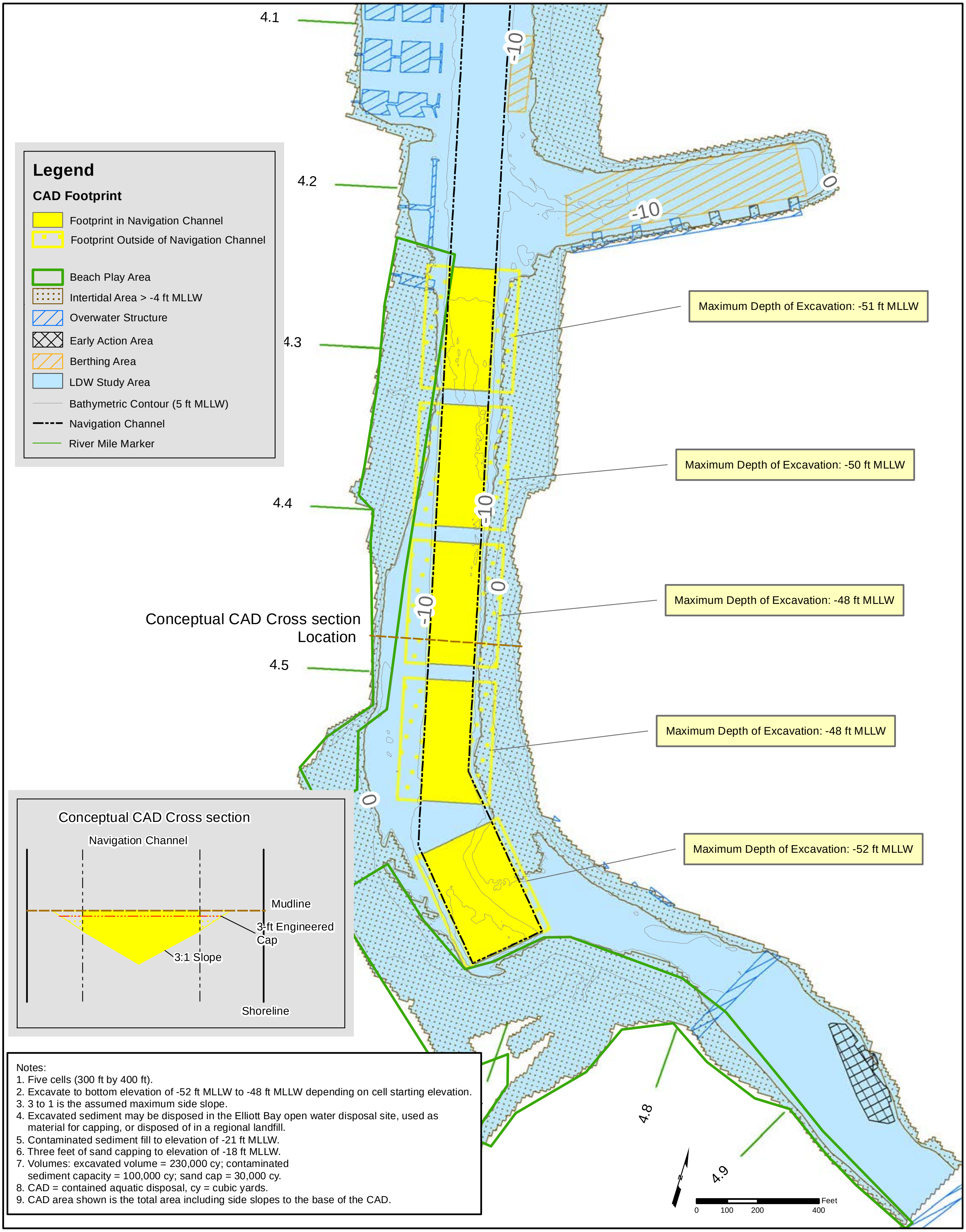
FIGURE 8-8



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

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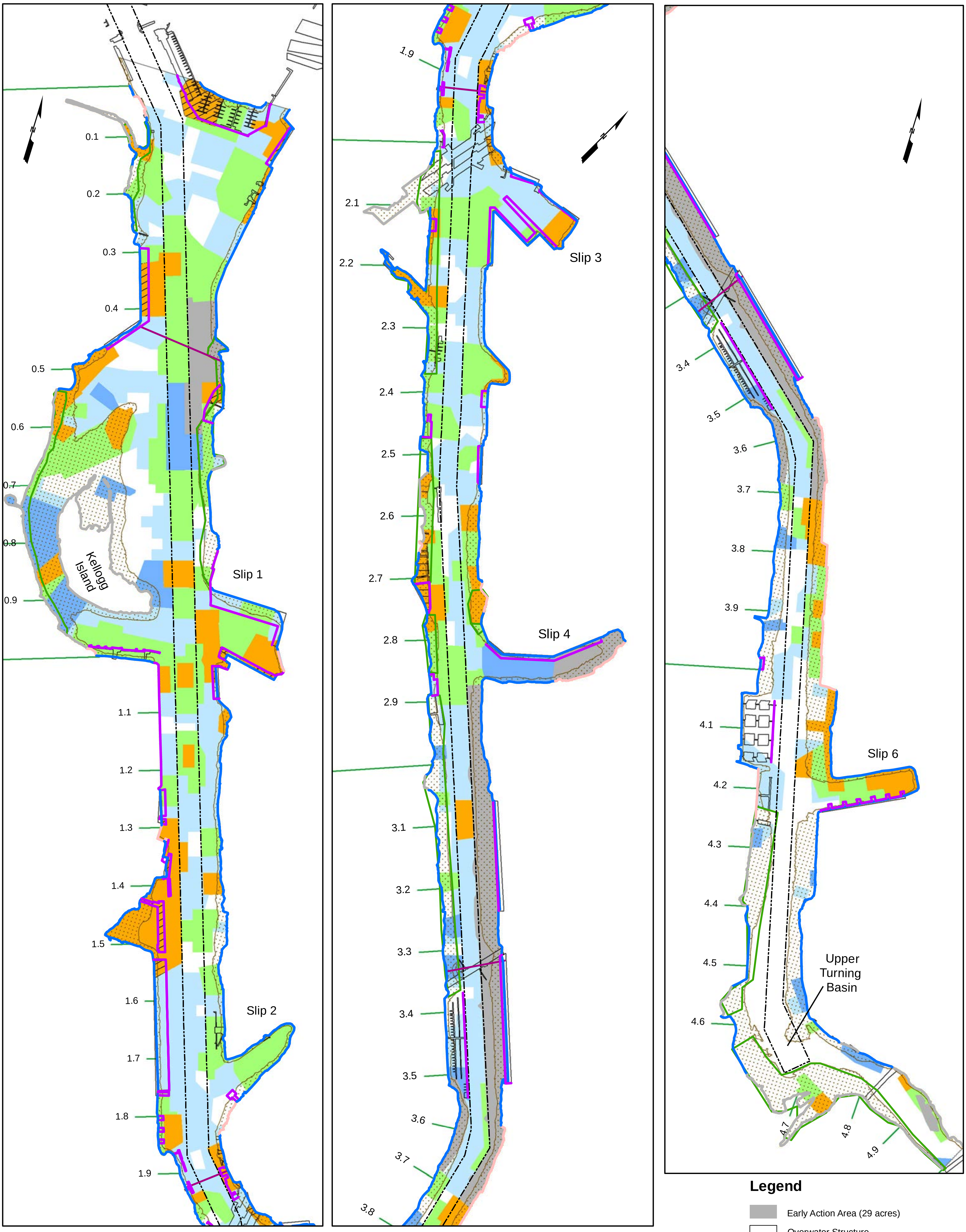

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (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 (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)

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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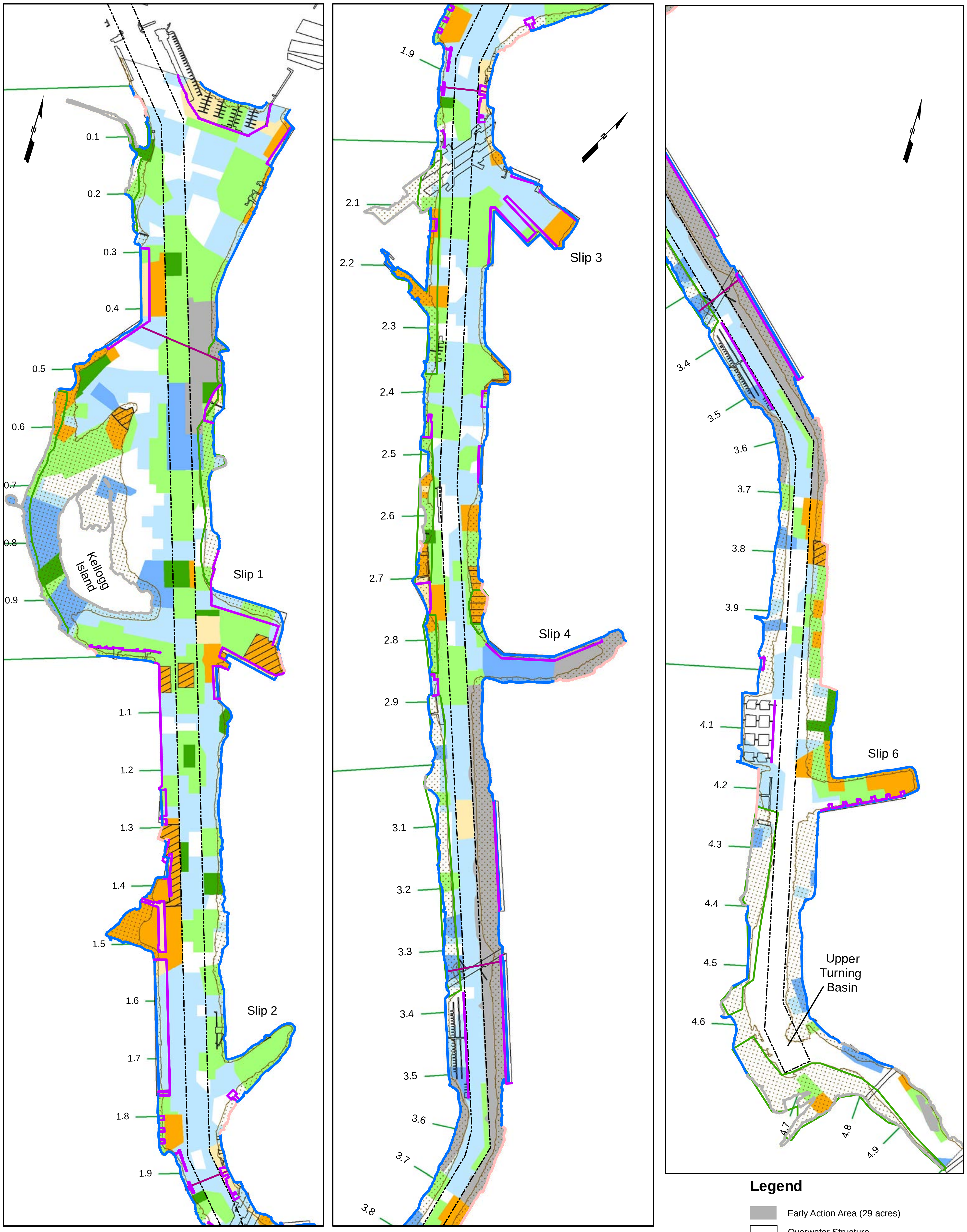
FIGURE 8-10



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)

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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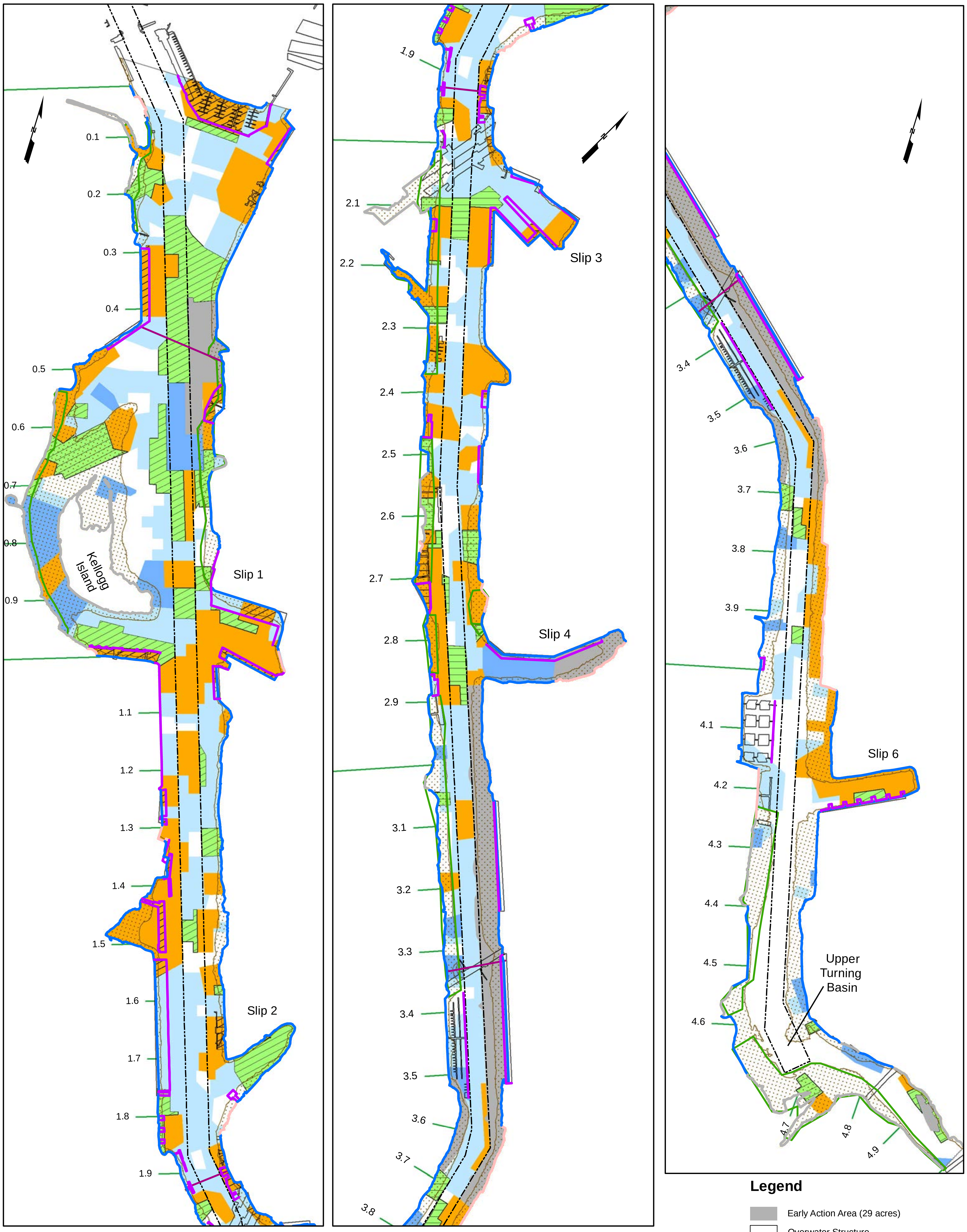
FIGURE 8-11



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)

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 Removal Technology Assignments

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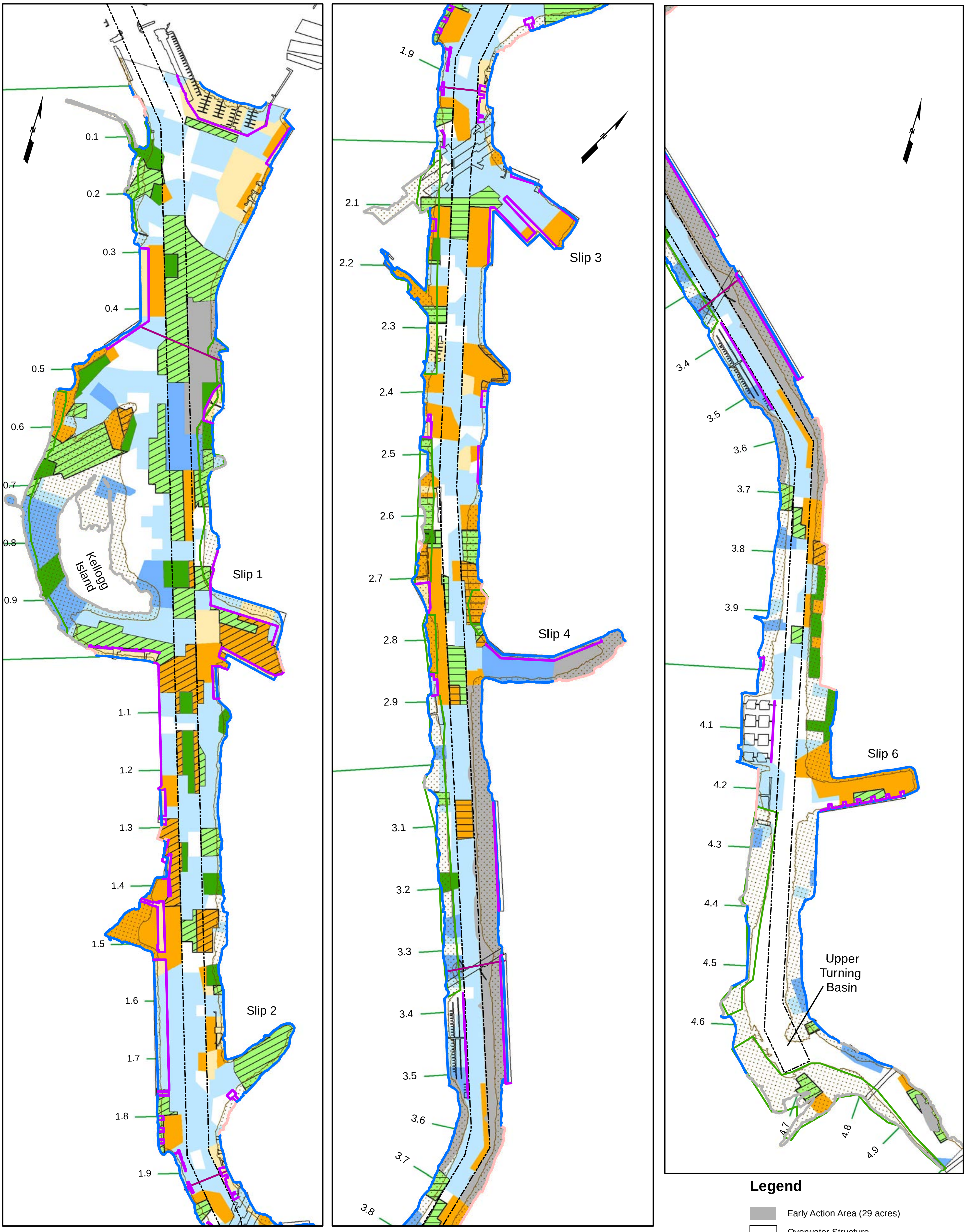
FIGURE 8-12



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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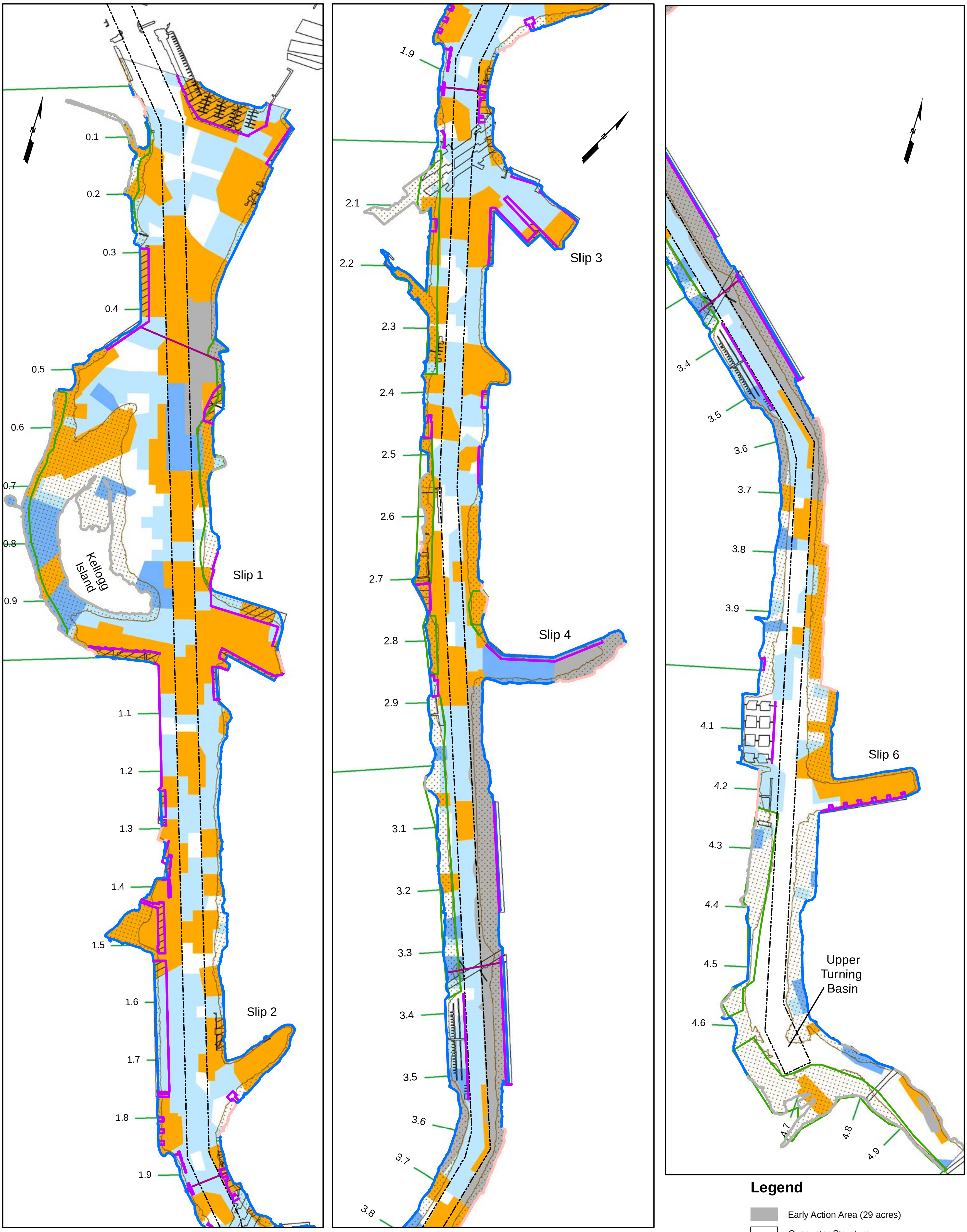
Alternative 4 Combined Technology Assignments

FIGURE 8-13



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

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

AECOM

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Alternative 5 Removal and Alternative 5 Removal with Treatment Technology Assignments

FIGURE 8-14

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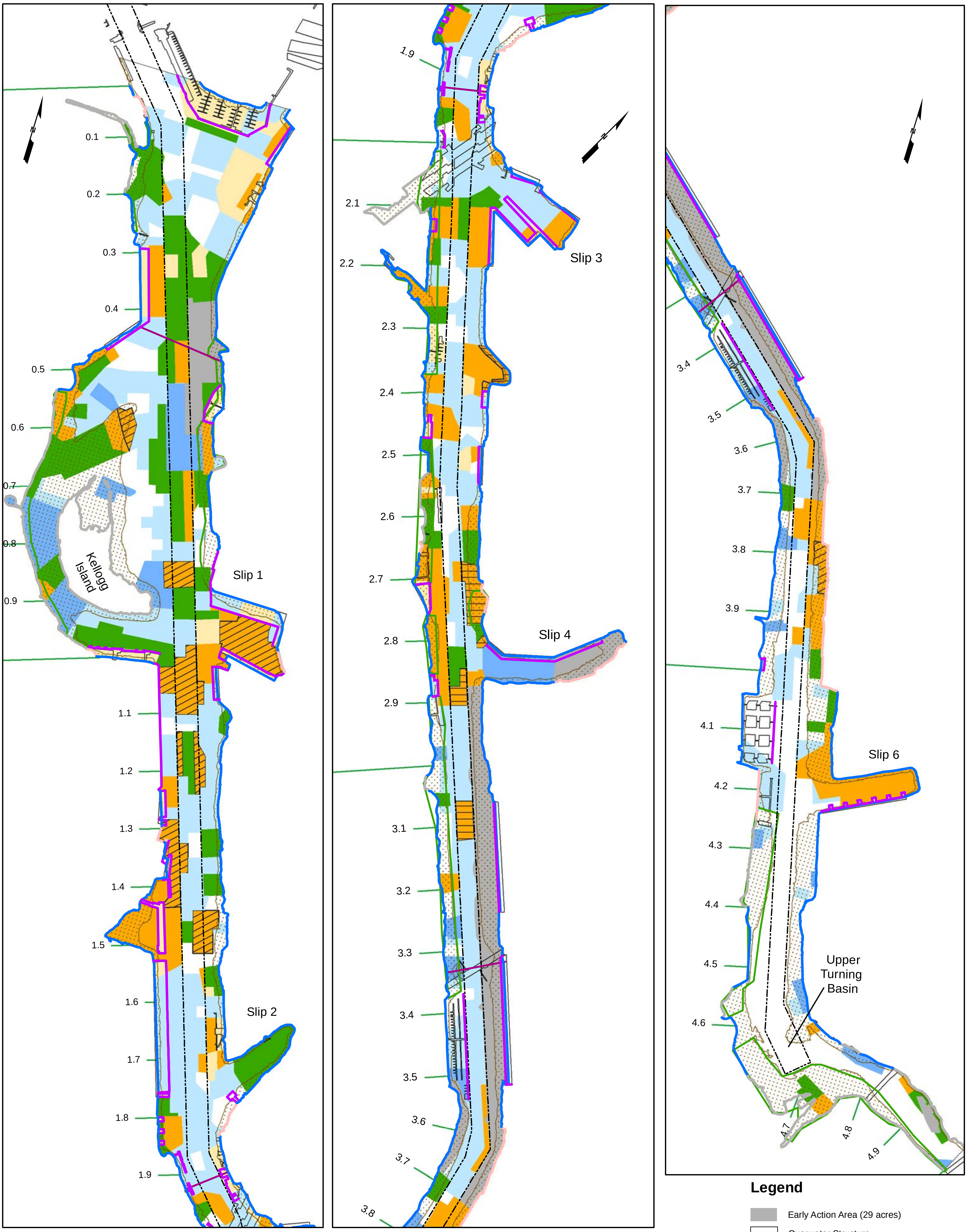

Notes:
1. Technology assignments are for the FS and may change based on additional data.
2. AOPC 1 represents the area > Alternative 5 RALs
3. AOPC 2 represents the area > Alternative 6 RALs
4. The total FS study area is 441 acres.
5. MNR(10) is the area predicted to achieve the post-construction target (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 (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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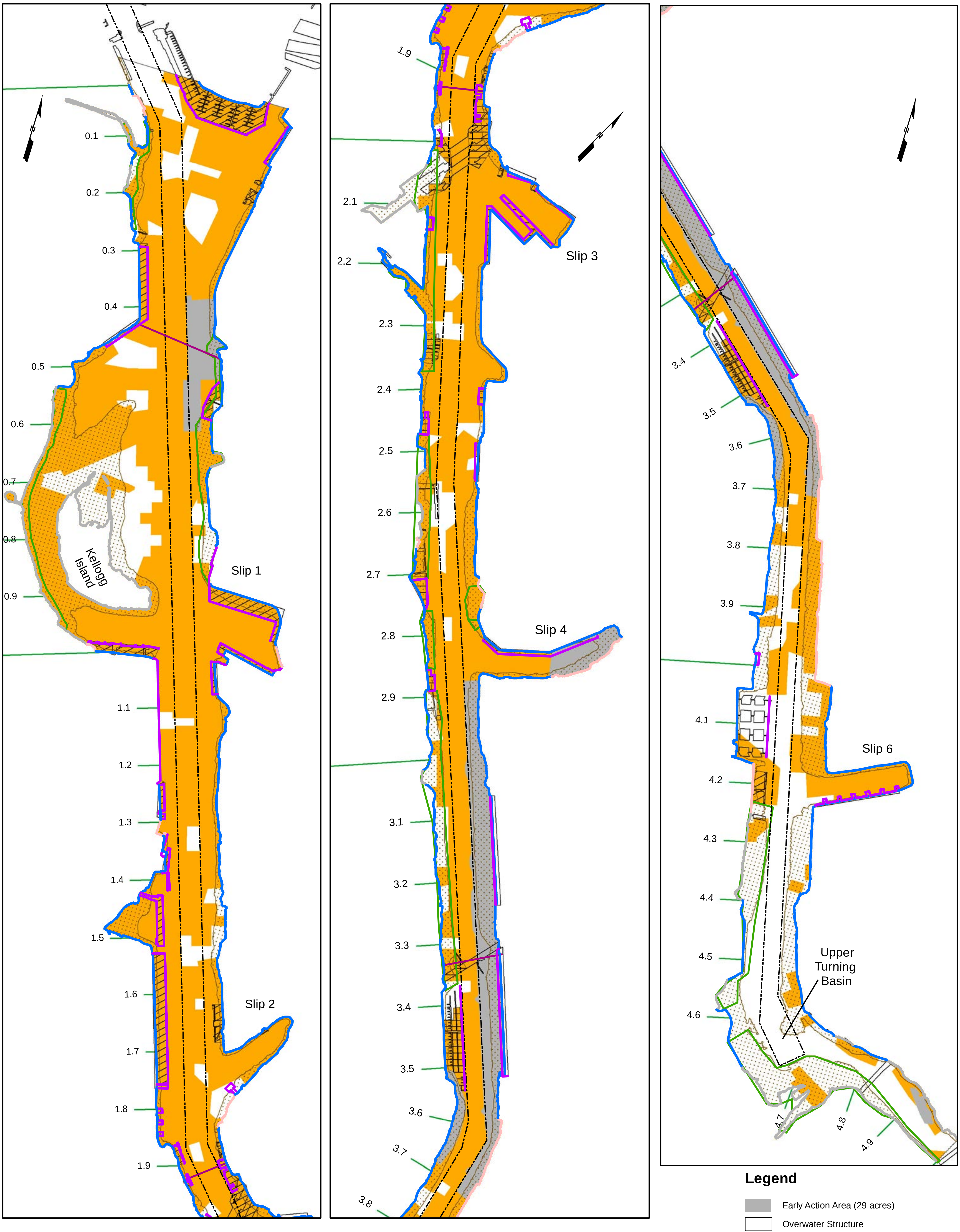
FIGURE 8-15



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

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 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)

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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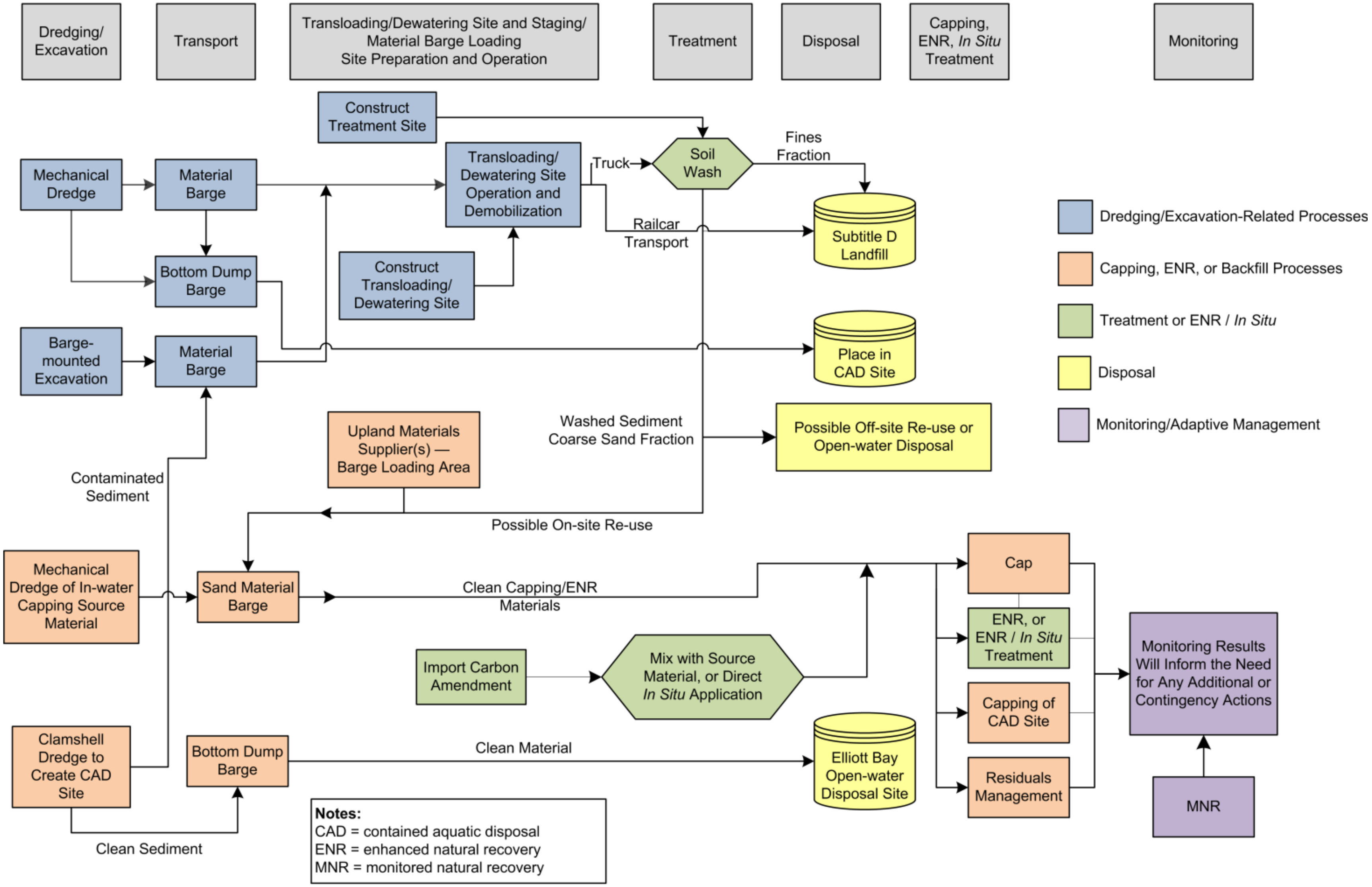
FIGURE 8-17

Figure 8-18 Generalized Process Flow Diagram of Active Remedy Elements



Notes:
CAD = contained aquatic disposal
ENR = enhanced natural recovery
MNR = monitored natural recovery

9 Detailed Analysis of Individual Remedial Alternatives

This section presents a detailed analysis of the remedial alternatives, using the feasibility study (FS) criteria outlined in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the National Contingency Plan (NCP), and other relevant guidance. As discussed in Section 8, these alternatives cover the range of potential remedial actions considered to be feasible for cleanup of the Lower Duwamish Waterway (LDW). A comparative evaluation of the remedial alternatives under CERCLA occurs in Section 10 of this FS. Evaluation of the remedial alternatives under the Washington State Model Toxics Control Act (MTCA) occurs in Section 11 of this FS.

9.1 Overview of NCP Evaluation Criteria

The NCP requires consideration of nine evaluation criteria to address the CERCLA statutory requirements (Table 9-1).

The first two criteria are categorized as threshold criteria:

- Overall protection of human health and the environment
- Compliance with applicable or relevant and appropriate regulations (ARARs).

For any alternative, these two criteria must be met to be considered viable as a remedy for cleanup in the LDW. The next five criteria are balancing criteria:

- Long-term effectiveness and permanence
- Reduction of toxicity, mobility, or volume through treatment
- Short-term effectiveness
- Implementability
- Cost.

These five balancing criteria are weighed within the context of evaluating an alternative as a whole. These five criteria are grouped together and with the threshold criteria form the basis for the detailed evaluation. The last two criteria are modifying criteria:

- State/Tribal acceptance
- Community acceptance.

These are typically assessed following agency and public comment on the U.S. Environmental Protection Agency's (EPA’s) Proposed Plan. Community and Tribal stakeholders have been kept informed and have provided input throughout the remedial investigation/feasibility study (RI/FS), as discussed later in this section. The State of Washington, through the Department of Ecology (Ecology), co-issued the RI/FS Order with EPA and has been actively engaged in oversight of the RI/FS.

In this section of the FS, the CERCLA criteria are used to evaluate each remedial alternative. The key ideas and concepts embodied by the criteria and application to the specific circumstances of the LDW site are presented in the following subsections.

9.1.1 Threshold Criteria

CERCLA prescribes threshold criteria that must be met by a remedial alternative. This section discusses how an alternative meets these criteria. It serves as a summary of how the alternatives achieve the cleanup objectives (described in Section 9.1.2.3, Short-term Effectiveness), and what expected statutory or other relevant requirements must be achieved during implementation of the remedial action.

9.1.1.1 Overall Protection of Human Health and the Environment

This criterion addresses whether a remedial alternative provides adequate protection of human health and the environment. EPA guidance (EPA 1988) states that the assessment of overall protection draws on the assessments conducted under other evaluation criteria, especially long-term effectiveness, short-term effectiveness, and compliance with ARARs. The assessment of overall protection provided for each remedial alternative describes how site risks are eliminated, reduced, or controlled using treatment, engineering controls, institutional controls, or, more typically, combinations of these general response actions.

9.1.1.2 Compliance with ARARs

ARARs for cleanup of the LDW were presented in Section 4. Two ARARs are discussed in this section to evaluate the remedial alternatives: federal and state Surface Water Quality Criteria (RCW 90-48, WAC 173-201A) and MTCA (WAC 173-340).[1] The Washington State Sediment Management Standards (SMS) (WAC 173-204) are also part of MTCA and are ARARs under CERCLA. The SMS contain numerical criteria for the protection of benthic invertebrates and a narrative standard for the protection of human health that is the same as the fundamental human health standard in MTCA for all media. The SMS numerical sediment criteria do not address effects of bioaccumulative contaminants on higher trophic level organisms, including humans.

The other ARARs listed in Section 4, Table 4-1, are not discussed explicitly as part of evaluating the remedial alternatives. The remedial alternatives (other than Alternative 1, the no further action alternative) are assumed to comply with these ARARs, because the required engineering design and agency review process can ensure

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[1] The Washington SMS (WAC 173-204) are used to establish cleanup levels for sediment under MTCA. The SMS are ARARs under CERCLA. The SMS are also promulgated water quality criteria in Washington State but will be discussed in the sections that address MTCA criteria.

that the selected remedy complies with those ARARs. For example, the construction elements for the remedial alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region and elsewhere around the country. All of the alternatives can be designed and implemented in compliance with ARARs pertaining to management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste). Such ARARs may affect implementation but do not have a marked effect on whether a remedial alternative is fundamentally viable. Further, the remedial design phase can address the various land use and resource protection ARAR requirements (e.g., habitat preservation, mitigation).

Surface Water Quality Standards

Requirements for compliance with surface water quality ARARs during in-water construction are captured in project-specific Section 401 Water Quality Certifications. These certifications generally require water quality monitoring at a compliance boundary located downstream of the construction area. Compliance with the requirements of Water Quality Certifications is expected to be viable through the use of operational and structural best management practices (BMPs).

Active remedial measures for the water column are not technically feasible and are therefore not included as part of the remedial alternatives. While significant water quality improvements are anticipated from sediment remediation and source control, it may not be technically practicable for any alternative to meet certain federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain. Further, it is difficult to account for watershed-wide source control efforts, particularly changes in water and sediment quality entering the LDW from the Green/Duwamish River system. For this reason, more definitive statements on whether, and to what extent, certain water quality criteria will be met or potentially waived, on or before completion of remedial action (based on technical impracticability), cannot be made at this time.

Model Toxics Control Act

MTCA regulations governing the selection of cleanup standards, among others, are ARARs under CERCLA and requirements under MTCA. MTCA provides that cleanup levels cannot be set at concentrations lower than natural background when risk-based threshold concentrations (RBTCs; based on a 1×10^{-6} excess cancer risk threshold for individual hazardous substances and a 1×10^{-5} total excess cancer risk threshold for all hazardous substances; or a non-cancer hazard index of 1.0) are below natural background (WAC 173-340-705(6), (706)(6)). As described in the development of preliminary remediation goals (PRGs) in Section 4, the PRGs for total polychlorinated biphenyls (PCBs) and dioxins/furans for the human seafood consumption scenario and for arsenic for all direct contact exposure scenarios are based on estimates of natural background because the 1×10^{-6} RTBC values are lower than natural background. Natural background concentrations are based on the 95% upper confidence limit on the mean (UCL95) of the 2008 EPA Ocean Survey Vessel (OSV) *Bold* survey dataset from Puget Sound (EPA OSV *Bold* survey; EPA 2008 and DMMP 2009). All of the remedial alternatives are expected to leave sediment on site with concentrations above the estimated natural background concentrations for total PCBs and dioxins/furans. MTCA cleanups are interim rather than final until they achieve cleanup standards (WAC 173-340-355(2), 360(4)(d) and (e)). Final CERCLA remedial action that does not meet natural background, where MTCA would require it, will require an ARAR waiver under CERCLA on or before completion of remedial action.

MTCA also includes the requirement to comply with the state SMS, which are intended to reduce and ultimately eliminate adverse effects to biological resources and significant human health threats from sediment contamination. The SMS contain numerical criteria based on protecting the marine benthic invertebrate community (hence the numeric SMS criteria apply to remedial action objective (RAO) 3, but not to the other three LDW RAOs). Cleanup standards under the SMS are established within an allowable range of concentrations, based on consideration of net environmental effects, cost, and technical feasibility, and are applied on a point-by-point basis. The less stringent or upper end of this range is the minimum cleanup level (MCUL) that is not to be exceeded 10 years after completion of the active cleanup actions. The MCUL is the same numerical value as the cleanup screening level (CSL), which defines the upper end of contaminant concentrations associated with minor adverse effects for benthic organisms. The more stringent or lower end of the range is the cleanup objective or sediment quality standard (SQS). Site-specific cleanup standards must be as close as practicable to the SQS/cleanup objective. Longer times to achieve these standards may also be approved where it is not technically practicable to achieve them within a 10-year period.

For this FS, a remedial alternative's ability to achieve the cleanup objective for RAO 3 is estimated based on the following metrics:[2]

- More than 98% of FS surface sediment dataset stations is predicted to achieve the SQS.
- More than 98% of the LDW surface area is predicted to achieve the SQS.

These metrics acknowledge that the SMS has some flexibility in defining practicability to achieve the SQS. In addition, the FS recognizes that, given the uncertainty in predictions of future contaminant concentrations based on model- and contaminant-specific assumptions, achievement of 100% compliance with the SQS may not prove to be practicable. Cleanup standards will be established in the Record of Decision (ROD). Small numbers of SQS exceedances may represent no more than the potential to have

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[2] Estimated areas are based on the sum of Thiessen polygon-derived areas for predicted station exceedances following remediation and are referenced to the total surface area of the LDW (441 acres). Both SMS benthic compliance metrics were defined for use in developing FS area, volume, and cost estimates, and do not represent a metric to be applied for compliance monitoring.

isolated minor adverse effects on the benthic community, and those may not merit further action based on a number of factors, such as sediment toxicity test results, as prescribed in the SMS. Adaptive management measures (e.g., verification monitoring, contingency actions) may become necessary, consistent with the technical feasibility provisions of the SMS, in response to isolated or localized SQS exceedances.

9.1.2 Balancing Criteria

Table 9-1 presents the five balancing criteria for CERCLA remedy selection along with the two threshold and two modifying criteria and summarizes the evaluation factors used to assess each one. The following subsections describe the balancing criteria specifically and the metrics used to evaluate each criterion.

9.1.2.1 Long-term Effectiveness and Permanence

This balancing criterion evaluates the relative magnitude and type of residual risks that would remain at the site after active remediation and passive remediation (monitored natural recovery [MNR]) under each alternative. In addition, long-term effectiveness and permanence assess the adequacy and reliability of the controls that are used to manage residual risks from contamination remaining at the site after remediation (e.g., from subsurface contamination and surface contamination remaining above PRGs) or from treatment residuals.

Magnitude and Type of Residual Risk

Each remedial alternative considered two types of residual risk following cleanup. One is the residual risks to humans, wildlife, and the benthic community from surface sediment contaminant concentrations remaining on site at the completion of active remediation and over time as a result of additional natural recovery. These were estimated using concentration output from the bed composition model (BCM), as described in Section 9.2. The second type of residual risk, the subject for the remainder of this subsection, is the risk from contaminated subsurface sediment that remains in place after remediation (e.g., under caps or in areas remediated by enhanced natural recovery/*in situ* treatment [ENR/*in situ]* or MNR), and which might, through disturbance, be transported to the surface.

CERCLA guidance also refers to residual risk "…from untreated waste or treatment residuals at the conclusion of remedial activities," stating that the "…potential for this risk may be measured by the volume or concentration of contaminants in waste, media, or treatment residuals remaining on the site." Evaluation of this form of residual risk following remediation (including MNR) focuses on the potential for exposure of sediments remaining in the subsurface that contain contaminants of concern (COCs) above levels needed to achieve cleanup objectives. The majority of the incoming sediment load is from upstream inputs rather than lateral inputs, which along with BCM assumptions of contaminant concentrations on these inputs, leads to the prediction that LDW surface sediments will resemble inputs from the Green/

Duwamish River in the long term (i.e., the upstream sediment inflows dominate the long-term predictions). The BCM does not take into account the potential for certain deep disturbance mechanisms to expose subsurface contamination and increase surface sediment contaminant concentrations. Thus, model output does not reflect potential differences among alternatives from this factor.

Disturbance of Subsurface Sediment. Mechanisms for deep disturbance of subsurface sediment include vessels maneuvering under emergency and high-power operations, ship groundings, earthquakes, or operations such as dock construction/maintenance and vessel maintenance activities. Construction is a regulated activity that may be more easily managed through institutional controls than other activities such as vessel scour. Natural erosion or scour from high-flow conditions in the LDW was evaluated as part of sediment transport modeling. As discussed in Section 5.2.3.5, few areas in the LDW that show significant empirical evidence of high-flow erosion (10-cm scour depth or more) also have subsurface contamination. Other scour may occur in the LDW that was not modeled in the FS such as high-power vessel operations, earthquake-induced movements of sediment, and flows larger than the Howard Hanson Dam's ability to regulate.[3] Vessel scour and earthquakes are the mechanisms with the greatest potential to expose subsurface contamination in both magnitude and duration sufficient to increase average surface sediment contaminant concentrations. As discussed in Section 2, earthquakes could expose subsurface contamination as a direct result of the ground motion or indirectly (e.g., tsunamis). Earthquake effects are difficult to predict because the nature and magnitude of ground motions depend on earthquake type, location of the epicenter, and magnitude. Also, exposure of subsurface contamination is not the only means whereby surface sediment concentrations and associated risks can increase following an earthquake. Upland impacts caused by earthquakes, both laterally and upstream (e.g., spills, liquefaction of subsurface materials that could flow to the surface, landslides), could affect post-earthquake surface sediment conditions.

The potential for and magnitude of subsurface contaminant exposure from these disturbance mechanisms decrease as the concentration, depth below mudline, and area of subsurface contamination decrease. Several metrics were used in this FS to semi-quantitatively assess the magnitude of remaining subsurface contamination. This assessment focused on conditions within areas of potential concern (AOPCs) 1 and 2, where the majority of sediment contamination resides in the LDW, and thus where exposure of subsurface sediment has the greatest potential to increase surface sediment concentrations.[4] The metrics used included:

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[3] The Howard Hanson Dam is designed to manage flows at a 144-year return flood or greater.

[4] For perspective, 52 core stations are located in the 110 acres of LDW outside of AOPCs 1 and 2. The mean and UCL95 of the vertically averaged total PCB concentration data from these core stations are

- ***The number of sediment cores in the FS dataset that have COC concentrations above the SQS or CSL at any depth.*** For each alternative, core counts were reported separately for: 1) the area outside of the dredge prism and cap footprint, and 2) the area outside the dredge prism but inside the cap footprint. The FS dataset contains far fewer cores than surface samples, and the cores may not be spatially representative. Many cores were located in areas where available evidence such as a nearby current or historical source indicated subsurface contamination might be present. Nevertheless, the number of cores remaining with SQS or CSL exceedances in these locations is one indicator of subsurface contamination that would remain after implementation of each alternative.
- ***Descriptive statistics (mean, UCL95, and percentiles) of vertically averaged total PCB concentrations for cores remaining outside of the dredge prism and cap footprint.*** These averages were reported for the 0- to 2-foot (ft) and 2- to 4-ft depth intervals (see Appendix M, Part 1, Tables M-9a and M-9b). Descriptive statistics for the vertically averaged total PCB core data across these two depth intervals provides a relative measure of the concentration magnitude with depth for total PCBs, which, if disturbed, could increase surface sediment contaminant concentrations. The 0- to 2-ft depth interval is used as the reasonable maximum depth where contaminated subsurface sediment could be disturbed and exposed in areas with possible significant scour and disturbance. PCB data were used because PCBs are a widespread contaminant in the subsurface, and therefore a good indicator of overall subsurface contamination.
- ***Descriptive statistics (mean) of vertically averaged total PCB concentrations for cores remaining inside the cap and partial dredge/cap footprint***. These averages were reported for the 0- to 4-ft depth interval[5] (see Appendix M, Part 1, Table M-9c**).** This serves a similar purpose as described above in second bullet.
- ***Areas (acres) within AOPCs 1 and 2 that are not dredged and that, as a consequence, leave some degree of contamination in the subsurface.*** Surface areas remediated by technologies other than dredging (removal) serve as another relative indicator of the potential for exposing subsurface contamination. This is because dredging removes the contamination and the

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68 and 120 µg/kg dw, respectively. These parameters are constant across the range of remedial alternatives.

[5] The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4-ft interval was estimated as a vertical average of equal parts clean capping material and native sediment using the total PCB concentration from the 0- to 2-ft and 2- to 4-ft intervals in the subsurface FS baseline dataset.

other remedial technologies leave subsurface contamination in place. This metric does not mean that unacceptable subsurface contaminant concentrations necessarily exist across the full extent of areas not dredged. Nevertheless, more dredged and capped areas within AOPCs 1 and 2 should translate into less subsurface contamination that could potentially be exposed.

The metrics described above are grouped by recovery category for evaluating residual risks in this FS (see Section 6.3 for definition of recovery categories[6]). This distinction is relevant because exposure potential is presumed to be greater in Recovery Category 1 areas compared to areas in Recovery Categories 2 and 3. Natural recovery can be expected to improve and stabilize surface sediments over time in areas designated as either Recovery Category 3, or to a lesser extent, Recovery Category 2.

This analysis also considered that exposure potential is not equal between capped areas and ENR/*in situ* areas or natural recovery areas. Caps are engineered systems in which the cap thickness and material are selected based on well-understood design principles and experience gained through widespread use at other sites. Caps are designed to handle location-specific conditions up to predetermined design thresholds. Areas undergoing ENR or MNR do not have the same degree of protectiveness as caps, because they are not intended to ensure isolation. Thus, the potential for subsurface sediment to be exposed by scour or future uncontrolled human disturbance is greater beneath MNR and ENR areas than in capped areas. The potential for such impacts diminishes in severity and duration as natural recovery (i.e., burial) progresses.

An additional analysis was conducted to address the potential for disturbances to expose subsurface contamination and its effect on surface sediment total PCB concentrations (for details see Appendix M, Part 5 and Section 5.3.1.2). The analysis was designed to estimate effects over a range of cumulative disturbances resulting from an unspecified combination of disturbance mechanisms (e.g., vessels operating outside of normal operating parameters, construction and maintenance of overwater structures, and earthquakes).

Impacts from the cumulative disturbances were assumed proportional to the total area disturbed and the subsurface contaminant concentrations as described below:

- The area disturbed was assumed to be within AOPCs 1 and 2, where the majority of contamination posing unacceptable risk resides in the LDW.
- The frequency, duration, and aerial extent of subsurface sediment disturbance is unknown. The calculations assumed areal disturbances that

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[6] Briefly, Recovery Category 1 areas are presumed to have limited recovery potential because of scour. Recovery Category 2 areas have less certain recovery potential. Recovery Category 3 areas are predicted to recover.

resulted in the continuous exposure of subsurface sediments spanning a range of 0 to 10% (approximately 45 acres) of the LDW.

- The area disturbed was allocated to dredging, capping, and other technologies in proportion to the technology assignments assumed for each remedial alternative.
- The total PCB spatially-weighted average concentration (SWAC) in the portion of disturbed area not remediated by dredging or capping was assumed to be equivalent to the estimated mean subsurface concentration in the 0- to 2-ft interval from cores located outside of the dredge prism and cap footprint.
- The total PCB SWAC of disturbed sediment in dredged or capped areas was assumed to be equivalent to the long-term model-predicted concentration (see Section 9.3 for BCM results).

Results were expressed as an increase in the long-term model-predicted site-wide total PCB SWAC as a function of area continually disturbed (see Figure 2 in Appendix M, Part 5). Since the frequency, duration, and magnitude of such events is unknown, the metric adopted for this analysis is the disturbance area[7] needed to produce a measurable difference in the long-term model-predicted concentration. A difference of 25% is considered the minimum change needed to detect a difference between two SWAC values. This minimum percent difference is based on the collective consideration of sampling variability, analytical variability, statistical considerations, and spatial interpolation methodology. Sample and analytical variability have greater influence on results at lower concentrations. Handling of non-detect values also contribute to variability at lower concentrations. In the RI (Windward 2010), concentration differences at the same locations were considered within the range of analytical variability when results had less than or equal to 25% increase or decrease compared to the initial concentration.[8] Differences in spatial interpolation methods can vary the long-term SWAC value by more than 20% (see Appendix A and Section 10.2.1.3).

Contamination Remaining in Subsurface After Remediation. Additional reference materials were developed for location-specific evaluations of the remedial alternatives in regard to technology assignments, the extent of subsurface contamination removed, the COCs responsible for subsurface sediment contamination (defined for this analysis as detected contaminant concentrations exceeding the SQS). The maps provide a spatial

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[7] The disturbance area would need to be continually exposed over time.

[8] Among analytical methods that are recognized as appropriate, variances of up to 25% in the results are not uncommon. These variances can also occur between two analyses of the same sample using the same method. This analytical uncertainty should be taken into consideration when defining an increase or decrease in the change of concentration values compared to original concentrations (See Section 4.2.3.1 - Resampled Stations from the RI; Windward 2010).

distribution of remaining subsurface contamination not captured in summary statistics. These materials are available in Appendix G as:

- Plan-view maps of the alternatives that show the technology assignments, recovery categories, surface sediment point exceedances above the remedial action levels (RALs) specific to that remedial alternative, and sediment core locations.
- Three-panel maps showing the subsurface contamination remaining in the upper 4 ft of sediment at each core location for each remedial alternative. The panels provide technology assignments, scour areas, recovery categories, and the predicted SMS exceedance status in the 0- to 2-ft and 2- to 4-ft intervals following construction.
- Figures showing all sediment cores outside of the early action areas (EAAs) in the LDW, the SMS exceedance status for each core interval following active remediation, and the technology assignments at each core location for each remedial alternative.
- Tables that provide: 1) the concentrations for all detected COCs that exceed the SQS in the subsurface sediment dataset (excluding cores in EAAs), 2) the recovery category for the area around the core, and 3) the remedial alternative under which the core location and interval is first dredged or otherwise actively managed.

Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage contaminated sediment that remains at the site. For this FS, the assessment focuses on monitoring, maintenance, and institutional controls.

- Alternative 1 assumes completion of monitoring and maintenance specific to the EAA work, as well as institutional controls required under the enforcement agreements governing the EAA work. Alternative 1 adds only LDW-wide baseline and long-term monitoring. The existing seafood consumption advisory issued by the Washington State Department of Health (WDOH) is expected to continue. No environmental covenants are required for areas of contamination outside of the EAAs. No other institutional controls described in Section 8, such as the waterway user's notification program, are required.
- For Alternatives 2 through 6, the amount of monitoring and maintenance is assumed to increase in proportion to the area undergoing remediation by capping, ENR, and MNR. Areas that are dredged yield permanent risk reduction by removing contamination from the LDW. Areas that are capped yield more permanent risk reduction than those addressed by ENR or MNR.

Dredged areas require the least long-term monitoring and maintenance. Capped and ENR areas require moderate amounts of long-term monitoring and maintenance to ensure that subsurface contamination remains in place. MNR requires a longer period of intensive monitoring to track surface sediment conditions over time until results indicate that contaminant concentrations have reached acceptable levels (e.g., PRGs or long-term values below which further reduction is formally found to be impracticable by EPA). In all cases, physical and chemical monitoring data will be used to determine the condition of the remedy. As needed, repairs would likely consist of thin-layer sand applications but could, if necessary, involve engineered cap repair or removal of contaminated sediment. Additional monitoring and maintenance would be included for the EAAs if necessary to make monitoring of these areas consistent with monitoring of similar areas elsewhere in the LDW.

- LDW-wide institutional controls are a required element of Alternatives 2 through 6. As discussed in Section 7, an Institutional Controls Plan for the LDW will include seafood consumption advisories and public outreach and education programs. This is because none of the alternatives can achieve the total PCB and dioxin/furan PRGs that are set to natural background for RAO 1, human seafood consumption. Alternatives 2 through 6 also assume an enhanced notification, monitoring, and reporting program for areas of the LDW where contamination remains in place above levels needed to achieve cleanup objectives following cleanup activities. A third Institutional Controls Plan element is the use of environmental covenants, the primary proprietary control used in federal environmental remediation actions in states such as Washington that have adopted the Uniform Environmental Covenants Act (UECA; see Section 7.2.1). The covenant controls (or prevents) the owners of the property that is subject to the covenant from conducting (or allowing to be conducted) any unconditioned or uncontrolled activity that could result in the release or exposure of buried contaminants to people or the environment. Institutional Controls plans for the EAAs would be modified or created as necessary to be consistent with plans for the rest of the LDW.

For FS evaluation purposes, the adequacy and reliability of the controls (monitoring, maintenance, institutional controls) are assumed to be proportional to the area remediated by capping, ENR, and MNR.

9.1.2.2 Reduction of Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce the toxicity, mobility, or volume of contaminants permanently and significantly. This assessment is accomplished by analyzing the destruction of toxic contaminants, the reduction of the total mass of toxic contaminants, the irreversible reduction in contaminant mobility, or the reduction in total volume of contaminated material that is accomplished by one or more treatment components of the remedial alternative.

The NCP (40 CFR Section 300.430(a)(1)(iii)) states that EPA "generally shall consider the following expectations in developing appropriate remedial alternatives:

- …use treatment to address principal threats posed by a site, wherever practicable. Principal threats for which treatment is most likely to be appropriate include liquids, areas contaminated with high concentrations of toxic compounds, and highly mobile materials.
- …use engineering controls, such as containment, for waste that poses a relatively low long-term threat or where treatment is impracticable."

EPA guidance defines principal threat waste as a source material that is highly toxic or highly mobile that generally cannot be reliably contained or would present a significant risk to human health or the environment should exposure occur, such as drummed waste or pools of non-aqueous phase liquids (EPA 1991a). No direct evidence has been found of non-aqueous phase liquids in LDW sediments and EPA has determined that most of the contaminated sediments in the LDW outside the EAAs are low-level threat wastes.[9]

The maximum concentrations detected for the four human health risk drivers in surface and subsurface sediment are: 2,100 nanograms toxic equivalent per kilogram dry weight (ng TEQ/kg dw) for dioxins/furans, 890,000 micrograms (µg)/kg dw for total PCBs,[10] 2,000 milligrams (mg)/kg dw for arsenic, and 11,000 µg TEQ/kg dw for carcinogenic polycyclic aromatic hydrocarbons (cPAHs). Direct contact risks are low relative to seafood consumption risks (maximum direct contact reasonable maximum exposure [RME] excess cancer risk is 2×10^{-4}, as compared to an excess cancer risk of 3×10^{-3} for seafood consumption; see Tables 3-4a, 3-6a, and 3-6b of the FS).

This balancing criterion is designed to assess the degree to which alternatives comply with the preference for treatment in CERCLA, which is even stronger for material that qualifies as principal threat waste. Removal and disposal, capping, ENR, and MNR are

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[9] One sample collected from the Trotsky area contained 2,900,000 µg/kg dw total PCBs. This sample corresponds to a small volume of oily material that could be considered for treatment after better characterization in the remedial design phase, but it is of insufficient quantity to influence the overall development and evaluation of alternatives. The area in question would be remediated in Alternatives 2 through 6.

[10] Excluding two outliers, the highest of which was 2,900,000 µg/kg dw PCBs (see Section 2.3.2.3).

not treatment technologies under CERCLA.[11] While these technologies reduce mobility and toxicity, they do not do so through treatment. Once contaminated sediment is dredged and disposed of at a landfill, aquatic receptors (e.g., fish and shellfish) cannot come into contact with the material and it cannot bioaccumulate into fish and shellfish and be consumed by humans and wildlife. Capping physically and chemically contains the contaminants beneath the cap, thereby reducing mobility and exposure potential. ENR and MNR reduce surface sediment contaminant concentrations through burial, which in turn reduces mobility and toxicity.

Fifty percent of the total ENR area for each remedial alternative is assumed to include *in situ* treatment using activated carbon or other sequestering agents. Activated carbon lowers the mobility of contaminants, reducing the toxicity and bioavailability to biological receptors directly in areas where it is applied and indirectly site-wide through reduced releases to the water column. Similar agents could also be incorporated into caps to reduce contaminant bioavailability. For this reason, alternatives with more area remediated by ENR/*in situ* rank comparatively higher than alternatives relying on any of the other non-treatment technologies. In addition to *in situ* treatment, Alternative 5R-Treatment includes a soil washing treatment technology.[12]

9.1.2.3 Short-term Effectiveness

Short-term effectiveness addresses how an alternative affects human health and the environment during the construction phase of the remedial action, and until cleanup objectives are achieved. This criterion includes the protection of workers and the community during construction, environmental impacts that might result from construction, and the length of time until cleanup objectives are achieved.

Environmental impacts are evaluated, in part, based on habitat disturbance, dredged material resuspension and releases, consumption of natural resource materials (e.g., for capping), landfill capacity utilization, transportation mileage, particulate matter, and gas emissions (including carbon dioxide [CO_2], nitrogen oxides [NO_x] and sulfur oxides [SO_x]). The degree of habitat disturbance is measured as the amount of active remediation in intertidal and shallow subtidal areas above -10 ft mean lower low water (MLLW). Transportation mileage, particulates (PM_{10}), and gas emissions are used to evaluate potential short-term impacts to the community and workers. Estimates for gas emissions based on heavy equipment use and transportation are provided in Appendix L. In addition, general disruptions and inconveniences to the public and commercial community (e.g., noise and lights from night-time operations, traffic, and

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[11] Some biodegradation and dechlorination of organic compounds can be expected to occur in sediments over the long term. This mechanism is considered to yield limited risk reduction for more recalcitrant contaminants compared to the primary recovery mechanism of burial.

[12] Costs are provided in Appendix I to add treatment by soil washing to any alternative (see also Section 11, Table 11-7).

temporary waterway restrictions) can be expected to increase with the duration of construction. Fish and shellfish tissue concentrations are also expected to increase and remain elevated during the course of the multi-year construction periods and for some time thereafter, based on documented experience at other sites (City of Tacoma and Floyd|Snider 2007b, BBL 1995a and 1995b, Bauman and Harshbarger 1998). As discussed in Section 9.2, the alternatives are organized and sequenced to remediate contaminated sediment using a "worst-first" approach. While COC concentrations in resident fish and shellfish tissue are expected to remain elevated during construction, the concentrations of sediment contamination being remediated would presumably decrease over time as a result of the "worst-first" sequencing. Thus, COC concentrations in resident fish and shellfish tissue, while remaining elevated above predredge concentrations, may decrease as construction progresses toward completion. Reliance on MNR produces none of the short-term environmental impacts associated with construction, but the contamination remains in place and continues to affect human health and the environment while natural recovery processes are taking place.

Resuspension of contaminated sediment is a well documented short-term impact during dredging. Coarser resuspended material resettles, primarily onto the dredged surface and areas just outside the dredge footprint (near-field). Fine-grained material that is slow to resettle may be transported well beyond the dredge operating area (far-field). Dredging also releases contaminants into the dissolved phase (i.e., the water column). Dredging-related mass transfer can be reduced by using BMPs (e.g., silt curtains, debris removal, equipment selection; see Section 7.4.3) but not eliminated.

The total amounts of PCBs transported out of the LDW from dredging, natural erosion of the sediment bed, and pass-through of suspended sediment from upstream are estimated in Part 2 of Appendix M. Releases during dredging and associated export estimates are based on empirical dredge release data from projects that employed BMPs to control such releases. The export estimates are rough approximations, but are considered useful to provide an indication of total PCB export across alternatives. The export analysis also indicates that the greatest source of total PCB exports to Elliott Bay and Puget Sound, over the long term, is from upstream suspended sediments passing through the LDW. Export is estimated at approximately 155 kg of PCBs over a period of 42 years, which corresponds to the construction time of Alternative 6R, the longest construction period among all the alternatives (see Appendix M, Part 2, Figure 4). Dredge releases are predicted to result in greater export of PCBs from the LDW than other sources present within the site (natural bed erosion and lateral inputs), but far less than exports from upstream. Based on the analysis in Appendix M, dredge-release exports (i.e., total mass) are greater for alternatives with longer construction duration.

The time to achieve cleanup objectives is most readily defined as the time from the start of remedial construction to when PRGs are achieved. However, as discussed previously (Section 9.1.1.2) and later in this section (Section 9.3), it is not anticipated to be technically practicable to achieve either PRGs based on natural background or direct contact PRGs for cPAHs at some beaches. In these cases, cleanup objectives are as close as practicable to the PRGs. This FS uses long-term model-predicted concentrations as estimates of "as close as practicable" to the natural background based PRGs. A risk-based metric of 1×10^{-6} is used, instead of the long-term model-predicted concentration, to estimate the time to achieve the direct contact cleanup objective for cPAHs in the beach play scenario.[13] The conditions used in this FS for estimating the time to achieve cleanup objectives are:

- **RAO 1 (Seafood Consumption):** Because long-term modeling results predict that no alternative will meet RAO 1 PRGs for PCBs and dioxins/furans, the time to achieve long-term model-predicted values for these contaminants is used in this evaluation. As discussed in Section 3, clam tissue-to-sediment relationships based on the RI data for both arsenic and cPAHs were too uncertain to develop sediment PRGs. The relationships between clam tissue and sediment concentrations for arsenic and cPAHs and methods to reduce concentrations of these contaminants in clam tissue will be subject to further study in the remedial design and construction phases. Therefore, it is not known at this time whether sediment remediation will reduce cPAH or arsenic concentrations in clam tissues and risks to humans who consume them (see Section 3). Despite these practical limits and uncertainties in remedial performance, risks can be reduced through a combination of active remediation, source control, natural recovery, and institutional controls, with institutional controls being used only to the extent that additional remedial measures cannot practicably achieve further risk reduction.

- **RAO 2 (Direct Contact):** The time to achieve the following metrics is the time to achieve cleanup objectives for RAO 2:

  - Where possible, the time to achieve PRGs for all three direct contact exposure scenarios (i.e., netfishing, tribal clamming, beach play)

  - Time to reduce concentrations such that total excess cancer risks (all four risk drivers combined) are less than or equal to 1×10^{-5} and a non-cancer hazard index less than or equal to 1

  - Where the model predicts that certain PRGs may not be met:

    - Time to reduce concentrations such that excess cancer risks for cPAHs is less than or equal to 1×10^{-6}

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[13] As a result of rounding, predicted cPAH concentrations of up to 134 µg TEQ/kg result in an excess cancer risk estimate of 1×10^{-6}.

  - Time to reduce arsenic concentrations such that excess cancer risks are less than 1 × 10^{-5} and long-term model-predicted values are achieved. [14]

- **RAO 3 (Benthic):** As discussed in Section 9.1.1.2, for the purpose of this evaluation, the metrics used to assess achievement of cleanup objectives for RAO 3 are at least 98% of FS surface sediment dataset stations and more than 98% of the LDW surface area with contaminant concentrations or toxicity test results below the SQS.

- **RAO 4 (Ecological):** Time to achieve the RAO 4 PRG for total PCBs in surface sediments, which corresponds to a hazard quotient of 1 for river otters.

These predicted outcomes are based on modeling and therefore are subject to uncertainty (see Section 9.3.5). Uncertainty bounds on time to achieve cleanup objectives (using the metrics described above) were not estimated.

9.1.2.4 Implementability

This criterion assesses the technical and administrative feasibility of implementing a remedial alternative and the availability of services and materials required for implementation. Technical feasibility encompasses the complexity and uncertainties associated with the alternative, the reliability of the technologies, the ease of undertaking additional remedial actions if necessary, and monitoring requirements.

Administrative feasibility includes the activities required for coordination with other offices and agencies (e.g., obtaining permits for any off-site activities or rights-of-way for construction). For example, a key administrative feasibility factor for the LDW is that in-water construction is not allowed year round to protect juvenile salmon and bull trout migrating through the LDW. The in-water work window is assumed to be October 1 to February 15, a period that will be confirmed by EPA in consultation with the National Marine Fisheries Service and U.S. Fish and Wildlife Service before implementation. In addition, coordination with the Tribes is necessary to ensure that impacts to tribal fishing are minimized during remedial activities.

Availability of services and materials includes the availability of necessary equipment, materials, and specialists, and the ability to obtain competitive bids for construction. Dredging and capping are mature technologies. Similar remedial and non-remedial (maintenance, construction) actions have been implemented in the LDW and elsewhere in the Puget Sound region. Services, equipment, and materials (e.g., sand and aggregate) are locally or regionally available. Regional upland landfills are authorized

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[14] None of the remedial alternatives are likely to achieve the direct contact PRG for arsenic, which is based on natural background concentrations, and therefore the long-term model-predicted concentration range is used.

to receive contaminated sediment and have done so on several recent projects in or near the LDW. Debris is expected to complicate, but is not likely to significantly delay, construction efforts.

One significant technical implementability challenge is remediation under piers and other above-water structures. For example, diver-assisted hydraulic dredging is difficult to implement and a potentially dangerous activity from a worker health and safety perspective. A suite of potential remedial actions was described in Section 8 that, based on location-specific engineering evaluations, can be implemented in areas under and around overwater structures. Maintaining flexibility in construction methods through the remedial design phase is an important consideration for these areas.

The LDW is a working industrial waterway that has the necessary infrastructure to support sediment remediation activities. Nevertheless, careful coordination will be required among government agencies and private entities to design, schedule, and construct the cleanup actions. Further, it will be important to evaluate whether source controls have been implemented to a sufficient degree before or as a part of remedy construction (e.g., to stabilize erodible embankments) to limit recontamination potential.

Institutional controls are a requirement of all remedial alternatives to manage human health risks from seafood consumption (Section 8.2.2.6). The primary control mechanisms are seafood consumption advisories in conjunction with public education and outreach programs. In addition, environmental covenants will be used to protect capped, ENR, and MNR areas where contamination is left in place above levels needed to achieve cleanup objectives. Both controls are difficult to monitor. Environmental covenants are difficult to enforce. Seafood consumption advisories are not enforceable and are generally understood to have limited effectiveness. One objective of the public education/outreach effort is to improve compliance with the advisories. Concerns associated with use of these institutional controls include the burden placed on Tribes exercising their treaty rights and other people who fish in the LDW (see Section 7.2.2.2). Institutional controls should therefore be relied upon only to the minimum extent practicable. These programs would likely be developed and administered by the responsible parties with EPA and Ecology oversight and with participation from local governments, Tribes, and other community stakeholders.

Metrics used to gauge the relative magnitude of technical and administrative implementability of the alternatives include the surface areas actively managed (dredging and all active technologies) and the dredge volumes, because areas and volumes are considered proportional to the degree of difficulty to implement and manage them. Acreage subject to MNR is also considered because passive remediation in the form of MNR requires significant administrative effort over the long term to oversee and coordinate sampling, data evaluation, and contingency actions, if needed.

9.1.2.5 Cost

The cost criterion evaluates the capital and long-term operation, monitoring, and maintenance (O&M) costs of each remedial alternative. O&M costs include long-term maintenance, repair, and monitoring costs for dredging, capping, ENR/*in situ*, and MNR. This criterion also includes costs for long-term monitoring and institutional controls. Costs for contingency actions are included in the O&M to account for the potential that some areas assumed in the FS as suitable for no action or less aggressive technologies (e.g., ENR or MNR) will require dredging based on information gained either during remedial design or as a result of long-term monitoring. This specific contingency action cost and the separate 35% contingency factor applied to capital costs (see Appendix I) are assumed to cover a range of assessment and repair work that might be needed (e.g., following an earthquake of moderate but not severe magnitude). Consistent with CERCLA guidance, the cost estimates were prepared in the absence of detailed engineering design information and have a target level of accuracy ranging from +50% to -30% (see Section 8.4.7 and Appendix I).

It is important to recognize that the scale, complexity, and uncertainties associated with a large sediment remediation project, such as for the LDW, may contribute to cost estimation inaccuracies beyond those typically encountered in a CERCLA FS for smaller, less complex projects. The actual costs of the sediment cleanup in the LDW depend on the final scope of the remedial action, along with the implementation schedule, actual labor and material costs at the time of implementation, competitive market conditions, and other variable factors that may affect project costs.

The cost estimates developed in this FS are expressed in net present value (2011) dollars and are calculated using a discount rate of 2.3% (see Appendix I for details). Discount factors take into account the time value of money and the difference between the expected rate of return on invested funds and the expected rate of inflation. The duration of the construction for some remedial alternatives is predicted to span a period longer than 10 years (Alternatives 4R, 5R, 5R-T, 6C, and 6R), which could be associated with significant inflationary pressures depending on economic conditions. In particular, fuel prices and landfill tipping fees are not likely to remain at current levels. Increases in fuel prices will translate into higher construction, transportation, and disposal costs.

The estimated total cost to complete the in-water work for the EAAs is approximately $95 million, based on documented costs for the Diagonal/Duwamish, Slip 4, and Norfolk projects and projected engineering and construction costs for Terminal 117, Boeing Plant 2, and Jorgensen Forge. This cost is provided for informational purposes, but is not included in the estimated costs for Alternatives 1 through 6 because those actions are not part of the alternatives being evaluated in this FS. However, completion of the EAAs alone contributes substantially toward risk reduction and overall cleanup of the LDW (see Section 9.2) while impacting overall costs. Further, the cost estimates in this FS do not include any investments in upland source control, upland cleanups adjacent to or near the LDW, long-term monitoring of EAAs, or habitat mitigation. Discussions of cost uncertainty and sensitivity related to key cost factors (e.g., dredged material volume) are presented in Appendix I.

9.1.3 Modifying Criteria

The final two detailed evaluation criteria are the modifying criteria: state and tribal acceptance and community acceptance.

Ecology co-issued the RI/FS Order and has overseen its implementation with EPA. Based on discussions with EPA and Ecology, this FS anticipates that Ecology will work with EPA to select the preferred remedy published in the Proposed Plan and will similarly work with EPA on the ROD. While the community acceptance criterion refers to acceptance of EPA's preferred alternative in its Proposed Plan, rather than the FS, the input of both tribal and community groups was sought during preparation of the FS, including quarterly meetings with resource agencies, the community advisory groups, and tribal representatives. In late 2010, EPA and Ecology invited the public to review and comment on the October 2010 Draft Final FS for the LDW. More than 300 letters were received from individuals, businesses, interest groups, tribes, and government agencies. The information from these letters was summarized in a March 2011 Fact Sheet. Following are the key topic areas contained in the letters:

- The importance of reducing pollution entering the LDW to avoid new contamination and to help keep cleaned-up areas from becoming contaminated again (i.e., source control).
- Concern about the cost of the cleanup and who will pay for it.
- Concern that cleanup of the LDW is not anticipated to achieve contaminant concentrations that would allow people to eat an unrestricted amount of resident fish and shellfish.
- A desire for flexibility in cleanup decision-making.
- A request for an environmental justice analysis to identify vulnerable communities affected by the cleanup, and how these communities will be affected by each of the alternatives.

EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the ROD following the public comment period on EPA's Proposed Plan. In the interim, community and stakeholder groups will continue to be engaged by EPA and Ecology during quarterly stakeholder meetings and in other forums.

9.2 Tools Used to Estimate Contaminant Reduction Over Time

Performance of the remedial alternatives is, in part, evaluated based on reductions in contaminant concentrations (and therefore risks) over time. The BCM predicts changes over time in surface sediment concentrations of COCs resulting from sediment deposition, surficial mixing, and burial, the primary mechanism of natural recovery in the LDW. Section 5 provides a description of the model, its relationship to the sediment transport model (STM), and contaminant concentrations associated with incoming sediments (e.g., upstream and lateral). The framework for applying the BCM to each remedial alternative is discussed herein. An important element of the BCM framework is how each remedial alternative is sequenced both spatially and temporally. Later in Section 9.3.1, surface sediment contaminant concentrations modeled using the BCM are presented and discussed for each remedial alternative.

9.2.1 Temporal Concepts

Figure 9-1 illustrates several temporal concepts that have specific meanings for discussing and evaluating the remedial alternatives. First, construction of the selected remedy will not begin immediately following issuance of the ROD. Several years will likely elapse before construction begins. This time prior to construction of the remedy will allow for completion of the EAAs, priority source control, negotiation of a Consent Decree (or other enforcement action, such as issuance of a Unilateral Administrative Order(s) by EPA) for the performance of remedial action, remedial design/planning, baseline monitoring, and verification monitoring. The construction period is the time assumed necessary to construct each remedial alternative. The in-water construction period for each alternative spans multiple work seasons, as described in Section 8. The BCM is used to predict changes in surface sediment SWACs through remediation and natural recovery, beginning with construction and extending for a period of 45 years. The 45-year model period includes the 42-year construction period of Alternative 6R. The BCM uses as its starting condition completion of the EAAs; it assumes no natural recovery prior to the start of construction of the FS alternatives. The BCM output is used to predict the time to achieve cleanup objectives (see Section 9.1.2.3).

9.2.2 BCM Framework Adopted for the Remedial Alternatives

The BCM uses STM output in 5-year increments across a 30-year hydrograph of the Green/Duwamish River (Section 5). This section discusses how the 5-year temporal output is reconciled with the estimated construction periods of the remedial alternatives.

Figure 9-2 depicts the BCM framework for the remedial alternatives developed in Section 8. The framework produces output in 5-year intervals commensurate with the STM results, which were also provided in 5-year intervals.[15] The estimated construction

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[15] Conducting the analysis in shorter (e.g., 1-year) intervals confers too high a level of model accuracy given model input parameters. Specifically, model results are dependent on the annual hydrograph applied from one year to the next. Therefore, longer periods of analysis on the order of 5- to 10-year increments represent average predicted responses that are more appropriate for evaluating processes such as natural recovery that take place over multi-year time scales.

periods for each alternative are shown in the second column of Figure 9-2. The construction periods are estimated to the nearest year and, therefore cannot be matched exactly with the 5-year BCM intervals. The construction periods and the 5-year model intervals are reconciled by using the 5-year BCM output nearest the construction period as described in the following examples:

- Alternative 3C has an estimated construction period of 3 years. For this case, the 5-year BCM output for the area outside the actively remediated footprint and replacement values applied within the actively remediated footprint are used to calculate SWACs for each exposure area. These SWACs approximate surface sediment conditions at the end of construction. This time frame reconciliation method results in a 2-year calculation bias. That is, the end of construction SWACs for Alternative 3C reflect two additional years of natural recovery outside the actively remediated footprint, and do not account for two years of natural recovery within the actively remediated footprint that would have occurred if the replacement values could be applied at Year 3 instead of Year 5.
- Similarly, Alternative 3R has an estimated construction period of 6 years. Again, the 5-year BCM output for the area outside the actively remediated footprint and replacement values applied within the actively remediated footprint are used to calculate SWACs for each exposure area that, in turn, approximate surface sediment conditions at the end of construction. However, in this case, the time frame reconciliation results in a 1-year calculation bias wherein the end of construction SWACs do not account for one year of natural recovery outside the actively remediated footprint, and do not reflect an additional year's worth of natural recovery within the actively remediated footprint that would have occurred if the replacement values could be applied at Year 6 instead of Year 5.

In all cases, this method of reconciling the construction and model output periods results in no more than a 2-year bias. This is well within construction period and model uncertainties, and as becomes apparent later in this section and in Section 10, has a negligible to minor effect on the evaluation of the alternatives in terms of effectiveness and time to achieve cleanup objectives.[16]

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[16] The effect of rounding to the nearest BCM 5-year model output can result in a bias of more than 2 years in the time to achieve cleanup objectives for some alternatives. For example, assuming the desired SWAC outcome is not met at year 15 but it is met at year 20, it is unknown when the actual outcome occurs because it could be any time between these two time periods. The interval between two time periods is not interpolated, and predictions are not made on finer resolution than 5-year increments.

A second important feature of the model is the assumed temporal sequencing or allocation of each remedial alternative's actively remediated footprint. Because it is impossible to predict the actual sequencing of multi-year remediation projects, sequencing was consistent across the remedial alternatives to the extent practicable. This simplifies the BCM analysis and allows for a comparable analysis across alternatives. The sequencing has two elements:

- The combined and removal alternatives are, respectively, sequenced such that the footprints of smaller alternatives (e.g., Alternative 3R) are assumed to be remediated first as part of the larger alternatives (e.g., Alternative 5R). In this manner, the larger footprint alternatives build upon the smaller ones and all alternatives therefore remove higher priority (hot spots) areas first.
- Once the opportunity to sequence actions under the smaller alternatives is exhausted, remediation of the remaining area is spatially sequenced from upstream to downstream in 5-year increments defined using dredge production rate assumptions (applies only to Alternatives 6C and 6R).

Thus, specific areas identified for active remediation as part of two different remedial alternatives are assumed to be remediated at the same time in the BCM framework. For example, Alternative 6C is constructed over a 16-year period and spans three BCM intervals. Construction during the first 5 years is sequenced exactly like Alternative 5C. At this point, Alternative 6C is approximately one-third complete. The framework assumption for the balance of Alternative 6C is to incrementally progress from the head of the LDW (near the Upper Turning Basin) to the mouth of the LDW (Reach 1), upstream to downstream. This sequencing is illustrated in Figure 9-3. The more complex sequencing of Alternative 6R is shown in Figure 9-4. The latter more clearly shows the assumed progression of active remediation from upstream to downstream. This sequencing aspect of the BCM framework is assumed only to lend consistency to the FS evaluation of remedial alternatives and is not intended to constitute or represent a specific sequencing recommendation. The assumed sequencing from more contaminated areas to less contaminated areas in the BCM framework predicts a more optimal decline in SWACs than what would occur if the remedial actions were coordinated and sequenced differently. This is discussed in greater depth as part of the comparative evaluation of alternatives (Section 10.2.3.4).

The BCM framework models natural recovery from the beginning of construction but only for those areas that are not being actively remediated. Therefore, in any 5-year period, all areas of the LDW that are not undergoing active remediation are being modeled for sediment inputs to the existing bed. Areas outside of the active remediation footprint are modeled using the full complement (30 years) of STM output in 5-year intervals. Areas that undergo active remediation and that are then modeled into the future after construction use STM output that excludes contributions to bed composition during the period prior to construction. This is indicated in Figure 9-2 by the subscripted numerical values associated with each 5-year interval. For example, the active portion of Alternative 3 is remediated in the first 5-year period. This area receives the post-remedy bed sediment replacement value at the end of construction (see Section 5) and the BCM predicts changes in surface sediment contaminant concentrations from that point forward. At Year 10 of the hydrograph, the BCM calculation for this same area uses STM output representing conditions between Years 5 and 10 of the hydrograph. This is indicated by the symbol 10_5.[17] Also, in cases where active remediation for a given area begins five or more years into the overall construction period, the BCM is applied to that specific footprint both before and after construction.

Finally, surface sediment contaminant concentrations at the start of construction (and BCM modeling) for Alternatives 2 through 6 assume post-remedy bed sediment replacement values in the EAA areas. Concentrations across the remainder of the LDW are interpolated values from the FS baseline surface sediment dataset (Appendix A). This is likely a conservative assumption on two fronts. It does not account for the approximately 20-year period over which much of the data were collected and during which some level of natural recovery has potentially occurred. It also does not account for natural recovery during the period of remedial design, priority source control, and EAA clean up, all of which are presumed to occur in a 5-year period before the start of construction of any of the other alternatives.

9.2.3 Food Web Model Application for the Remedial Alternatives

A food web model (FWM; Windward 2010) was developed for the RI/FS to estimate relationships between total PCB concentrations in surface sediment, the water column, and seafood tissue for the purposes of: 1) estimating RBTCs for total PCBs in sediment for the seafood consumption scenarios (see Section 8 and Appendix D of the RI), and 2) assessing residual risks in the FS from PCBs following remediation to support the detailed and comparative evaluation of alternatives.[18] For both purposes, the key input to the FWM are total PCB concentrations found both in surface sediment and in water. These input concentrations are coupled with diet and biological uptake assumptions in the FWM to predict total PCB concentrations in the tissue of aquatic species that are found in the LDW following remedial action.

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[17] Because Alternative 6R has an estimated construction period that exceeds 30 years (i.e., the span of the hydrograph used in the STM), the hydrograph and associated STM output are repeated (starting over at year zero) through the end of BCM modeling.

[18] Of the four risk drivers (arsenic, cPAHs, dioxins/furans, and PCBs) only PCBs were modeled using a food web bioaccumulation model. Most of the risk from arsenic and cPAHs was related to consumption of clams, and the relationships between arsenic and cPAH concentrations in clams and sediment were too uncertain to derive predictive regression models. Dioxins and furans were not modeled because tissue data were not collected; risks from dioxins/furans associated with seafood consumption were assumed to be unacceptable and thus remedial efforts for dioxins/furans will be based on background and other feasibility considerations. Additional efforts will be undertaken to examine the relationship between concentrations of arsenic and cPAHs in clam tissue and sediment.

In the FS, total PCB surface sediment concentrations were predicted for each alternative over time using the BCM (see Sections 5.2 and 9.2.2). Predictions of total PCB concentrations in the water column were based on ranges of total PCBs in sediment and on an assumed relationship between total PCB concentrations in the water column and in surface sediment. Three different total PCB water concentrations were used, as described below:

- 0.6 nanograms per liter (ng/L) water concentrations when surface sediment has total PCB concentrations less than 100 µg/kg dw. This water concentration was estimated by considering model output derived from King County's Environmental Fluid Dynamics Code (EFDC) model (see Appendix D of the RI). The model assumed an average LDW-wide total PCB sediment concentration of 40 µg/kg dw, a total PCB water concentration from the Green/Duwamish River (upstream of the LDW) of 0.1 ng/L, and zero PCB input from lateral sources (e.g., storm drains). This water concentration was used for the majority of the residual risk analyses.
- 0.9 ng/L water concentrations when surface sediment has total PCB concentrations between 100 and 250 µg/kg dw. This water concentration was selected because it is halfway between the 0.6 ng/L described above and the 1.2 ng/L described below.
- 1.2 ng/L water concentrations when surface sediment has total PCB concentrations greater than 250 µg/kg dw. This water concentration was assumed based on the best-fit parameter set used in the FWM for the RI (Table D.5-3 in the RI). This concentration is slightly below the LDW-wide mean concentration of 1.43 ng/L (Table D.4-1 of RI) estimated by the EFDC model and the mean concentration of 1.3 ng/L for the 2005 empirical data (see Table D.4-2 of the RI). This water concentration was used to portray baseline conditions.

As a point of reference, total PCB concentrations in water from the Green/Duwamish River, which is the upstream source of surface water to the LDW, ranged from 0.04 to 0.8 ng/L in 2005 and from 0.04 to 2.4 ng/L in 2007 (Mickelson and Williston 2006; Williston 2008). The total PCB concentration in water in Elliott Bay, the source of saline water to the LDW, ranged from 0.056 to 0.089 ng/L in 2005 (Mickelson and Williston 2006).

9.3 Predicted LDW-wide and Area-specific SWAC and Risk Reductions

Risk-driver concentrations following remediation, as well as estimates of risk based on these concentrations are key metrics for evaluating effectiveness of the remedial alternatives. This section summarizes site-wide and area-specific SWACs and risks over time for each alternative. This information is referred to and used throughout the remainder of this FS. These model results are based on the best-estimate BCM input parameters that were developed earlier in Section 5. Additional perspective on the sensitivity of model output to changes in input parameters is also provided.

9.3.1 Changes in Sediment Bed Concentrations

Table 9-2a contains the site-wide, clamming area, and beach play (as a single area) SWACs predicted using the BCM output for total PCBs, arsenic, cPAHs, and dioxins/furans. The results are tabulated as a function of time, with time=0 being the point when construction of each remedial alternative begins (with the exception of Alternative 1, which has no additional construction after completion of the EAAs). Table 9-3 contains model-predicted SWACs for the individual beaches.

Figures 9-5a through 9-5h plot the site-wide SWACs from Table 9-2a to enable visual appraisal of the time trends. The combined-technology and removal-technology alternative results are shown on separate figures. Excluding Alternative 1, the model predicts a similar long-term decline in site-wide SWACs among the remedial alternatives. Twenty years represent a reasonable approximation of when the long-term model-predicted trends flatten out and yield very little additional reduction with more time. The combined alternatives are predicted to reduce SWACs more rapidly than the removal alternatives, because the former actively remediate a larger footprint in a shorter period of time. This is because more acreage can be remediated by capping and ENR than by dredging during each construction season. Thus, for example, Alternatives 5C and 6C are predicted to reduce the total PCB SWAC to 70 µg/kg dw in 5 years, whereas Alternatives 3R through 6R reduce the SWAC to 86 µg/kg dw (approximately a 20% difference) in the same period of time. A similar comparison of differences at the 5-year mark (i.e., short term) shows smaller differences for the other risk drivers, except arsenic, which exhibits negligible differences among the alternatives.

Table 9-2b presents model results for the SMS risk drivers. As discussed in Section 5, the BCM was applied on a point basis to SMS risk drivers using the following representative contaminants: phthalates, metals, and individual PAH compounds, along with PCBs and arsenic. These contaminants were sufficiently represented with upstream and lateral data from which BCM input values could be established (see Section 5.2 for more details of this analysis). The model output was converted to the two metrics assumed in this FS for evaluating whether the alternatives are expected to achieve the SQS: the percentage of FS dataset stations predicted to comply and the percentage of LDW surface area predicted to comply (see Section 9.1.1.2). Values for the area-based metric are charted as a function of time in Figures 9-6a and 9-6b.

From information presented in the foregoing tables and figures, the following general observations can be made, organized here by RAO:

- **RAO 1 (Table 9-2a; Figures 9-5a through 9-5h)**
  - In the long term, concentrations (SWACs) for total PCBs and dioxins/furans are predicted to reach very similar values regardless of alternative, in varying time frames with varying degrees of uncertainty, a consequence of burial by upstream (Green/Duwamish River) sediments.
  - None of the alternatives are predicted to achieve total PCB and dioxin/furan PRGs for the human seafood consumption scenario; these PRGs are based on natural background concentrations.
- **RAO 2 (Tables 9-2a and 9-3; Figures 9-5a through 9-5h)**
  - All alternatives reduce total PCB and dioxin/furan concentrations below the direct contact PRGs for all exposure scenarios.
  - All alternatives reduce cPAH concentrations below the PRGs established for the netfishing and tribal clamming scenarios.
  - The cPAH PRG for the beach play scenario (90 µg TEQ/kg dw) is predicted to be met in the long term at Beaches 2, 6, and 8. The model predicts that the cPAH PRG is not achieved at all other beaches. This is mostly a function of the post-remedy bed sediment replacement values and the lateral input values used in the model, because in many cases the entire beach play areas are remediated. In the case of Beach 3, model results are influenced by assumptions used for outfall discharges in that beach area, which may not be reflective of actual discharges at that location.
  - The direct contact PRG for arsenic, based on the natural background value of 7 mg/kg dw, is closely approached (within 2 to 3 mg/kg dw), but is not predicted to be achieved in any exposure area by any of the remedial alternatives. This is because the mid-range upstream (9 mg/kg dw) and post-remedy bed sediment replacement values (10 mg/kg dw) used in the model are higher than natural background.
- **RAO 3: (Table 9-2b and Figures 9-6a and 9-6b)**
  - Alternative 1 is predicted to require 20 years of natural recovery after construction to achieve the SQS.

  - Alternatives 2 through 6 are predicted to achieve the SQS before the end of construction, at the end of construction, or, in the case of Alternative 2, within 10 years after construction.[19]

- **RAO 4: (Table 9-2a; Figures 9-5a and 9-5b)**
  - All alternatives are predicted to achieve a site-wide total PCB SWAC well below the PRG (128 µg/kg dw) for protection of the river otter.

The BCM results plotted in Figures 9-5a through 9-5h are based on values of upstream, lateral, and post-remedy bed sediment replacement model input parameters that represent best estimates of what will influence LDW contaminant concentrations over time (see Section 5.2.3). However, best estimate values are based on limited data and are uncertain. Therefore, calculations were performed to gauge the sensitivity of remedial alternative outcomes to the range of input parameter values previously developed in Section 5 (Table 9-4). Uncertainty bounding of the trends in Figures 9-5a through 9-5h is represented using the Alternative 6R BCM output. The uppermost curve is based on using all high input parameters and the lowermost curve is based on using all low input parameters.[20] The differences in model SWAC results using the low-end and high-end input parameters range from less than a factor of 2 (for arsenic) to nearly an order of magnitude (for total PCBs).

Assuming reasonably effective source control, SWACs are predicted to approach values reflecting the upstream inputs. However, inputs from all sources are time-variable and difficult to predict; high and low bounds on these estimates are included to capture this uncertainty. In addition, as noted in Section 9.1.2.1 and Appendix M, Part 5, subsurface contamination remaining in areas of the LDW that are neither dredged nor capped has the potential to become exposed and alter the predicted SWACs. Future monitoring will be required to evaluate actual changes in the long-term concentrations achieved during and after active remediation.

As discussed in Section 4, no alternative is predicted to achieve the RAO 1 PRGs for total PCBs and dioxins/furans, which have been set to natural background in this FS. Also, seafood consumption risks for the arsenic and cPAHs were not quantified in the RI/FS as discussed in Section 3.3.1. Therefore the evaluation of alternatives uses an estimate of the best practicably achievable result, based on long-term model-predicted concentrations for total PCBs and dioxins/furans. Table 9-5 presents differences among

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[19] Alternatives 2 and 3 were not originally designed to achieve the SQS within 10 years after construction, but the FS's comparative model runs include natural recovery processes outside of the active footprint during construction. The result is that lower surface sediment contaminant concentrations are predicted in a shorter time.

[20] Refer to Table 9-4 for bounding results for each individual alternative. Low and high sensitivities of risk-driver SWACs to BCM input values for all exposure areas (site-wide, clamming, and individual beach play areas) are available in Appendix M, Part 1 (Tables M-6 and M-7 series).

the alternatives using long-term, model-predicted, site-wide SWACs from Alternative 6R (the most aggressive of the remedial alternatives) as the basis for comparison.[21] The results are based on using the mid (base case) BCM input values (Table 9-2a). Due to the dominant influence of the upstream input parameters in the model, the alternatives converge to the same approximate SWACs over time. Differences among the alternatives compared to the "base" (Alternative 6R) for arsenic, cPAHs, and dioxins/ furans are very insensitive to time and descend to low single digit percentages in 15 to 25 years. Differences for total PCBs are slightly more pronounced. For example, the total PCB SWACs for Alternatives 3C, 3R, 4C, 4R, 5C, and 5R are within 25% of the long-term Alternative 6R value in 15 years and decline slowly to about a 3 to 9% difference by the end of the model run (45 years). Based on this analysis, risk-driver concentrations are assumed to reach long-term values when the site-wide PCB SWAC decreases to the range of 40 to 50 µg/kg dw.

9.3.2 Changes in Tissue Concentrations for Total PCBs

Table 9-6 presents predictions of total PCB concentrations in fish and shellfish tissue using the FWM, assumed water concentrations, and site-wide total PCB SWACs estimated using the BCM (as discussed in Section 9.2.3). Predicted total PCB concentrations in tissue are not shown during the construction period because tissue contaminant concentrations are expected to remain elevated as a result of contaminants being released to the water column during in-water construction activities.

Because the FWM used similar long-term sediment and water concentrations for each alternative, when comparing the same time period, predicted PCB tissue concentrations are similar for each alternative that has completed construction. For example, 15 years after construction begins, all alternatives completed by that time are predicted to achieve PCB tissue concentrations in English sole fillets of approximately 200 to 240 µg/kg ww.

The output from the FWM has inherent uncertainties, as described in Section 9.3.5.2 of the FS and in Appendix D of the RI (Windward 2010). In the FS, uncertainty in predicted tissue concentrations is partly attributable to using: 1) BCM-predicted surface sediment concentrations that are outside of the empirically based calibration range of the FWM and 2) predictions of future water column concentrations.

To partially investigate these uncertainties, analyses were conducted by varying total PCB concentrations in sediment and water. Specifically, the effect of varying total PCB concentrations in water from 0.1 ng/L to 0.9 ng/L was assessed assuming a total PCB sediment concentration of 45 µg/kg dw. This surface sediment concentration fell within

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[21] Additional estimated risk-driver concentrations in surface sediment during and following construction of each remedial alternative and for other areas of the LDW are available in Appendix M, Part 1. Table M-1 compiles sediment concentrations by Reaches 1, 2, and 3, while Table M-2 summarizes SWACs for intertidal areas.

the range of site-wide and reach-wide long-term SWACs for various remedial alternatives from the draft final FS. FWM runs with total PCB surface water concentrations ranging from 0.1 and 0.9 ng/L resulted in predicted tissue concentrations on the order of ± 35% from those estimated using 0.6 ng/L. Excess cancer risk and non-cancer hazard quotient estimates using the various water assumptions were within a factor of two of each other (see Appendix M, Part 4).

Sensitivity analyses were also conducted by varying the total PCB concentration in surface sediment at a water concentration of 0.6 ng/L. The model results presented in Table 9-6 use mid-range upstream and lateral sediment inputs to the BCM. Using low-range or high-range sediment input values instead would result in lower or higher tissue concentration predictions, respectively, on the order of ± 60% (see Appendix M, Part 4).

9.3.3 Risk Reduction for Human and Ecological Health

The SWAC predictions discussed above can be used to estimate the risks associated with total PCBs for human health seafood consumption (RAO 1), the risks associated with all four risk drivers for human health direct contact (RAO 2), and risks associated with total PCBs for river otter (RAO 4). These estimates are relevant to evaluating the effectiveness of the remedial alternatives.

9.3.3.1 Excess Cancer Risks from Resident Seafood Consumption

Table 9-7a summarizes estimates of excess human cancer risks from consuming seafood that contains PCBs for all remedial alternatives at various times. Tissue concentrations estimated by the FWM (Windward 2010; Table 9-6 of this FS), using site-wide total PCB SWACs in surface sediments, were used to estimate risks.[22]

A substantial portion of the baseline risks associated with the consumption of resident seafood in the LDW is attributable to total PCBs. Total excess cancer risk from resident seafood consumption (i.e., from PCBs, cPAHs, and arsenic) in the LDW is of the same magnitude as the risk from total PCBs (Windward 2007b). It is unknown how much dioxins/furans contribute to overall baseline risks because tissue data were not collected for all species and locations evaluated for the other risk drivers.[23] Given

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[22] Uncertainties associated with the STM and BCM models (as assessed in Section 9.3.5) are additive to the uncertainties associated with the food web model (see Section 9.3.5).

[23] Dioxins and furans are not included in the total excess cancer risk calculation for the RME seafood consumption scenarios. However, after the Human Health Risk Assessment (HHRA; Windward 2007b) was finalized, a small dataset became available for skin-off English sole fillets from a May 2007 Puget Sound Ambient Monitoring Program (now the Puget Sound Assessment and Monitoring Program) sampling effort near Kellogg Island. The risks associated with dioxins/furans would be 6×10^{-5} for the Adult Tribal RME scenario (Tulalip data) (see Table 3-5 of Section 3 for more information). These risks for dioxins/furans were calculated based on the assumption that all seafood in the market basket diet for the RME scenarios had the same dioxin/furan concentrations as those in the fillets of English sole collected in 2007 near Kellogg Island. These dioxin/furan risk estimates are lower than the 2×10^{-3} baseline risks for total PCBs.

that: 1) total seafood consumption risk is of the same order of magnitude as PCB risks, and 2) it is not possible to predict cPAH and arsenic seafood consumption risks from their sediment concentrations based on available data (see Section 3.3.1), the use of total PCB risks to evaluate total risk reduction posed by various alternatives is reasonable.

It is uncertain to what extent the remedial alternatives will reduce seafood consumption risks associated with arsenic, cPAHs, and dioxins/furans. Remediation of dioxins/furans to background sediment concentrations will reduce risks to the maximum extent practicable. The majority of the risk associated with cPAHs and arsenic is associated with consumption of resident clams. Further research will be done in the remedial design phase to better understand the effect of sediment remediation on arsenic and cPAH tissue concentrations in clams. It is also uncertain whether any remedial alternative will achieve the MTCA risk threshold of 1×10^{-6} for cPAHs. Finally, none of the alternatives are expected to achieve the MTCA risk threshold for arsenic because tissue concentrations from non-urban areas of Puget Sound exceed the risk threshold of 1×10^{-6} (see Appendix B).

Lifetime excess cancer risks associated with PCBs for all three RME seafood consumption scenarios evaluated in the RI are represented in Table 9-7a.[24] Effectiveness of the remedial alternatives is discussed in this section for the three RME scenarios. Results for the non-RME scenarios (see Appendix M, Part 1) provide additional context for purposes of risk communication. Color shading in Table 9-7a identifies predicted excess cancer risk, which is rounded to the nearest order of magnitude for each calculated value. Figures 9-7a through 9-7c present the predicted residual total PCB seafood consumption risks for the three RME scenarios at the end of construction and 10 years after construction for each remedial alternative. Note that once construction is complete, the predicted seafood consumption excess cancer risk corresponding to the Adult Tribal RME scenario is similar for Alternatives 2 through 6, is uniformly of magnitude 10^{-4} (between 2×10^{-4} and 3×10^{-4}), and does not decrease further regardless of the remedial alternative (Table 9-7a). Excess cancer risk is also predicted to be similar in the long term among alternatives for the Child Tribal RME scenario (risks from 3×10^{-5} to 4×10^{-5}) and the Adult Asian and Pacific Islander (API) RME scenario (risks of 5×10^{-5} to 6×10^{-5}). Risk estimates using mean total PCB concentrations in non-urban tissue from Puget Sound (see Appendix B) are shown in Figures 9-7a through 9-7c for informational purposes.

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[24] See Appendix M, Part 1 (Table M-3), for excess cancer risks for the non-RME (informational) seafood consumption scenarios.

9.3.3.2 Non-cancer Risks from Resident Seafood Consumption

Table 9-7b[25] summarizes estimates of non-cancer hazard quotients for humans based on RME seafood consumption scenarios and for river otters from consuming seafood that contains total PCBs. No alternative is predicted to result in non-cancer hazard quotients of less than 1.0 for the human health RME scenarios. For the river otter, all remedial alternatives are predicted to result in hazard quotients of less than 1. Figures 9-8a through 9-8c show the human health residual seafood consumption non-cancer hazard quotients for total PCBs at the end of construction and 10 years after construction. The predicted Adult and Child Tribal RME seafood consumption non-cancer hazard quotients associated with total PCBs exceed 1 for all alternatives. In the long term, Alternatives 2 through 6 are predicted to have a non-cancer hazard quotient of either 4 or 5 for these scenarios and the hazard quotient does not decrease further regardless of the remedial alternative. Non-cancer hazard quotients estimated using mean concentrations of non-urban PCB tissue data from Puget Sound (see Appendix B) are shown in Figures 9-8a through 9-8c for informational purposes.

9.3.3.3 Direct Contact Risks

Total direct contact excess cancer risks for the four human health risk drivers combined are presented in Table 9-8 and Figures 9-9a and 9-9b. Total excess cancer risks are 1×10^{-5} or less for all exposure scenarios after completion of the EAAs. Direct contact excess cancer risks from total PCBs and dioxins/furans are reduced by all alternatives to less than 1×10^{-6} (the MTCA requirement) for all exposure scenarios (Tables M-5a and M-5d). For cPAHs, long-term predicted excess cancer risks are less than 1×10^{-6} (the MTCA requirement) for the netfishing (site-wide) and tribal clamming scenarios (Table M-5c). For cPAHs, excess cancer risks at the individual beaches are predicted to be at 1×10^{-6} or lower with one exception, Beach 3 (Beach 3 is actively remediated, but recontamination is predicted; Table M-5c). Direct contact excess cancer risks for arsenic are between 1×10^{-5} and 1×10^{-6} for all alternatives (1×10^{-6} excess cancer risks are below natural background concentrations) (Table M-5b).

Under baseline conditions, unacceptable direct contact non-cancer hazard quotients were predicted only for total PCBs at Beach 4 (Section 3.2.2). This area is actively remediated by Alternative 2 and therefore unacceptable non-cancer hazard quotients are not expected for any direct contact scenario for Alternatives 2 through 6.

9.3.4 Other Analyses

Appendix M provides other model results, residual risk tables, and additional analyses for the remedial alternatives. The appendix is organized as follows:

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[25] See Appendix M-Part 1 (Table M-4) for non-cancer hazard quotients for the non-RME (informational) seafood consumption scenarios.

- Part 1 (Remaining BCM Output, Residual Risks, and Post-remedy Bed Sediment Replacement Value Sensitivity Runs): Predicted concentrations for risk drivers in surface sediment during and following construction, excess cancer risks, and non-cancer hazard quotients are presented. These include predicted surface sediment concentrations of the four human health risk drivers for three LDW reaches (Table M-1) and intertidal areas (Table M-2). In addition, for each remedial alternative, Tables M-3 and M-4 present estimated total PCB risks for alternative human health seafood consumption scenarios (i.e., other than the reasonable maximum exposure [RME] scenarios). The Table M-5 series presents estimated risks for human health direct contact scenarios for each risk driver (only total excess cancer risks were shown in Table 9-8). Low and high sensitivity of risk-driver SWACs and corresponding excess cancer risks for direct contact are presented for the individual risk drivers in the Table M-6 series and the Table M-7 series. Post-remedy bed sediment replacement value sensitivity runs using predicted site-wide total PCB SWACs are presented in Table M-8 and Figures M-1 through M-24. The Table M-9 series present summary statistics for subsurface sediment concentrations remaining after construction in capped, partially dredged and capped, ENR, MNR, verification monitoring, and AOPC 2 areas at 0- to 2-ft, 2- to 4-ft, and more than 4-ft depths.

- Part 2 (Memorandum – Estimate of PCB Exports from the Lower Duwamish Waterway): Exports of PCBs from the LDW as a result of natural erosion of bed-source sediments and exports associated with dredging losses are estimated. Site-related PCB export is compared to export from upstream and lateral sources. PCB export is discussed in Section 9.1.2.3 (Short-Term Effectiveness).

- Part 3 (Memorandum – Change in Total PCB Mass in Surface Sediment for Remedial Alternatives Calculated Using the Bed Composition Model): Mass of total PCBs in the top 10 cm of surface sediment for each remedial alternative. For each remedial alternative, changes in the total mass of PCBs in surface sediments (0 to 10 cm) of the entire LDW were estimated both at the completion of construction and following the 45-year period over which natural recovery was modeled. The focus of these estimates was on surface sediments because those represent exposure in the biologically active zone.

- Part 4 (Food Web Model Sensitivity): FWM output and associated predicted seafood consumption risks based on different assumptions of total PCB concentrations in water (Figure 1) and FWM output and associated predicted seafood consumption risks based on low, mid, and high BCM inputs (Figure 2).

- Part 5 (Potential Exposure of Subsurface Contamination – Evaluation of Effects on Total PCB SWAC): The potential for deep disturbances to expose subsurface contamination remaining in the upper 4 ft after active remediation and the potential effect on surface sediment total PCB concentrations (see additional discussion in Section 9.1.2.1).

9.3.5 Uncertainty Considerations When Evaluating Alternatives

The information presented in Sections 9.2 and 9.3 serves as a foundation for evaluating whether, to what extent, and when the remedial alternatives reduce concentrations and risks to levels needed to achieve cleanup objectives. Uncertainty in various forms is inherent in the methods used for this analysis. This section discusses the nature and potential magnitude of uncertainty to inform the detailed evaluation of alternatives (Sections 9.4 through 9.9) and the comparative evaluation to follow (Section 10). Individual factors contributing to uncertainty and the magnitude of each are presented first, followed by a summary discussion of how this information can be considered in the evaluation of alternatives, especially Alternatives 3 through 6. Alternatives 1 and 2 may have greater uncertainty bounds than described herein. Alternative 1 assumes active remediation of only the EAAs has been completed and it relies on natural recovery in the remaining areas (including Recovery Category 1 areas). Alternative 2 leaves some "hot spot" areas of contamination in place and calls for MNR in Recovery Category 1 areas, which, as defined previously, have a low expectation for recovery.

9.3.5.1 Surface Sediment Concentration Estimates

Sediment Transport Model

Uncertainty in the STM predictions resulting from uncertainty in the model input parameters was examined in the STM report (QEA 2008). This analysis was used to develop both reasonable and maximum reasonable upper and lower bounding simulations. These simulations were intended to provide a reasonable range of net sedimentation rates for the LDW. The reasonable and maximum reasonable upper and lower bounding simulations were used to evaluate how STM uncertainty affected BCM results. The results from these bounding simulations are discussed in Section 5.5.2 and in Appendix C, Part 6 and are briefly summarized here.

STM results were taken at the end of the 10-year model run for reasonable and maximum reasonable upper and lower bounding simulations around the base case. These were used as inputs to the BCM to compute the total PCB SWAC for each simulation assuming a surface sediment concentration profile following remediation of the EAAs. Relative to the base-case total PCB SWAC predictions, the bounding simulation results were as follows:

- Reasonable lower to upper STM simulations: -16% and +31%
- Maximum reasonable lower to upper STM simulations: -19% and +35%.

If the calculations were modeled for a longer period of time, these bounding differences would narrow, because the range of sedimentation rates has diminished influence on predictions of surface sediment contaminant concentrations over longer periods of time. In the short term, alternatives that rely on more natural recovery, like Alternatives 1, 2, and 3, will be affected more by this uncertainty. The long-term SWAC could be higher (or lower) than the best-estimate model predicted concentrations, and the recovery time to reach them, depending on system processes (i.e., sedimentation, scour) and all of the alternatives would be affected similarly.

Bed Composition Model

For the BCM, uncertainty exists in the contaminant concentration input: the existing sediment bed (i.e., before remediation starts), the post-remedy bed sediment replacement value and both lateral and upstream sources. This uncertainty will exist well into the future based on the variable nature of these sources. However, a range of concentrations were developed (in Section 5) to evaluate the uncertainty in lateral, upstream, and post-remedy bed sediment replacement values. Specifically, the best-estimate BCM input values were bracketed by lower- and upper-bound values based on statistical analysis of several line-of-evidence datasets. For the lateral inputs, the low and high estimates are meant to capture a range of uncertainty associated with potential future source control measures. Note also that for any set of lateral and upstream inputs, the post-remedy bed sediment replacement values have diminished influence over time on SWAC predictions and associated uncertainty. This is because in the long-term the replacement value contributes progressively less to the concentration calculation.

Table 9-4 provides SWAC predictions for each remedial alternative using the following different combinations of the low, mid (i.e., base case) and high parameter values:

- All low BCM input values
- All high BCM input values
- Mid (upstream and replacement value), high (lateral) BCM input values.

For comparison with the STM bounding outcomes discussed above, the total PCB SWAC for Alternative 1 at Year 10, differs by -37% to +64% from the base case estimate. Thus, the SWAC calculation is more sensitive to the range of BCM contaminant concentration input values than it is to the range of net sedimentation rates from the STM bounding simulations discussed above.

At the end of the 45-year modeling period, the total PCB SWAC is predicted to be approximately 40 µg/kg dw for all alternatives. The bounding simulations (all low and then all high input parameters) produce concentrations of approximately 10 and 100 µg/kg dw respectively. Table 9-4 also contains results of modeling wherein the upstream and post-remedy bed sediment replacement parameters are set to mid values and the lateral value is set to high. This results in 45-year model predicted total PCB SWACs between 50 and 55 µg/kg dw. This indicates that the calculations are most sensitive to the upstream values, and also suggests that regional source control can improve the long-term results. Similar observations, but varying in the magnitude of differences, apply to arsenic, cPAHs, and dioxins/furans (Table 9-4).

For evaluating the remedial alternatives, these results have much the same effect as described above for STM uncertainty. The interim and long-term SWACs will likely vary around the base case best-estimate and within the indicated range, and all of the alternatives should be affected similarly.

Exposure of Subsurface Sediment

The STM and BCM do not address mechanisms such as vessel scour, maintenance activities, earthquakes, and construction projects that have the potential to expose subsurface contamination left in place following remediation. As discussed in Sections 5.3.1.2, 5.5, and 9.1.2.1, these mechanisms may disturb and expose subsurface contamination. This may result in increased contaminant concentrations in surface sediment over what is predicted by the BCM. It is not possible to reliably evaluate earthquake-induced effects, and therefore, they are not included in this analysis.

Two types of uncertainty in the subsurface sediment exposure analysis may affect surface sediment predictions: 1) the fact that the available cores in AOPCs 1 and 2 may not be representative of subsurface conditions over these broad areas contributes to uncertainty in the mean subsurface concentrations used in the analysis, and 2) a lack of information on how much of the LDW might be affected by disturbances. Therefore, a range of conditions (number of acres disturbed) were represented in the subsurface sediment exposure analysis.

SWAC vs. UCL95

The statistic used to represent spatially-weighted contaminant concentrations is important in determining whether and when cleanup levels are achieved. CERCLA and MTCA require that health-protective estimates of contaminant concentrations be used to assess site risks and determine compliance with cleanup levels. This is typically done by using the UCL95 contaminant concentration. The UCL95 is an upper-bound probability estimate of the average concentration.

The sediment data used to support the FS were collected for various reasons, and are not randomly located. In general, sampling locations were concentrated in areas with high levels of contamination, and more widely spaced in areas with lower levels of contamination. Computation of average contaminant concentrations from available data unadjusted for over-representation of contaminated areas will overestimate LDW-wide contaminant concentrations.

Consequently, in the FS, inverse distance weighting (IDW) interpolation was used to reduce the effect of higher density sampling in contaminated areas on calculating LDW-wide contaminant concentrations of arsenic, total PCBs, and cPAHs. The concentration statistic derived from IDW interpolations is the SWAC. SWACs are used in the FS to estimate whether and when cleanup objectives are achieved.

Unfortunately, there is no general consensus in the scientific community on reliable procedures for developing UCL95 on SWACs calculated from the concentration grids that are the outputs of the BCM. For this reason, the SWAC approach was used in the FS for comparing the remedial alternatives. The use of SWACs rather than the UCL95 to evaluate the effectiveness of the remedial alternatives may therefore result in lower estimates of area-wide concentrations and risks.

The uncertainty introduced by using model-predicted SWACs in the FS, instead of UCL95 values, is considered acceptable for comparing and contrasting the alternatives because differences between the two are likely much smaller than the range of uncertainty in model output attributable to other factors, as discussed above. Further, the error (whether under or overpredicted) is expected to be consistent among alternatives. Over the long term, the difference between the empirically-derived SWAC and UCL95 will diminish as the variance in the collected data is reduced by both active and passive remediation.

Ultimately, determination of residual risks and compliance with risk- and background-based standards will be determined using UCL95 values based on actual post-remediation monitoring data.

9.3.5.2 Estimation of Risks Associated with Future Seafood Consumption

The key uncertainties in estimating future seafood ingestion risks presented in Section 9.3.3 are associated with the exposure assumptions selected in the baseline human health risk assessment (HHRA) (Windward 2007b) and the predictions of seafood tissue concentrations using the FWM. These uncertainties are discussed below.

HHRA Exposure Assumptions

In the HHRA, various seafood consumption scenarios were developed to characterize human exposure in the LDW. Because knowledge of current and future site use is imperfect, the scenarios evaluated in the HHRA were intended to provide a health-protective estimate of future risks. However, their applicability to the future is uncertain.

Important input parameters in the HHRA included the following, all of which could be different in the future: seafood consumption rate, diet composition, and exposure frequency/duration.

In addition, total seafood consumption risks in the HHRA were calculated as the sum of risk estimates for numerous contaminants, with the majority of seafood ingestion risk being associated with PCBs, arsenic, and cPAHs. However, post-remedy tissue concentrations could only be estimated for PCBs for the following reasons. The majority of the risk associated with arsenic and cPAHs was attributable to the consumption of clams; however, the clam tissue-sediment relationships for arsenic and cPAHs were too uncertain to predict future risks for these COCs. In addition, fish and shellfish tissue data were not collected to estimate current or future risks for dioxins/furans. Thus, only residual risks associated with PCBs could be estimated for the various remedial alternatives, and those underestimate total risk to an unknown extent.

Food Web Model

The FWM was developed to estimate the relationship between total PCB concentrations in fish and shellfish tissue and sediment. This relationship was used to estimate seafood consumption RBTCs for total PCBs in sediment for the RI (Windward 2010) (see Section 8 in the main body of the RI and Appendix D, Section D.9) and to estimate residual risks from consumption of PCBs in seafood that may remain following various sediment cleanup actions. Three key uncertainties are associated with the use of the FWM for calculating residual risks:

1) The FWM was calibrated using tissue data collected in the late 1990s through 2005. The FWM has never been used with a different set of sediment and water concentrations to assess how accurately it can estimate tissue concentrations outside the range to which the FWM was calibrated. It is unknown how predictive the model will be under lower sediment concentrations following remedial actions.
2) There is uncertainty in the predicted post-remedy sediment PCB concentrations that are a key input parameter to the FWM. These post-remedy sediment PCB concentrations are based on the BCM, which is subject to its own set of uncertainty issues, as described above in Section 9.3.5.1.
3) There is uncertainty in the estimated post-remedy water PCB concentrations that are also a key input parameter to the FWM, especially at low sediment concentrations, and where subsurface contaminated sediment remains that may increase contaminant concentrations in the water column if the sediments are disturbed. The FWM becomes increasingly sensitive to the water PCB concentration as the sediment PCB concentration decreases. These post-remedy water PCB concentrations are estimated using best professional judgment.

Sections 9.2.3, 9.3.2, and 9.3.5.1 discuss the uncertainties associated with the sediment and water PCB concentrations used as input to the FWM, and how higher or lower sediment or water PCB concentrations could affect FWM-predicted tissue PCB concentrations.

A complete discussion of FWM uncertainties and sensitivities is provided in Appendix D of the RI (Windward 2010).

9.3.5.3 Summary

STM/BCM predictions indicate that over the 45-year model period, the sediments depositing in the LDW will be dominated by upstream Green/Duwamish River solids. Therefore, all of the remedial alternatives are predicted to approach contaminant concentrations similar to those on upstream Green/Duwamish River solids in the long term. The quantified uncertainty for modeled predictions is greater than the projected differences in outcomes among alternatives.

The model-predicted surface sediment SWACs do not account for exposure of buried contaminated sediments by mechanisms such as emergency vessel scour in areas that are neither dredged nor capped. As described above and in Appendix M, Part 5, a range of subsurface scour areas was evaluated for its potential effect on the total PCBs SWAC. While the STM/BCM predict similar long-term outcomes among all the alternatives, consideration of subsurface contamination indicates that alternatives that remove more subsurface contamination would be more likely to achieve the long-term model-predicted SWAC. Adaptive management, included in the O&M program, could potentially address adverse effects of disturbances that expose subsurface contamination, but its efficacy is tied to the ability to identify and make repairs as needed.

Prediction of tissue concentrations and associated human health risks from the total PCB SWAC estimates are compounded by uncertainties in FWM predictions and uncertainties in the underlying human health risk estimates. Thus, predicted future tissue concentrations and associated risks could be over or underestimated and should be viewed as only approximations. The predictions of tissue concentrations and risks are nevertheless useful for comparing the alternatives because the uncertainties in the FWM and risk assessment methods are the same for all alternatives and all of the alternatives would be affected similarly.

9.4 Detailed Analysis of Alternative 1: No Further Action

Alternative 1 consists of monitoring site conditions after completing cleanup actions at the EAAs (29 acres; Table 9-9). This alternative 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).[26]

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[26] Alternative 1 is the designated CERCLA "no action" alternative. The analyses of alternatives for the EAA removal actions are documented in other reports and are not addressed in this FS.

9.4.1 Overall Protection of Human Health and the Environment

The EAAs were previously identified as containing some of the highest levels of sediment contamination in the LDW. Cleanups have already been conducted at three EAAs (two under a 1991 Natural Resource Damages (NRD) Consent Decree and one under an EPA CERCLA removal order). EPA cleanup decisions for the other two EAAs have been issued. This FS assumes that cleanup of these EAAs will be completed, regardless of which remedial alternative is selected for the remainder of the LDW. No project-specific engineering or institutional controls are assumed for areas outside of the EAAs. Therefore, reduction of contaminant concentrations and risks outside of the EAAs will occur only to the degree achieved by ongoing natural recovery processes.

The stacked bar chart in Table 9-9 shows the predicted relative contributions that completing the EAAs and natural recovery make toward reducing human health risk-driver (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) concentrations in surface sediment from the baseline concentrations. The completion of the EAAs reduces the site-wide total PCB SWAC by approximately 49%. Natural recovery is predicted to reduce total PCB concentrations by an additional 27% in the long term. Reduction of the site-wide arsenic SWAC after completion of the EAAs and with natural recovery is predicted to be approximately 41% in the long term. With this reduction, the predicted arsenic SWAC is approximately 2.5 mg/kg dw above the natural background concentration of 7 mg/kg dw. Reduction in the site-wide cPAH SWAC after completion of the EAAs is an estimated 9% and natural recovery is predicted to contribute to significant cPAH SWAC reduction (64%) in the long term. The completion of the EAAs accounts for an estimated 8% reduction in the site-wide dioxin/furan SWAC, but natural recovery is predicted to yield an additional 74% reduction in this risk driver over the long term. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximations because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future. Predictions for Alternative 1 have the highest uncertainty because the alternative leaves the largest area of unremediated subsurface contamination in place.

Alternative 1 is predicted to provide limited protection of human health and the environment. While it is predicted to achieve cleanup objectives for some of the RAOs, it includes no provisions for site-wide institutional controls to manage residual risks. Alternative 1 includes site-wide monitoring to ascertain actual levels of protection achieved over time. However, the alternative does not assume any actions (e.g., contingency actions) in response to the monitoring data.

With these considerations, Alternative 1 does not meet the threshold criterion of overall protection of human health and the environment.

9.4.2 Compliance with ARARs

Alternative 1 similarly does not comply with ARARs because it is not predicted to achieve certain MTCA and surface water quality numerical cleanup standards and does not include institutional controls (other than those developed for the EAAs), beyond the existing WDOH seafood consumption advisory, to manage residual risks. Alternative 1 would also not meet the MTCA requirement (WAC 173-340-440(6)) and similar CERCLA policy for primary reliance on remediation rather than institutional controls.

PRGs for total PCBs and dioxins/furans (seafood consumption by humans) and arsenic (direct contact) are unlikely to be achieved, because the PRGs for these exposure scenarios are based on natural background (a MTCA requirement). Compliance with some water quality standards also may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs.

9.4.3 Long-term Effectiveness and Permanence

9.4.3.1 Magnitude and Type of Residual Risk

Under Alternative 1, remediation of the EAAs combined with ongoing natural recovery processes are predicted to reduce risks over time, but Alternative 1 is not expected to achieve cleanup objectives for all RAOs. The long-term residual excess cancer risks to humans consuming seafood that contains total PCBs are predicted to be 2×10^{-4} and 3×10^{-5} for the Adult Tribal RME and Child Tribal RME scenarios, respectively. Non-cancer hazard quotients are predicted to be 5 and 10 for the Adult and Child Tribal RME scenarios, respectively. For RAO 2, the total direct contact excess cancer risk (all four risk drivers combined) in each exposure area is predicted to be less than or equal to 1×10^{-5} and the non-cancer hazard index is predicted to be less than 1. Residual excess cancer risks for direct contact are predicted to be 1×10^{-6} or less for total PCBs, dioxins/furans, and cPAHs for all areas except at Beach 3 for cPAHs (Appendix M, Tables M-5a, M-5c, and M-5d). Excess cancer risks for direct contact from arsenic remain between 1×10^{-5} and 1×10^{-6} in all exposure areas. Ultimately, adverse effects to the benthic community are unlikely because surface sediment concentrations are predicted to be reduced to the SQS within 20 years, through ongoing natural recovery. Finally, the residual hazard quotient for wildlife consumption of seafood containing total PCBs is predicted to be less than 1.

Table 9-10 presents the post-construction sediment conditions for Alternative 1; this alternative leaves all contaminated sediment outside of the EAAs in place. An area of 63 acres (40 in AOPC 1 and 23 in AOPC 2) is identified as Recovery Category 1. Areas with lower exposure potential (approximately 140 acres in AOPC 1 and 99 acres in AOPC 2) are in Recovery Categories 2 and 3. This alternative leaves a total of 70 core stations in place that contain subsurface sediment exceeding the CSL in unremediated areas; 25 of these cores are located in Recovery Category 1. The remaining 45 core stations are located in Recovery Categories 2 and 3.

Based on the approach outlined in Section 9.1.2.1, Table 9-10 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place for Alternative 1, after the completion of the EAAs. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining, and areas of potential concern are presented by recovery category and depth below mudline for the area within AOPCs 1 and 2. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Contamination located in the 0- to 2-ft sediment depths is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 70 cores with concentrations greater than the CSL remain outside of the EAA footprint. The mean total PCB concentrations in all of the remaining cores are 431 and 486 µg/kg dw in the 0- to 2-ft and 2- to 4-ft depth intervals, respectively (Table 9-10; upper panel).
- Areas Outside EAAs – The sediment surface area outside of the EAA footprint is 302 acres, of which 63 acres reside in Recovery Category 1 areas, 40 in AOPC 1, and 23 in AOPC 2 (Table 9-10, center panel).
- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain outside of the EAA footprint are illustrated in the lower panel of Table 9-10. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are likely to expose buried contamination in the upper 2 ft, an area of approximately 11 acres at this mean concentration (431 µg/kg dw) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5).

9.4.3.2 Adequacy and Reliability of Controls

With the exception of the likely continuation of the existing seafood consumption advisory and site-wide monitoring, no controls extend to areas outside the EAA boundaries. This geographic limitation on controls would not be adequate for managing residual risks elsewhere at the site. Alternative 1 retains the greatest amount of contaminated subsurface sediment (see Section 9.4.3.1 and Table 9-10) that could be exposed at the surface and which could be difficult to identify and manage into the future.

9.4.4 Reductions in Toxicity, Mobility, or Volume through Treatment

No treatment is included in Alternative 1 to reduce toxicity, mobility, or volume of contaminated sediments. A treatment element (carbon amendment to reduce the mobility of contaminants [Integral 2007]) was included in the Slip 4 EAA cap; however, the EAAs are being performed pursuant to past decisions and only future actions to be addressed in the ROD are subject to evaluation in this FS.

9.4.5 Short-term Effectiveness

9.4.5.1 Community and Worker Protection

Alternative 1 assumes no further remedial action following construction of the EAA projects. Alternative 1 would not cause any additional risks to the community and workers from construction. Risks to workers and the community associated with monitoring are considered negligible.

9.4.5.2 Environmental Impacts

Environmental impacts associated with implementation of Alternative 1 are negligible because the only physical activity is monitoring. The total exports of PCBs from the LDW from the upstream and lateral sources and from natural erosion of the sediment bed over the course of 42 years are estimated to be 155, 8, and 3 kg, respectively (see Figure 4 in Appendix M, Part 2).

9.4.5.3 Time to Achieve Cleanup Objectives

Achievement of RAO 1 will likely ultimately require a combination of remediation and institutional controls. Alternative 1 is predicted to achieve the RAO 1 cleanup objectives discussed in Section 9.4.3.1 in 25 years, but does not include institutional controls to manage any residual risks.

Alternative 1 is predicted to achieve the MTCA total excess cancer risk (all four risk drivers combined) threshold (1×10^{-5}) for all direct contact exposure areas for RAO 2 within 5 years (after the end of EAA construction). Within 25 years, this alternative is also predicted to achieve a direct contact risk threshold of 1×10^{-6} through natural recovery for total PCBs, cPAHs, and dioxins/furans (considered individually), except for Beach 3 (cPAHs; Table 9-9).

Similarly, Alternative 1 is predicted to achieve the cleanup objective for RAO 3 (i.e., the SQS) within 20 years, through ongoing natural recovery.

Finally, Alternative 1 is predicted to achieve the total PCB cleanup objective associated with RAO 4 within 5 years through natural recovery.

9.4.6 Implementability

Alternative 1 is administratively implementable. The only action undertaken is monitoring. Further, because this is the CERCLA no action alternative, no contingency actions are assumed to be undertaken in response to monitoring data.

9.4.7 Cost

The cost for Alternative 1 is $9 million for site-wide monitoring, agency oversight, and reporting. The cost for completing construction of the EAAs is approximately $95 million, based on documented costs for the Diagonal/Duwamish, Slip 4, and Norfolk projects and projected engineering and construction costs for Terminal 117, Boeing Plant 2, and Jorgensen Forge. These EAA costs are provided here for informational purposes and are not used in the comparative analysis of alternatives.

9.4.8 State, Tribal, and Community Acceptance

Alternative 1 is unlikely to be acceptable to the state, tribes, and community. Stakeholder comments and concerns have and will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.5 Detailed Analysis of Alternative 2R

Scope, performance, and cost summaries for Alternatives 2R and 2R with contained aquatic disposal (2R-CAD) are presented in Table 9-11.

9.5.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Table 9-11 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternatives 2R and 2R-CAD emphasize removal and disposal of sediment from the actively remediated areas. Alternative 2R-CAD disposes a portion of dredged material in one or more CAD facilities, whereas all contaminated sediment that is dredged by Alternative 2R goes to upland landfill disposal. Both alternatives address 32 acres of contaminated sediment through dredging and partial dredge and cap, and have an MNR footprint of 125 acres. These two alternatives have an estimated construction period of 4 years during which short-term effects to the community, workers, and the environment occur as described in Section 9.5.5 below.

The stacked bar chart in Table 9-11 shows the relative contributions that construction and natural recovery make toward reducing surface sediment concentrations of the four human health risk drivers (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) from the baseline concentrations. Completion of the EAAs, coupled with the 32 acres of dredging and partial dredging/capping in Alternative 2R, are predicted to reduce the site-wide total PCB SWAC by approximately 59%. Natural recovery is predicted to reduce total PCB concentrations by an estimated additional 29% in the long term. In the long term, the site-wide arsenic SWAC is predicted to be reduced an estimated 42% after completion of the EAAs, construction of the active components of Alternative 2R, and natural recovery. With this reduction, the predicted arsenic SWAC is approximately 2 mg/kg dw above the natural background concentration of 7 mg/kg dw. The site-wide cPAH SWAC is predicted to be reduced an estimated 22% after completion of the EAAs and the active components of Alternative 2R. Natural recovery is predicted to contribute to additional cPAH SWAC reduction in the long term. Completion of the EAAs and active remediation of Alternative 2R together are predicted to reduce the site-wide dioxin/furan SWAC nearly 70%. Natural recovery is predicted to yield an additional 14% reduction in this risk driver over the long term. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximations because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future. Predictions for Alternative 2R and 2R-CAD are more uncertain than for subsequent alternatives, because they assume that unremediated subsurface contamination in scour areas will not be exposed in the future.

Neither Alternative 2R nor 2R-CAD can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenarios (RAO 1). Alternatives 2R and 2R-CAD are predicted to achieve cleanup objectives for human health direct contact (RAO 2) with the exception of arsenic (which is set to natural background) and cPAHs at certain beaches, as discussed further below. Both alternatives are predicted to achieve the SQS (RAO 3 PRG) within 10 years after the 4-year construction period, for a total of approximately 14 years. The PRG for protection of wildlife (RAO 4) is predicted to be achieved by both alternatives.

Long-term residual risks from contaminated surface and subsurface sediment left in place are predicted to be similar for both alternatives, except that 2R-CAD includes an on-site CAD that will have to be managed in perpetuity, as discussed below in Section 9.5.3. Estimated times to achieve cleanup objectives (i.e., the PRGs associated with each RAO or long-term model-predicted concentrations/risk thresholds) and other interim risk reduction milestones are shown in the lower panel of Table 9-11 and discussed in Section 9.5.5.3.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are implemented to reduce seafood consumption exposures. Further, LDW-wide recovery processes are monitored to assess the reduction in long-term human health risks. Long-term monitoring, maintenance, and institutional controls are required for both alternatives. The level of effort associated with these activities is expected to be greater for Alternative 2R-CAD. While both alternatives use partial dredging and capping and MNR over a surface area of 128 acres, 2R-CAD has an additional 23 acres of CADs to monitor and maintain.

9.5.2 Compliance with ARARs

Alternatives 2R and 2R-CAD are expected to comply with ARARs except as follows:

- The alternatives are unlikely to achieve the total PCB and dioxin/furan PRGs for human seafood consumption. These PRGs are MTCA-based ARARs that are set at natural background because the RBTCs are below natural background.
- Similarly, the alternatives are unlikely to achieve the arsenic PRG for direct contact (another MTCA-based ARAR). This PRG is based on natural background, because the RBTC is below natural background.
- Surface water quality in the LDW is expected to improve as a result of sediment remediation and upland source control. However, compliance with some federal and state water quality standards (ARARs) may not be feasible, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs.

ARAR waivers based on technical impracticability may be issued by EPA for a final remedial action that cannot achieve ARARs.

In addition, the alternatives are predicted to achieve the SQS within 10 years after the 4-year construction period, for a total of 14 years. However, given predictive uncertainties, this may not be practicably achievable. If this were the case, EPA and Ecology may authorize a longer cleanup time frame if they find it is not practicable to achieve the cleanup standards (as defined by WAC 173-340-570(4)) within a 10-year period (WAC 173-204-580[3][b]).

9.5.3 Long-term Effectiveness and Permanence

9.5.3.1 Magnitude and Type of Residual Risk

The active remedial measures of Alternatives 2R and 2R-CAD reduce surface sediment contaminant concentrations (Tables 9-2a, 9-2b and 9-3) and the BCM predicts that further reductions will continue over time until the long-term model-predicted values are reached (Figures 9-5a through 9-5h). Residual risks from contaminated surface sediment left in place are predicted to persist into the future, subject to incremental changes tied to source control and continuing natural recovery. The long-term residual excess cancer risks to humans consuming seafood that contains total PCBs are predicted to be 2×10^{-4} (Adult Tribal RME) and 3×10^{-5} (Child Tribal RME). The Adult and Child Tribal RME seafood consumption non-cancer hazard quotients associated with total PCBs are predicted to be above 1, at 5 and 10, respectively. The total direct contact excess cancer risk (all four risk drivers combined) in each exposure area is predicted to be less than or equal to 1×10^{-5} and the non-cancer hazard index is predicted to be below 1.0. Residual excess cancer risks for direct contact are predicted to be 1×10^{-6} or less for total PCBs, dioxins/furans, and cPAHs for all areas, except for cPAHs at Beach 3 (Appendix M, Tables M-5a through M-5d). Direct contact risks from arsenic are predicted to remain between 1×10^{-5} and 1×10^{-6} in all exposure areas. Ultimately, adverse effects to the benthic community would be addressed because surface sediment concentrations are predicted to be reduced to below the SQS through natural recovery. Finally, the residual hazard quotient for wildlife consumption of seafood containing total PCBs is predicted to be less than 1.

Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place after active remediation is complete. Alternatives that remediate more area by removal through dredging or isolation through capping (with long-term monitoring and maintenance of the cap) have lower potential for residual risks from exposure of subsurface sediment by all disturbance mechanisms. Alternatives 2R and 2R-CAD dredge or partial dredge/cap only 32 acres (Table 9-11). The CAD facility, within which dredged material is deposited and contained, is estimated to cover an area of 23 acres. The potential for exposure of subsurface sediments in capped areas would be limited through engineering design of the caps, monitoring, and institutional controls.

The greatest exposure potential is from areas outside of the dredge, cap, and CAD footprints where subsurface contamination is expected to remain without the isolation provided by the cap or CAD. Based on the approach outlined in Section 9.1.2.1, Table 9-12 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining, and areas remediated by technologies other than dredging within AOPCs 1 and 2 are presented by recovery category and depth below mudline. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Sediment contamination located in the 0- to 2-ft depth interval is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 37 cores with concentrations greater than the CSL and 47 with concentrations less than the CSL remain outside of the dredge and cap footprint following active remediation. The mean total PCB concentrations in all of the remaining cores (i.e., in ENR, MNR, verification monitoring, and AOPC 2 areas) are 395 and 450 µg/kg dw in the 0- to 2-ft and 2- to 4-ft depth intervals, respectively (Table 9-12; upper panel).

- Areas Not Dredged or Capped – The sediment surface area that is neither dredged nor capped is 270 acres, of which 47 acres reside in Recovery Category 1 areas (Table 9-12, center panel).
- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain outside of the dredge and cap footprints are illustrated in the lower panel of Table 9-12. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are more likely to expose buried contamination in the upper 2 ft, an area of approximately 14 acres at this mean concentration (395 µg/kg dw) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5).

9.5.3.2 Adequacy and Reliability of Controls

The 29 acres dredged under Alternative 2 may require some short-term management to address dredge residuals, but will require little monitoring and maintenance in the long term. The 3 acres remediated by partial dredge and cap will require long-term monitoring and maintenance, as will the 125 acres of MNR (Table 9-11). The potential for caps needing to be replaced in the future is considered to be low. MNR, as a technology, is less reliable than active technologies (e.g., dredging and capping) in part because sedimentation rates and contaminant input concentrations are uncertain components of natural recovery. Also, natural erosion, propeller scour, and earthquakes can more easily expose buried contaminated sediment in an MNR area. In addition to the monitoring component, controls for MNR include provisions for contingency actions. An important assumption underlying development of the remedial alternatives is that 15% percent of the total MNR areas of the alternatives (approximately 22 acres) are assumed to require some form of contingency action (dredging is assumed for costing purposes although other technologies such as ENR/*in situ* treatment could be used) based on findings, either during remedial design or as a result of long-term monitoring, indicating unacceptable performance. Under Alternative 2, 24 acres assigned to MNR are in Recovery Category 1 (Table 9-12), where the potential for contingency actions is higher.

Alternative 2R-CAD has additional monitoring and maintenance requirements associated with the 23-acre CAD facility. Modeling results predict that in the long term, the effectiveness of source controls for the LDW and inputs from the Green/Duwamish River will be the primary factors governing surface sediment contaminant concentrations. Alternatives 2R and 2R-CAD leave a large amount of contaminated subsurface sediment in place (see Section 9.5.3.1 and Table 9-12) that could be exposed at the sediment surface and has a high potential to affect long-term SWACs. Exposure of the material could be difficult to identify and manage into the future.

Both Alternatives 2R and 2R-CAD require an Institutional Controls Plan because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface sediment with COC concentrations above levels needed to achieve cleanup objectives remains in place (Section 9.5.3.1). The Institutional Controls Plan will consist of, at a minimum:

- Seafood consumption advisories and public outreach and education programs.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.
- Environmental covenants for areas with residual contamination above levels needed to achieve cleanup objectives.

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and therefore have limited reliability.

The combination of monitoring, maintenance, institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow the remedial alternatives to be adaptively managed, as needed, based on new information.

9.5.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Alternatives 2R and 2R-CAD rely on removal and disposal of sediments from the most contaminated areas (i.e., hot spots). Remaining sediment contamination is managed primarily by MNR. These two alternatives do not actively treat contaminated sediment.

9.5.5 Short-term Effectiveness

9.5.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the estimated 4-year construction period. Fish and shellfish tissue concentrations are predicted to remain elevated during construction and for some time thereafter, potentially resulting in increased seafood consumptions risks.

Local transportation impacts (traffic, noise, air pollution) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 2R: 380,000/100,000 and Alternative 2R-CAD: 180,000/47,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 17 and 18 metric tons for Alternatives 2R and 2R-CAD, respectively (Appendix L).

9.5.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is a well-documented short-term impact that occurs during environmental dredging operations (and also occurs to a lesser degree via natural and man-made erosion events [e.g., high-flow scour and propeller scour]). Dredging over the four construction seasons is estimated to result in the export of 6 kg of PCBs from the LDW for Alternative 2R (see Part 2 of Appendix M). For comparison and as documented in Appendix M, estimates of PCB export from other sources (i.e., upstream, lateral, and natural erosion in the LDW) over the 4-year construction period were 15, 1, and 2 kg, respectively (see Figure 4 in Appendix M, Part 2). Resuspension of contaminated sediments in the LDW from dredging will be reduced to the extent possible through the use of BMPs (see Section 7.4.3). Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through application of a thin layer of sand (9 inches, with the goal of achieving a minimum of 6 inches of coverage over the entire 29 acres dredged for Alternatives 2R and 2R-CAD).

Exports of PCBs from the LDW would be greater for Alternative 2R-CAD than for Alternative 2R as a result of dredged material being released over the CAD and settling through the water column. Some portion of the released dredged material would remain in suspension and be transported out of the LDW. No estimates were calculated for this additional contribution.

Estimates of air-borne gas emissions associated with Alternative 2R are presented in Appendix L. Implementation of this alternative would result in approximately 20,000 metric tons of CO_2 emitted to the atmosphere. Alternative 2R-CAD has estimated CO_2 emissions of 17,000 metric tons. The similarity in emission estimates for the two alternatives is based on the additional dredging required for the CAD site(s), which partially offsets the decrease from reduced off-site disposal. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. The FS assumes that rail and barge transport will be used to the maximum extent possible. This is a more efficient way to reduce air emissions and significantly reduces the CO_2 emissions of the project as compared to long-haul trucking. Appendix L describes additional BMPs for reducing this "carbon footprint," such as using alternative fuels. Estimated reductions associated with these BMPs are less than 10% because the majority of these emissions are associated with large equipment that is not suited to the use of alternative fuels.

For Alternatives 2R and 2R-CAD, the benthic community within approximately 13 acres of intertidal and shallow subtidal habitat above -10 ft MLLW would be impacted by active remediation, requiring time to regain ecological functions (Table 9-11). Another 61 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed.

The alternatives consume regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 200,000 cubic yards (cy) (Alternative 2R-CAD) and 120,000 cy (Alternative 2R) of granular material is used for all imported material requirements: capping, management of dredge residuals, habitat restoration, and backfilling of dredged intertidal areas to their original grade. The landfill capacity consumed by Alternative 2R is proportional to the volume of material removed and disposed of in the landfill (700,000 cy). Alternative 2R-CAD reduces consumption of landfill capacity to 330,000 cy because approximately half of the dredged material is disposed of in the CAD(s).

9.5.5.3 Time to Achieve Cleanup Objectives

The lower panel of Table 9-11 summarizes the predicted times to achieve cleanup objectives for each RAO (expressed as the time to achieve the PRGs or the time to achieve long-term model-predicted concentrations, as described in Section 9.1.2.3). This table also reports the time to achieve some interim risk reduction milestones.

For RAO 1, the long-term model-predicted concentrations are predicted to be reached within 24 years for total PCBs and within 9 years for dioxins/furans. As discussed in Section 9.3.5, the primary uncertainties are associated with the Green/Duwamish River inputs, source control, natural recovery beyond the construction period, the potential for contaminated subsurface sediments to be exposed in the future, and the efficacy of removal efforts. After construction, the excess cancer risk associated with PCBs for all three RME seafood consumption scenarios is predicted to be reduced to 3×10^{-4} or less depending on the RME scenario and the non-cancer hazard quotient is predicted to be 16 or less. Within 9 years, the Child Tribal RME seafood consumption excess cancer risk associated with PCBs is predicted to be reduced further via natural recovery to 4×10^{-5} and the non-cancer hazard quotient is predicted to be 13.

The time to achieve RAO 2 cleanup objectives has several components: total risks, risks for individual risk drivers, and three exposure areas (netfishing, clamming, and beach play). Some of the risk thresholds for direct contact are achieved after construction of Alternative 2 is completed (Table 9-11). cPAHs are the primary limiting factor for the time required to achieve RAO 2 cleanup objectives in beach and clamming areas. The minimum time to achieve RAO 2 cleanup objectives depends on when natural recovery reduces cPAH concentrations sufficiently to reach an individual excess cancer risk of 1×10^{-6}. This is predicted to occur in all exposure areas (except Beach 3) within 19 years after construction begins. Direct contact risk reduction occurs much earlier for other areas, as beaches and clamming areas are remediated. Following construction of Alternative 2, a non-cancer hazard quotient of less than 1 for PCBs is achieved at Beach 4,[27] and individual excess cancer risks from total PCBs and dioxins/furans are

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[27] No other exposure areas had HQs > 1 for any COC.

reduced to 1×10^{-6} in all exposure areas. Arsenic is predicted to reach the long-term model-predicted concentration within 4 years.

For RAO 3, achieving the SQS requires a period of natural recovery following active remediation and RAO 3 is predicted to be achieved within 14 years after construction begins.

The RAO 4 PRG is predicted to be achieved at the end of construction (4 years).

As noted previously, because predicted outcomes are based on modeling, they are approximations and therefore uncertain (see Section 9.3.5). Uncertainty bounds on time to achieve cleanup objectives for each RAO were not estimated.

9.5.6 Implementability

The CAD component of Alternative 2R-CAD is a significant administrative challenge from the standpoints of locating, using, and maintaining one or more CAD facility. Difficulties potentially include sequencing remedial projects for effective CAD use; uncertainties concerning the property rights and management authority of the Port of Seattle for the portions of the LDW formerly owned by the Commercial Waterway District; potential disruption of navigation and tribal fisheries throughout construction, filling, and closure; obtaining agreements among multiple parties for CAD use; costs; maintenance; and liability.

Alternative 2R has a construction period of 4 years, actively remediates 32 acres, and thus has a low potential for technical difficulties that could lead to schedule delays. Alternative 2 has the highest RALs of any remedial alternative, which should be the easiest to achieve; however, inadequate removal of contaminated sediment or the need to manage residuals remaining after dredging could require administrative effort to determine the need for additional actions.

MNR requires significant administrative effort over the long term to oversee and coordinate MNR sampling, data evaluation, and contingency actions, if any are needed. Alternative 2R relies on reducing contaminant concentrations through MNR over 125 acres, of which 24 acres are located in Recovery Category 1. This recovery category is predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. For this reason, some additional future remedial actions are predicted to be more likely for Alternatives 2R and 2R-CAD based on monitoring data indicating inadequate performance in achieving all cleanup objectives.

9.5.7 Cost

Total costs for Alternatives 2R and 2R-CAD are \$220 million and \$200 million, respectively (see Appendix I for details). The 2R-CAD costs are slightly lower than those for Alternative 2R because less sediment volume would be transported off-site for disposal. Total costs include estimated O&M costs of $46 million and $48 million, respectively, and include costs for maintenance and/or contingency actions in capping and MNR areas. All costs are presented on a net present value basis (see Appendix I for details and cost uncertainties).

9.5.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the RI/FS, and a summary of opinions provided by these groups on the Draft Final FS. Stakeholder comments and concerns will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.6 Detailed Analysis of Alternative 3: Combined and Removal

Scope, performance, and cost summaries for Alternatives 3C and 3R are presented in Tables 9-13 and 9-14.

9.6.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Tables 9-13 and 9-14 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 3C emphasizes a combination of remedial technologies—dredging with upland disposal, capping, and ENR/*in situ* treatment, where appropriate. Alternative 3R emphasizes removal and upland disposal of sediment from the actively remediated areas. Both alternatives address 58 acres of contaminated sediment through active remedial technologies and have an MNR footprint of 99 acres. Alternatives 3C and 3R have estimated construction periods of 3 and 6 years, respectively during which the community, workers, and the environment are affected as described in Section 9.6.5 below.

The stacked bar charts in Tables 9-13 and 9-14 show the relative contributions that construction and natural recovery make toward reducing surface sediment concentrations of the four human health risk drivers (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) from the baseline concentrations. Completion of the EAAs, coupled with the 58 acres of active remediation in Alternatives 3C and 3R, are predicted to reduce the site-wide total PCB SWAC by approximately 62%. Natural recovery is predicted to reduce total PCB concentrations by an additional 26% in the long term. The site-wide arsenic SWAC is predicted to be reduced by an estimated 42% after construction of the EAAs, completion of the active components of Alternatives 3C and 3R, and ongoing natural recovery. With this reduction, the predicted arsenic SWAC is approximately 2 mg/kg dw above the natural background concentration of 7 mg/kg dw. The site-wide cPAH SWAC is predicted to be reduced by an estimated 32% after completion of the EAAs and the active components of Alternatives 3C and 3R. Natural recovery is predicted to contribute to an additional 44% reduction in the cPAH SWAC in the long term. Completion of the EAAs and active remediation together are predicted to reduce the site-wide dioxin/furan SWAC by nearly 72%. Natural recovery is predicted to yield an additional 12% reduction in this risk driver over the long term. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximations because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future.

Neither Alternative 3C nor 3R can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenarios (RAO 1). Alternatives 3C and 3R are predicted to achieve most cleanup objectives for human health direct contact (RAO 2) with the exception of arsenic (which is set at natural background) and cPAHs at certain beaches, as discussed further below. Both alternatives are predicted to achieve the SQS (RAO 3 PRG) within approximately 5 years after the 3-year and 6-year construction periods for Alternatives 3C and 3R, respectively, for a total of approximately 8 and 11 years. The PRG for protection of wildlife (RAO 4) is predicted to be achieved by both alternatives.

Long-term residual risks from contaminated surface and subsurface sediment left in place are predicted to be similar for both alternatives, as discussed below in Section 9.6.3. However, Alternative 3R provides for more removal of subsurface contamination by dredging 50 acres and will require less long-term management than Alternative 3C, with 29 acres of dredging. Estimated times to achieve cleanup objectives (i.e., the PRGs associated with each RAO or long-term model-predicted concentrations/risks thresholds) and other interim risk reduction milestones are shown in the lower panels of Tables 9-13 and 9-14 and are discussed in Section 9.6.5.3.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are implemented to reduce seafood consumption exposures. Further, LDW-wide recovery processes are monitored to assess the reduction in long-term human health risks. Long-term monitoring, maintenance, and institutional controls are required for both alternatives. Both alternatives monitor and maintain 99 acres of MNR. However, the scope of monitoring and maintenance is higher for Alternative 3C because it has about 29 acres of capping and ENR/*in situ* treatment to monitor and maintain while Alternative 3R has only 8 acres of capping. The institutional controls programs for both alternatives are of similar scope and duration.

9.6.2 Compliance with ARARs

Alternatives 3C and 3R have many of the same ARAR compliance limitations as Alternative 2R (see Section 9.5.2). They are unlikely to comply with the MTCA-based ARARs that require PRGs to be set at natural background when RBTCs are below natural background. These include the total PCB and dioxin/furan PRGs for human seafood consumption and the arsenic PRG for direct contact. Surface water quality is expected to improve, yet it may not comply with some water quality standard ARARs, particularly those based on human consumption of bioaccumulative contaminants (e.g., PCBs). ARAR waivers based on technical impracticability may be issued by EPA for a final remedial action that cannot practicably achieve ARARs.

In addition, the alternatives are predicted to achieve the SQS within 5 years after the 3- and 6-year construction period, for a total of 8 and 11 years for Alternatives 3C and 3R, respectively. However, given predictive uncertainties, this may not be practicably achievable. If this were the case, EPA and Ecology may authorize a longer cleanup time frame if they find it is not practicable to achieve the cleanup standards (as defined by WAC 173-340-570(4)) within a 10-year period (WAC 173-204-580[3][b]).

9.6.3 Long-term Effectiveness and Permanence

9.6.3.1 Magnitude and Type of Residual Risk

The active remedial measures of Alternatives 3C and 3R significantly reduce surface sediment contaminant concentrations (Tables 9-2a, 9-2b, and 9-3) and the BCM predicts that further reductions will continue over time until the long-term model-predicted concentrations are reached (Figures 9-5a through 9-5h). After that, residual risks from contaminated surface sediment left in place are predicted to be the same as described for Alternative 2R (Section 9.5.3.1). These risks are predicted to persist into the future, subject to incremental changes tied to source control and continuing natural recovery.

Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place after active remediation is complete. Alternatives that remediate more area by removal through dredging or isolation through capping (with long-term monitoring and maintenance of the cap) have lower potential for residual risks from exposure of subsurface sediment by all mechanisms. Alternative 3C leaves more contaminated subsurface sediment in place than Alternative 3R, because it relies less on dredging (29 acres and 50 acres for Alternatives 3C and 3R, respectively; Tables 9-13 and 9-14). Alternatives 3C and 3R cap 19 and 8 acres, respectively.

The greatest exposure potential is from areas outside of the dredge and cap footprints where subsurface contamination is expected to remain without isolation provided by the cap. Based on the approach outlined in Section 9.1.2.1, Table 9-15 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining and areas remediated by technologies other than dredging within AOPCs 1 and 2 are presented by recovery category and depth below mudline. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Contamination located in the 0- to 2-ft sediment depths is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 32 and 24 cores with concentrations greater than the CSL (for Alternatives 3C and 3R, respectively) and 43 and 41 with concentrations less than the CSL (for Alternatives 3C and 3R, respectively) remain outside of the dredge and cap footprint following active remediation. The mean total PCB concentrations in all of the remaining cores are 356 and 300 µg/kg dw in the 0- to 2-ft depth interval (for Alternatives 3C and 3R, respectively), and 436 and 422 µg/kg dw in the 2- to 4-ft depth interval (for Alternatives 3C and 3R, respectively) (Table 9-15; upper panel).
- Areas Not Dredged or Capped – The sediment surface areas that are neither dredged nor capped are 254 and 244 acres (for Alternatives 3C and 3R, respectively), of which 43 acres reside in Recovery Category 1 areas (Table 9-15, center panel).
- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain within AOPC 1 and AOPC 2 but outside of the dredge and cap footprints are illustrated in the lower panel of Table 9-15. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are more likely to expose buried contamination in the upper 2 ft, an area of approximately 17 and 21 acres (for Alternatives 3C and 3R, respectively) at these mean concentrations (356 and 300 µg/kg dw, respectively) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5).

9.6.3.2 Adequacy and Reliability of Controls

Alternative 3C dredges a smaller area (29 acres) than Alternative 3R (50 acres). Because the area dredged by Alternative 3C is smaller, it would require less effort in the short term to manage dredging residuals than Alternative 3R, but would require more monitoring and maintenance in the long term. The 19 and 8 acres capped in Alternatives 3C and 3R, respectively, (including areas that are partially dredged and capped), would require long-term monitoring and maintenance, although the potential for caps requiring replacement in the future is considered to be low.

The 109 and 99 acres of ENR/*in situ* and MNR, respectively, under Alternatives 3C and 3R require more intensive monitoring, and may require contingency actions (Tables 9-13 and 9-14), MNR, as a technology, is less reliable than active technologies (i.e., dredging, ENR, and capping), in part because sedimentation rates and contaminant input concentrations are uncertain components of natural recovery. Also, mechanisms such as natural erosion, propeller scour and earthquakes can more easily expose buried contaminated sediment in an MNR area. An important assumption underlying development of the remedial alternatives is that 15% percent of the total ENR/*in situ* and MNR areas of both alternatives (approximately 16 and 15 acres for Alternatives 3C and 3R, respectively) are assumed to require some form of contingency action (dredging is assumed for costing purposes, although other technologies such as capping or ENR/*in situ* could be used) based on findings, either during remedial design or as a result of long-term monitoring, indicating unacceptable performance. Both alternatives manage 20 acres using these technologies in areas that are designated Recovery Category 1 (Table 9-15), where the potential for contingency actions is higher. Modeling results predict that in the long term, the effectiveness of source control and inputs from the Green/Duwamish River will be the primary factors governing surface sediment contaminant concentrations. Alternatives 3C and 3R leave contaminated subsurface sediment in place (see Section 9.6.3.1 and Table 9-15) that could be exposed at the sediment surface. Alternative 3R leaves less in place than Alternative 3C. Exposure of this material has a moderate potential to affect long-term SWACs and could be difficult to identify and manage into the future.

Both Alternatives 3C and 3R require an Institutional Controls Plan because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface sediment with COC concentrations above levels needed to achieve cleanup objectives remains in place (Section 9.6.3.1). The Institutional Controls Plan will consist of, at a minimum:

- Seafood consumption advisories and public outreach and education programs.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.
- Environmental covenants for areas with residual contamination above levels needed to achieve cleanup objectives.

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and therefore have limited reliability.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow the remedial alternatives to be adaptively managed, as needed, based on new information.

9.6.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Under Alternative 3C, 5 of the 10 acres remediated by ENR would include an *in situ* treatment technology, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-13). Alternative 3R contains no provisions to treat contaminated sediment.

9.6.5 Short-term Effectiveness

9.6.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction periods of Alternatives 3C and 3R. The construction period of Alternative 3C (3 years) is 3 years shorter than that for Alternative 3R (6 years). Therefore, risks to workers and the community are assumed to be proportionally higher for Alternative 3R. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 3R and for some time thereafter, potentially resulting in increased seafood consumption risks.

Local transportation impacts (traffic, noise, air pollution) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 3C: 320,000/84,000 and Alternative 3R: 490,000/130,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 15 and 23 metric tons for Alternative 3C and Alternative 3R, respectively (Appendix L).

9.6.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is a well-documented short-term impact that occurs during environmental dredging operations (and also occurs to a lesser degree via natural and man-made erosion events [e.g., high-flow scour and propeller scour]). Dredging over the three to six construction seasons (Alternatives 3C and 3R, respectively) was estimated to result in the export of 5 kg and 6 kg of PCBs from the LDW (see Part 2 of Appendix M). For comparison and as documented in the same part of Appendix M, estimates of PCB export from other sources (i.e., upstream, lateral, and natural erosion in the LDW) were 11, 1, and 2 kg for Alternative 3C over the 3-year construction period, and 22, 1, and 2 kg for Alternative 3R over the 6-year construction period (see Figure 4 in Appendix M, Part 2). Resuspension of contaminated sediments from dredging will be reduced to the extent possible through the use of BMPs (see Section 7.4.3). Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through application of a thin layer of sand (9 inches, with the goal of achieving a minimum of 6 inches of coverage over the area dredged for Alternatives 3C and 3R, 29 and 50 acres, respectively).

For Alternative 3C, the benthic community within approximately 28 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) within AOPC 1 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-13). Another 46 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed.

This alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 270,000 cy of imported granular material is used for capping, ENR/*in situ* treatment, and backfilling of dredged areas where return to grade is assumed. The landfill capacity consumed by Alternative 3C is proportional to the volume of dredged material removed and disposed of in the landfill (590,000 cy).

For Alternative 3R, the benthic community within approximately 28 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) within AOPC 1 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-14). Another 46 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed. An estimated 260,000 cy of imported granular material is used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to original grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (920,000 cy).

Estimates of air-borne gas emissions associated with Alternative 3C are presented in Appendix L. Implementation of this alternative would result in approximately 19,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Appendix L describes BMPs for reducing this "carbon footprint," such as using alternative fuels.

Alternative 3R has estimated CO_2 emissions of 27,000 tons. As with Alternative 3C, limited reductions in the carbon footprint of this alternative are possible through the use of BMPs.

9.6.5.3 Time to Achieve Cleanup Objectives

The lower panels of Tables 9-13 and 9-14 summarize predicted times to achieve cleanup objectives for each RAO (expressed as the time to achieve the PRGs or the time to achieve long-term model-predicted concentrations, as described in Section 9.1.2.3). These tables also report the time to achieve some interim risk reduction milestones.

For RAO 1, long-term model-predicted concentrations are predicted to be achieved 18 and 21 years after the start of construction for total PCBs for Alternatives 3C and 3R respectively, and 8 and 11 years after the start of construction for dioxins/furans for Alternatives 3C and 3R respectively. The primary uncertainties associated with these predictions are described for Alternative 2R, see Sections 9.3.5 and 9.5.5.3. Tables 9-13 and 9-14 also report post-construction seafood consumption (RAO 1) risk outcomes associated with PCBs. The excess cancer risk associated with PCBs for all three RME scenarios is predicted to be reduced to 3 × 10^{-4} or less and the non-cancer hazard quotient is predicted to be 15 or less. Within 8 years (Alternative 3C) and 11 years (Alternative 3R), the Child Tribal RME seafood consumption excess cancer risk associated with PCBs is predicted to decline via natural recovery to 4 × 10^{-5} and the non-cancer hazard quotient is predicted to be 11.

The time to achieve RAO 2 cleanup objectives has several components: total risks, risks for individual risk drivers, and three direct contact exposure areas (netfishing, clamming, and beach play). Many of the risk thresholds for direct contact are achieved after construction of Alternatives 3C and 3R is completed (Tables 9-13 and 9-14). cPAHs are the primary limiting factor for the time required to achieve RAO 2 cleanup objectives in a few beach areas. The minimum time to achieve RAO 2 cleanup objectives depends on when cPAH concentrations are reduced sufficiently by natural recovery to reach an individual excess cancer risk of 1 × 10^{-6}. This is predicted to occur in all exposure areas (except Beach 3) by the end of construction for both alternatives (3 years for Alternative 3C and 6 years for Alternative 3R). Following construction of the Alternative 2 active remedial footprint (which is part of the Alternative 3 active footprint), a non-cancer hazard quotient of less than 1 for PCBs is achieved at Beach 4[28], and individual excess cancer risks from total PCBs and dioxins/furans are reduced to 1 × 10^{-6} in all exposure areas. Arsenic is predicted to reach the long-term model-predicted concentration within 3 and 4 years for Alternatives 3C and 3R, respectively.

For RAO 3, achieving the SQS requires a period of natural recovery following active remediation and is predicted to be achieved within 8 years after construction begins for Alternative 3C, and within 11 years for Alternative 3R.

The RAO 4 PRG is achieved at the end of construction (3 years for Alternative 3C, and 6 years for Alternative 3R).

As discussed previously, because all predicted outcomes are based on modeling, they are approximations and therefore uncertain (see Section 9.3.5). Uncertainty bounds on time to achieve cleanup objectives for each RAO were not estimated.

9.6.6 Implementability

Alternatives 3C and 3R have construction periods of 3 and 6 years, respectively, actively remediate 58 acres, and are administratively implementable. Alternative 3C dredges approximately half the area and sediment volume of Alternative 3R, has a shorter construction period, and therefore is potentially subject to fewer technical or administrative delays. The use of ENR/*in situ* treatment in Alternative 3C makes this alternative susceptible to contingency actions should ENR/*in situ* not perform adequately. The potential for recontamination above RALs is considered low for both alternatives.

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[28] No other exposure areas had non-cancer hazard quotients greater than 1 for any COC.

MNR requires significant administrative effort over the long term to oversee and coordinate MNR sampling, data evaluation, and contingency actions, if any are needed. Alternatives 3C and 3R rely on reducing contaminant concentrations through MNR over 99 acres, of which 20 acres are located in Recovery Category 1. This recovery category is predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. For this reason, some additional actions are assumed likely for Alternatives 3C and 3R based on monitoring data indicating inadequate performance in achieving all cleanup objectives.

9.6.7 Cost

Total costs for Alternatives 3C and 3R are $200 million and $270 million, respectively (see Appendix I for details). Total costs include estimated O&M costs of $45 million and $43 million, respectively, and include costs for maintenance and/or contingency actions for capping, ENR/*in situ*, and MNR areas. All costs are presented on a net present value basis (see Appendix I for details and cost uncertainties).

9.6.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the RI/FS, and a summary of opinions provided by these groups on the Draft Final FS. Stakeholder comments and concerns will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.7 Detailed Analysis of Alternative 4: Combined and Removal

Scope, performance, and cost summaries for Alternatives 4C and 4R are presented in Tables 9-16 and 9-17.

9.7.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Tables 9-16 and 9-17 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 4C emphasizes a combination of remedial technologies—dredging with upland disposal, capping, and ENR/*in situ* treatment, where appropriate. Alternative 4R emphasizes removal and upland disposal of sediment from the actively remediated areas. Both alternatives address 107 acres of contaminated sediment through active remedial technologies and monitor 50 acres for natural recovery. Alternatives 4C and 4R have estimated construction periods of 6 and 11 years, respectively during which short-term effects to the community, workers, and the environment occur as described in Section 9.7.5 below.

The stacked bar charts in Tables 9-16 and 9-17 show the relative contributions that construction and natural recovery make toward reducing concentrations of the four human health risk drivers (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) in surface sediments from the baseline concentrations. Completion of the EAAs, coupled with the 107 acres of active remediation in Alternatives 4C and 4R, are predicted to reduce the site-wide total PCB SWAC by an estimated 67%. Natural recovery is predicted to reduce total PCB concentrations by an additional 26% in the long term. The site-wide arsenic SWAC is predicted to be reduced by an estimated 42% in the long term after completion of the EAAs, the active components of Alternatives 4C and 4R, and natural recovery. With this reduction, the predicted arsenic SWAC is approximately 2 mg/kg dw above the natural background concentration of 7 mg/kg dw. The site-wide cPAH SWAC is predicted to be reduced by an estimated 41% after construction of the EAAs and the active components of Alternatives 4C and 4R. Natural recovery is predicted to contribute to an additional 35% reduction in the cPAH SWAC in the long term. Completion of the EAAs and active remediation together are predicted to reduce the site-wide dioxin/furan SWAC nearly 74%. Natural recovery is predicted to yield an additional 9% reduction in this risk driver over the long term. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximate because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future.

Neither Alternative 4C nor 4R can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenarios (RAO 1). Alternatives 4C and 4R are predicted to achieve cleanup objectives for human health direct contact (RAO 2) with the exception of arsenic (which is set at natural background) and cPAHs at certain beaches, as discussed further below. Both alternatives achieve the SQS (RAO 3 PRG) at the end of construction. The PRG for protection of wildlife (RAO 4) is predicted to be achieved by both alternatives.

Long-term residual risks from contaminated surface and subsurface sediment left in place are predicted to be similar for both alternatives, as discussed below in Section 9.7.3. However, Alternative 4R provides for more removal of subsurface contamination by dredging 93 acres and will require less long-term management than Alternative 4C, with 50 acres of dredging. Estimated times to achieve cleanup objectives (i.e., the PRGs associated with each RAO or long-term model-predicted concentrations/risks thresholds) and other interim risk reduction milestones are shown in the lower panels of Tables 9-16 and 9-17 and are discussed in greater detail in Section 9.7.5.3.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are implemented to reduce seafood consumption exposures. Further, LDW-wide recovery processes are monitored to assess the reduction in long-term human health risks. Long-term monitoring, maintenance, and institutional controls are required for both alternatives. Although both alternatives use capping (including partial dredge and cap areas), ENR/*in situ* treatment, and MNR, Alternative

4C would have a higher level of effort with a total surface area of approximately 107 acres and Alternative 4R would have a lower level of effort with a total of 64 acres.

9.7.2 Compliance with ARARs

Alternatives 4C and 4R have many of the same ARAR compliance limitations as Alternatives 2R, 3C, and 3R (see Section 9.5.2). The alternatives are unlikely to comply with the MTCA-based ARARs that require PRGs to be set at natural background when RBTCs are below natural background. These include the total PCB and dioxin/furan PRGs for human seafood consumption and the arsenic PRG for direct contact. Surface water quality is expected to improve, yet it may not comply with some water quality standard ARARs, particularly those based on human consumption of bioaccumulative contaminants (e.g., PCBs). ARAR waivers based on technical impracticability may be issued by EPA for a final remedial action that cannot practicably achieve ARARs.

In addition, the alternatives are predicted to achieve the SQS immediately after the 6- and 11-year construction period for Alternatives 4C and 4R, respectively. However, given predictive uncertainties, this may not be practicably achievable. If this were the case, EPA and Ecology may authorize a longer cleanup time frame if they find it is not practicable to achieve the cleanup standards (as defined by WAC 173-340-570(4)) within a 10-year period (WAC 173-204-580[3][b]).

9.7.3 Long-term Effectiveness and Permanence

9.7.3.1 Magnitude and Type of Residual Risk

The active remedial measures of Alternatives 4C and 4R significantly reduce surface sediment contaminant concentrations (Tables 9-2a, 9-2b, and 9-3) and the BCM predicts that further reductions will continue over time until the long-term model-predicted concentrations are reached (Figures 9-5a through 9-5h). After that, residual risks (cancer and non-cancer) from contaminated surface sediment left in place are predicted to be the same as described for Alternative 2R (Section 9.5.3.1). These risks are predicted to persist into the future, subject to incremental changes tied to source control and continuing natural recovery.

Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place after active remediation is complete. Alternatives that remediate more area by removal through dredging or isolation through capping (with long-term monitoring and maintenance of the cap) have lower potential for residual risks from exposure of subsurface sediment by all disturbance mechanisms. Alternative 4C leaves more contaminated subsurface sediment in place than Alternative 4R, because it relies less on dredging (50 acres and 93 acres for Alternatives 4C and 4R, respectively; Tables 9-16 and 9-17). Alternatives 4C and 4R cap 41 and 14 acres, respectively.

The greatest exposure potential is from areas outside of the dredge and cap footprints where subsurface contamination is expected to remain without isolation provided by the cap. Based on the approach outlined in Section 9.1.2.1, Table 9-18 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining, and areas remediated by technologies other than dredging within AOPCs 1 and 2 are presented by recovery category and depth below mudline. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Contamination located in the 0- to 2-ft sediment depth interval is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 26 and 14 cores with concentrations greater than the CSL (for Alternatives 4C and 4R, respectively) and 26 and 23 with concentrations less than the CSL (for Alternatives 4C and 4R, respectively) remain outside of the dredge and cap footprint following active remediation. The mean total PCB concentrations in all sediment cores remaining after active remediation (i.e., in ENR, MNR, verification monitoring, and AOPC 2 areas) are 409 and 332 µg/kg dw in the 0- to 2-ft depth interval (for Alternatives 4C and 4R, respectively), and 424 and 401 µg/kg dw in the 2- to 4-ft depth interval (for Alternatives 4C and 4R, respectively) (Table 9-18; upper panel).

- Areas Not Dredged or Capped – The sediment surface areas that are neither dredged nor capped are 211 and 195 acres (for Alternatives 4C and 4R, respectively), of which 26 acres reside in Recovery Category 1 areas (Table 9-18, center panel).

- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain outside of the dredge and cap footprints are illustrated in the lower panel of Table 9-18. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are more likely to expose buried contamination in the upper 2 ft, an area of approximately 17 and 23 acres (for Alternatives 4C and 4R, respectively) at these mean PCB concentrations (409 and 332 µg/kg dw, respectively) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5).

9.7.3.2 Adequacy and Reliability of Controls

Alternative 4C dredges approximately half the area of Alternative 4R, thereby requiring a proportionately smaller effort in the short term to manage dredge residuals, but more monitoring and maintenance in the long term. The 41 and 14 acres capped in Alternatives 4C and 4R, respectively (including areas that are partially dredged and capped), will require long-term monitoring and maintenance, although the potential for caps requiring replacement in the future is considered to be low. The 16 acres of ENR/*in situ* under Alternative 4C and 50 acres of MNR under Alternatives 4C and 4R, require more intensive monitoring, and may require contingency actions (Tables 9-16 and 9-17), because sedimentation rates and contaminant input concentrations are uncertain components of natural recovery. Also, mechanisms such as natural erosion, propeller scour, and earthquakes can more easily expose buried contaminated sediment in these areas. An important assumption underlying development of the remedial alternatives is that 15% of the total ENR/*in situ* and MNR areas of these alternatives (10 acres for Alternative 4C and 8 acres for Alternative 4R) are assumed to require some form of contingency action (dredging is assumed for costing purposes although other technologies such as capping or ENR/*in situ* could be used) based on findings, either during remedial design or as a result of long-term monitoring, indicating unacceptable performance. MNR is managing only 3 acres located in Recovery Category 1, where the potential for contingency actions is higher. Modeling results predict that in the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River are the primary factors governing surface sediment contaminant concentrations. Alternatives 4C and 4R leave contaminated subsurface sediment in place (see Section 9.7.3.1 and Table 9-18) that could be exposed at the sediment surface. Alternative 4R leaves less in place than Alternative 4C. Exposure of this material could be difficult to identify and manage into the future.

Both Alternatives 4C and 4R require an Institutional Controls Plan because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface sediment COC concentrations above levels needed to achieve cleanup objectives remain in place (Section 9.7.3.1). The Institutional Controls Plan will consist of, at a minimum:

- Seafood consumption advisories and public outreach and education programs.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users.
- Environmental covenants for areas with residual contamination above levels needed to achieve cleanup objectives.

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and therefore have limited reliability.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow the remedial alternatives to be adaptively managed, as needed, based on new information.

9.7.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Under Alternative 4C, 8 of the 16 acres remediated by ENR would include an *in situ* treatment technology, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-16). Alternative 4R contains no provisions to treat contaminated sediment.

9.7.5 Short-term Effectiveness

9.7.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period for Alternative 4R (11 years) is about twice that for Alternative 4C (6 years). Therefore, risks to workers and the community are assumed to be proportionally higher for Alternative 4R. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 4R and for some time thereafter, potentially resulting in increased seafood consumption risks.

Local transportation impacts (traffic, noise, air pollution) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 4C: 440,000/120,000 and Alternative 4R: 740,000/200,000) estimated to support material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 22 and 35 metric tons for Alternative 4C and Alternative 4R, respectively (Appendix L).

9.7.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is a well-documented short-term impact that occurs during environmental dredging operations (and also occurs to a lesser degree via natural and man-made erosion events [e.g., high-flow scour and propeller scour]). Dredging over the 6 and 11 construction seasons (Alternatives 4C and 4R, respectively) was estimated to result in the export of 6 kg and 8 kg total PCBs from the LDW (see Part 2 of Appendix M). For comparison and as documented in the same part of Appendix M, estimates of PCB export from other sources (i.e., upstream, lateral, and natural erosion in the LDW) were 22, 1, and 2 kg for Alternative 4C over the 6-year construction period and 41, 2, and 2 kg for Alternative 4R over the 11-year construction period (see Figure 4 in Appendix M, Part 2). Resuspension of contaminated sediments from dredging will be reduced to the extent possible through the use of BMPs. Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through application of a thin layer of sand (9 inches, with the goal of achieving a minimum of 6 inches of coverage over the area dredged for Alternatives 4C and 4R, 50 and 93 acres, respectively).

For Alternative 4C, the benthic community within approximately 42 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) would be impacted by active remediation, requiring time to regain ecological functions (Table 9-16). Another 32 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 470,000 cy of imported granular material is used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (830,000 cy).

For Alternative 4R, the benthic community within approximately 42 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) within AOPC 1 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-17). Another 32 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed. An estimated 430,000 cy of imported granular material is used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to their original grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (1,400,000 cy).

Estimates of air-borne gas emissions associated with Alternative 4C are presented in Appendix L. Implementation of this alternative would result in approximately 27,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Alternative 4R has estimated CO_2 emissions of 42,000 metric tons. As described for Alternative 2R, limited reductions in the carbon footprint of less than 10% are possible through the use of BMPs for both alternatives.

9.7.5.3 Time to Achieve Cleanup Objectives

The lower panels of Tables 9-16 and 9-17 summarize predicted times to achieve cleanup objectives for each RAO (expressed as the time to achieve the PRGs or the time to achieve long-term model-predicted concentrations, as described in Section 9.1.2.3). These tables also report the time to achieve some interim risk reduction milestones.

For RAO 1 both alternatives are predicted to achieve the long-term model-predicted concentrations 21 years after the start of construction for total PCBs, and 11 years after the start of construction for dioxins/furans. The primary uncertainties associated with these predictions are described for Alternative 2R, see Sections 9.3.5 and 9.5.5.3. Tables 9-16 and 9-17 also report the post-construction seafood consumption (RAO 1) excess cancer risk outcomes associated with PCBs. The excess cancer risks associated with PCBs for all three RME seafood consumption scenarios are predicted to be reduced to 3×10^{-4} or less and have non-cancer hazard quotients that are predicted to be 14 or less.

Within 11 years (for both alternatives), the Child Tribal RME seafood consumption excess cancer risk associated with PCBs is predicted to decline via natural recovery to 4×10^{-5} and the non-cancer hazard quotient is predicted to be 12 (for both alternatives).

The time to achieve RAO 2 cleanup objectives in all exposure areas is: 3 years for Alternative 4C and 6 years for Alternative 4R (except for Beach 3). These times are consistent with the sequencing assumptions in which the footprints for Alternatives 3C and 3R (i.e., alternatives designed to actively remediate areas with direct contact risk) are remediated first. Following construction within the Alternative 3 remedial footprint (which is assumed to be remediated prior to the active footprint for Alternatives 4C and 4R), total direct contact excess cancer risks (all four risk drivers combined) are reduced to 1×10^{-5}, individual excess cancer risks from total PCBs and dioxins/furans are reduced to 1×10^{-6}, and a non-cancer hazard quotient of less than 1 for total PCBs is achieved in all areas.

The RAO 3 and RAO 4 PRGs are predicted to be achieved after construction is complete (6 years for Alternative 4C, and 11 years for Alternative 4R).

As discussed previously, because predicted outcomes are based on modeling, they are approximations and therefore uncertain. Uncertainty bounds on time to achieve cleanup objectives for each RAO were not estimated.

9.7.6 Implementability

Alternatives 4C and 4R have construction periods of 6 and 11 years, respectively, actively remediate 107 acres, and are administratively implementable. Alternative 4C dredges approximately half the area and sediment volume of Alternative 4R, has a shorter construction period, and therefore is potentially subject to fewer technical or administrative delays. The use of ENR/*in situ* in Alternative 4C makes this alternative susceptible to contingency actions should ENR/*in situ* not perform adequately. The potential for recontamination above RALs is considered low for both alternatives.

MNR requires significant administrative effort over the long term to oversee and coordinate MNR sampling, data evaluation, and coordination of contingency actions, if any are needed. Alternatives 4C and 4R rely on some reduction in contaminant concentrations through natural recovery (50 acres in AOPC 1) to achieve cleanup objectives for all RAOs, of which only a small portion (3 acres) is located in Recovery Category 1. The majority of natural recovery occurs in areas designated as Recovery Categories 2 and 3, which are less vulnerable to exposure of subsurface contaminated sediment. For this reason, the FS assumes that fewer additional actions are likely for these alternatives in response to monitoring data indicating inadequate performance.

9.7.7 Cost

Total costs for Alternatives 4C and 4R are $260 million and $360 million, respectively (see Appendix I for details). Total costs include estimated O&M costs of $40 million and

$38 million, respectively, and include costs for maintenance and/or contingency actions in capping, ENR/*in situ*, and MNR areas. All costs are presented on a net present value basis (see Appendix I for details and cost uncertainties).

9.7.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the RI/FS, and a summary of opinions provided by these groups on the Draft Final FS. Stakeholder comments and concerns will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.8 Detailed Analysis of Alternative 5: Combined, Removal, and Removal with Treatment

Scope, performance, and cost summaries for Alternatives 5C, 5R, and 5R-Treatment are presented in Tables 9-19 and 9-20.

9.8.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Tables 9-19 and 9-20 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 5C emphasizes a combination of remedial technologies: dredging with upland disposal, capping, and ENR/*in situ* treatment, where appropriate. Alternative 5R emphasizes removal and upland disposal of sediment from the actively remediated areas. Alternative 5R-Treatment applies soil washing treatment to a portion of the dredged material. All three alternatives address 157 acres of contaminated sediment through active remedial technologies. These alternatives do not employ MNR, but nevertheless rely on source control and natural recovery after construction to achieve long-term model-predicted concentration ranges. The construction periods for Alternatives 5C and 5R/5R-Treatment are estimated at 7 and 17 years, respectively during which short-term effects to the community, workers, and the environment occur as described in Section 9.8.5 below.

The stacked bar charts in Tables 9-19 and 9-20 show the relative contributions that construction and natural recovery make toward reducing surface sediment concentrations of the four human health risk drivers (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) from the baseline concentrations. Completion of the EAAs, coupled with the 157 acres of active remediation in Alternatives 5C, 5R, and 5R-Treatment, are predicted to reduce the site-wide total PCB SWAC by approximately 72%. Natural recovery is predicted to reduce total PCB concentrations by an additional 16% in the long term. After completion of the EAAs, construction of the active components of Alternatives 5C, 5R, and 5R-Treatment, and natural recovery, the site-wide arsenic SWAC is predicted to be reduced in the long term an estimated 42%. With this reduction, the predicted arsenic SWAC is approximately 2 mg/kg dw above the natural background concentration of 7 mg/kg dw. The site-wide cPAH SWAC is predicted to be reduced 47% after completion of the EAAs and the active components of Alternatives 5C, 5R, and 5R-Treatment. Natural recovery is predicted to contribute to an additional 28% reduction of the cPAH SWAC in the long term. Completion of the EAAs and active remediation together are predicted to reduce the site-wide dioxin/furan SWAC nearly 78%. Natural recovery is predicted to yield an additional 5% reduction in the concentrations of this risk driver over the long term. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximations because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future.

None of these remedial alternatives can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenario (RAO 1). Alternatives 5C, 5R, and 5R-Treatment are predicted to achieve cleanup objectives for human health direct contact (RAO 2) with the exception of arsenic (which is set at natural background) and cPAHs at certain beaches, as discussed further below. Soil washing (Alternative 5R-Treatment) does not provide additional overall protection to human health and the environment over that which can be achieved by Alternative 5R. All three alternatives are predicted to achieve the SQS (RAO 3 PRG) before the end of construction. The PRG for protection of wildlife (RAO 4) is predicted to be achieved by all three alternatives.

Long-term residual risks from contaminated surface and subsurface sediment left in place are predicted to be similar for these alternatives, as discussed below in Section 9.8.3. However, Alternatives 5R and 5R-Treatment provide for more removal of subsurface contamination by dredging 143 acres, and will require less long-term management than Alternative 5C, with 57 acres of dredging. Estimated times to achieve cleanup objectives (i.e., the PRGs or long-term model-predicted concentrations/risks) and other interim risk reduction milestones are shown in the lower panels of Tables 9-19 and 9-20 and are discussed in Section 9.8.5.3.

Institutional controls, including seafood consumption advisories and public outreach and education programs, are implemented to reduce seafood consumption exposures. Further, LDW-wide recovery processes are monitored to assess the reduction in long-term human health risks. Long-term monitoring, maintenance, and institutional controls are required for these alternatives. The level of effort associated with these activities is expected to be lower for Alternatives 5R and 5R-Treatment because they have only 14 acres of capping and no ENR/*in situ* treatment, as compared to a combined 100 acres of capping and ENR/*in situ* treatment combined for Alternative 5C.

9.8.2 Compliance with ARARs

Alternatives 5C and 5R/5R-Treatment have many of the same ARAR compliance limitations as remedial alternatives evaluated previously (see Section 9.5.2). They are unlikely to comply with the MTCA-based ARARs that require PRGs to be set at natural background when RBTCs are below natural background. These include the total PCB and dioxin/furan PRGs for human seafood consumption and the arsenic PRG for direct contact. Surface water quality is expected to improve, yet may not comply with some water quality standard ARARs, particularly those based on human consumption of bioaccumulative contaminants (e.g., PCBs). ARAR waivers based on technical impracticability may be issued by EPA for a final remedial action that cannot practicably achieve ARARs.

In addition, the alternatives are predicted to achieve the SQS before construction is completed, at 6 and 11 years for Alternatives 5C and 5R/5R-Treatment, respectively. These alternatives achieve the SQS in the same time frame as Alternative 4 because the larger footprint alternatives build upon the smaller ones.

9.8.3 Long-term Effectiveness and Permanence

9.8.3.1 Magnitude and Type of Residual Risk

The active remedial measures of Alternatives 5C and 5R/5R-Treatment significantly reduce surface sediment contaminant concentrations (Tables 9-2a, 9-2b, and 9-3) and the BCM predicts that further reductions will continue over time until the long-term model-predicted concentrations are reached (Figures 9-5a through 9-5h). After that, residual risks from surface sediment left in place are predicted to be the same as described for Alternative 2R (Section 9.5.3.1), and persist into the future, subject to incremental changes tied to source control and continuing natural recovery.

Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place after active remediation is complete. Alternatives that remediate more area by removal through dredging or isolation through capping (with long-term monitoring and maintenance of the cap) have lower potential for residual risks from exposure of subsurface sediment by all mechanisms. Alternative 5C leaves more contaminated subsurface sediment in place than Alternative 5R/5R-Treatment, because it relies less on dredging (57 acres and 143 acres for Alternatives 5C and 5R and 5R-Treatment, respectively; Tables 9-19 and 9-20). Alternatives 5C and 5R/5R-Treatment cap 47 and 14 acres, respectively.

The greatest exposure potential is from areas outside of the dredge and cap footprints where subsurface contamination is expected to remain without the isolation provided by the cap. Based on the approach outlined in Section 9.1.2.1, Table 9-21 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining, and areas remediated by technologies other than dredging within AOPCs 1 and 2 are presented by recovery category and depth below mudline. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Contamination located in the 0- to 2-ft sediment depths is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 22 and 5 cores with concentrations greater than the CSL (for Alternatives 5C and 5R/5R-Treatment, respectively) and 24 and 18 with concentrations less than the CSL (for Alternatives 5C and 5R/5R-Treatment, respectively) remain outside of the dredge and cap footprint following active remediation. The mean total PCB concentrations in all of the remaining cores are 343 and 253 µg/kg dw in the 0- to 2-ft depth interval (for Alternatives 5C and 5R/5R-Treatment, respectively), and 395 and 306 µg/kg dw in the 2- to 4-ft depth interval (for Alternatives 5C and 5R/5R-Treatment, respectively) (Table 9-21; upper panel).
- Areas Not Dredged or Capped – The sediment surface areas that are neither dredged nor capped are 198 and 145 acres (for Alternatives 5C and 5R/5R-Treatment, respectively), of which 23 acres reside in Recovery Category 1 areas (Table 9-21, center panel).
- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain outside of the dredge and cap footprints are illustrated in the lower panel of Table 9-21. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are more likely to expose buried contamination in the upper 2 ft, an area of approximately 22 and 43 acres (for Alternatives 5C and 5R/5R-Treatment, respectively) at these mean concentrations (343 and 253 µg/kg dw, respectively) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5).

9.8.3.2 Adequacy and Reliability of Controls

Alternative 5C dredges only about 40% of the area dredged by Alternatives 5R and 5R-Treatment. The latter two alternatives thereby require a proportionately larger effort in the short term to manage dredge residuals, but less monitoring and maintenance in the long term. The 47 and 14 acres capped in Alternatives 5C and 5R/5R-Treatment, respectively (including areas that are partially dredged and capped), will require long-term monitoring and maintenance.[29] However, the potential for caps needing to be

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[29] Alternatives 5C, 5R, and 5R-Treatment do not remediate any area by MNR.

replaced in the future is considered to be low because of the engineering involved in location-specific design. The 53 acres of ENR/*in situ* addressed under Alternative 5C require more intensive monitoring, and may require contingency actions (Tables 9-19 and 9-20). ENR/*in situ* is not used for any areas that are in Recovery Category 1. An important assumption underlying development of the remedial alternatives is that 15% percent (approximately 8 acres) of the total ENR/*in situ* area of Alternative 5C is assumed to require some form of contingency action (dredging is assumed for costing purposes although other technologies such as capping or ENR/*in situ* could be used) based on findings either during remedial design or as a result of long-term monitoring, indicating unacceptable performance. Modeling results predict that in the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River will be the primary factors governing surface sediment contaminant concentrations. Alternatives 5C, 5R and 5R-Treatment leave contaminated subsurface sediment in place (see Section 9.8.3.1 and Table 9-21) that could be exposed at the sediment surface. Alternative 5R leaves less in place than Alternative 5C. Exposure of this material could be difficult to identify and manage into the future but has a low potential to affect long-term SWACs.

Alternatives 5C, 5R, and 5R-Treatment require an Institutional Controls Plan because: 1) the PRGs for RAO 1 cannot be achieved, and 2) subsurface contaminated sediment above levels needed to achieve cleanup objectives remains in place (Section 9.8.3.1). The Institutional Controls Plan will consist of, at a minimum:

- Seafood consumption advisories and public outreach and education programs.
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users (only Alternative 5C).
- Environmental covenants for areas with residual contamination above levels needed to achieve cleanup objectives.

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and therefore have limited reliability.

Monitoring of in-water construction permit applications, waterway use, and notification of waterway users may not be needed for Alternatives 5R and 5R-Treatment or at least can be assumed to be of much reduced scope because the majority of AOPC 1 is dredged. For the same reason, the number of environmental covenants needed for Alternatives 5R and 5R-Treatment is comparatively small in keeping with the small area (14 acres) that uses partial dredge and cap.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow the remedial alternatives to be adaptively managed, as needed, based on new information.

9.8.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Under Alternative 5C, 26.5 of the 53 acres remediated by ENR would include an *in situ* treatment technology, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-19). Alternative 5R contains no provisions to treat contaminated sediment.

Alternative 5R-Treatment includes soil washing as a treatment component. Half of the estimated 1,600,000 cy of dredged sediment is expected to have sufficiently high sand content to warrant soil washing; hence, 800,000 cy would be taken to a soil washing facility for treatment. Assuming that only the sand portion of the sediment is recoverable and all other sediment would need to be disposed of in a Subtitle C or D landfill, it is estimated that approximately 400,000 cy of sediment would be potentially available for beneficial reuse.[30] The remaining 400,000 cy of fine-grained material would be disposed of in a regional landfill, along with the estimated 800,000 cy of sediment not suitable for treatment because it has too high a fine fractions for effective soil-washing. In summary, treatment by soil washing has the potential to decrease the volume of material requiring landfill disposal by roughly 400,000 cy if a viable reuse option can be identified. In addition, the treatment process generates an additional waste stream from process water that, while treated, releases large quantities of trace concentrations of dissolved contaminants back into the LDW. This treatment therefore increases the toxicity or mobility of contaminants.

9.8.5 Short-term Effectiveness

9.8.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period of Alternative 5C (7 years) is less than 50% of that for Alternatives 5R and 5R-Treatment (17 years). Therefore, risks to workers and the community are assumed to be proportionally higher for Alternatives 5R/5R-Treatment. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternatives 5R/5R-Treatment and for some time thereafter, potentially resulting in increased seafood consumption risks.

Local transportation impacts (traffic, noise, air pollution) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 5C: 480,000/130,000, Alternative 5R: 1,100,000/280,000, and Alternative 5R-Treatment:

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[30] As discussed in Section 9.8.5, implementability concerns may limit the ability to reuse the cleaner sands, which could lead to the need for disposal of the cleaner sands in a landfill.

800,000/210,000) estimated for support of material hauling operations (Appendix L). The particulate matter generated from all combustion activity (PM_{10}) is estimated to be 25, 50, and 44 metric tons for Alternatives 5C, 5R, and 5R-Treatment, respectively (Appendix L).

9.8.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is a well-documented short-term impact that occurs during environmental dredging operations (and also occurs to a lesser degree via natural and man-made erosion events [e.g., high-flow scour and propeller scour]). For Alternative 5C, dredging over the seven construction seasons was estimated to result in the export of 6 kg of PCBs from the LDW (see Part 2 of Appendix M). For Alternatives 5R and 5R-Treatment, dredging over 17 construction seasons was estimated to result in the export of 10 kg of PCBs from the LDW. For comparison and as documented in the same part of Appendix M, estimates of PCB export from other sources (i.e., upstream, lateral, and natural erosion in the LDW) were 26, 1, and 2 kg for Alternative 5C over the 7-year construction period and 63, 3, and 2 kg for Alternatives 5R and 5R-Treatment over the 17-year construction period (see Figure 4 in Appendix M, Part 2). Resuspension of contaminated sediments from dredging will be reduced to the extent possible through the use of BMPs (see Section 7.4.3). Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through application of a thin layer of sand (9 inches, with the goal of achieving a minimum of 6 inches of coverage over the area dredged for Alternatives 5C and 5R/5R-Treatment, 57 and 143 acres, respectively).

For Alternative 5C, the benthic community within approximately 59 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) within AOPC 1 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-19). Another 15 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 580,000 cy of imported granular material is used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to their original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (900,000 cy).

For both Alternatives 5R and 5R-Treatment, the benthic community within approximately 59 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) within AOPC 1 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-20). Another 15 acres above -10 ft MLLW within AOPC 1 and AOPC 2 are left undisturbed. An estimated 590,000 cy of imported granular material are used for capping and backfilling of dredged areas where return to their original grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (2,000,000 and 1,500,000 cy for Alternatives 5R and 5R-Treatment, respectively).

Estimates of air-borne gas emissions associated with Alternative 5C are presented in Appendix L. Implementation of this alternative would result in approximately 30,000 metric tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. The FS assumes that rail and barge transport will be used to the maximum extent possible. This is the most efficient way of reducing air emissions and significantly reduces the CO_2 emissions of the project as compared to long-haul trucking. Alternatives 5R and 5R-Treatment have estimated CO_2 emissions of 59,000 and 51,000 metric tons, respectively; emission calculation for Alternative 5R-Treatment assumes less transport to the landfill. Emissions from the treatment component of Alternative 5R-Treatment were not estimated. Therefore, differences in emissions between Alternatives 5R and 5R-Treatment may be less than suggested by the values stated above. As described for Alternative 2R, limited incremental reductions in the carbon footprint are possible through the use of BMPs for these alternatives.

9.8.5.3 Time to Achieve Cleanup Objectives

The lower panels of Tables 9-19 and 9-20 summarize predicted times to achieve cleanup objectives for each RAO (expressed as the time to achieve PRGs or the time to achieve long-term model-predicted concentrations, as described in Section 9.1.2.3). These tables also report the time to achieve some interim risk reduction milestones.

All risk reduction outcomes tracked for RAO 1 (Tables 9-19 and 9-20) are achieved at the end of construction, 7 and 17 years for Alternative 5C and Alternatives 5R and 5R-Treatment, respectively). After construction, dioxin/furan concentrations are consistent with long-term model-predicted concentrations site-wide. Additional time and natural recovery is needed after construction for total PCB concentrations to reach long-term model-predicted values site-wide (i.e., 17 years after construction begins for Alternative 5C and 22 years for Alternatives 5R and 5R-Treatment).

The time to achieve RAO 2 cleanup objectives in all exposure areas is 3 years for Alternative 5C and 6 years for Alternatives 5R and 5R-Treatment (except for Beach 3). These times are consistent with the sequencing assumptions in which the Alternatives 3C, 4C and 3R, 4R footprints (i.e., alternatives designed to actively remediate areas with direct contact risk) are remediated first. Following construction within the remedial footprints for Alternatives 3 and 4 (which are assumed to be remediated prior to the active footprint for Alternatives 5C, 5R, and 5R-Treatment), total direct contact excess cancer risks (all four risk drivers combined) are reduced to 1×10^{-5}, individual excess cancer risks from total PCBs and dioxins/furans are reduced to 1×10^{-6}, and a non-cancer hazard quotient of less than 1 for total PCBs is achieved in all areas.

For RAO 3, the PRGs are achieved within 6 years and 11 years for Alternatives 5C and 5R/5R-Treatment, respectively.

The RAO 4 PRG is achieved at the end of construction for the three alternatives. The site-wide surface sediment SWAC is predicted to be below the PRG before the end of construction. However, disturbances of contaminated sediment during construction are predicted to elevate seafood tissue concentrations through construction.

As discussed previously, because predicted outcomes are based on modeling, they are approximations and therefore uncertain (see Section 9.3.5). Uncertainty bounds on time to achieve cleanup objectives for each RAO were not estimated.

9.8.6 Implementability

Alternatives 5C and 5R have construction periods of 7 and 17 years, respectively, actively remediate 157 acres, and are administratively implementable. Alternative 5R-Treatment poses challenges related to locating, permitting, and operating the soil washing facility. In addition, finding an acceptable beneficial re-use of the treated sand fraction presents administrative implementability concerns. Alternative 5C dredges less than 50% of the area and sediment volume of Alternatives 5R and 5R-Treatment. The latter two alternatives also have a longer construction period, and therefore are potentially subject to more technical or administrative delays. The longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions because of recontamination, are important implementability considerations for these alternatives. Alternative 5C utilizes ENR/*in situ* to remediate 53 acres, making it more susceptible to contingency actions should ENR/*in situ* not perform adequately.

9.8.7 Cost

Total costs for Alternatives 5C, 5R, and 5R-Treatment are $290 million, $470 million, and $510 million, respectively (see Appendix I for details). Total costs include estimated O&M costs of $40 million for Alternative 5C and $36 million for Alternatives 5R and 5R-Treatment, and include costs for maintenance and/or contingency actions in capping and ENR areas. All costs are presented on a net present value basis (see Appendix I for details and cost uncertainties).

9.8.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the RI/FS, and a summary of opinions provided by these groups on the Draft Final FS. Stakeholder comments and concerns will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA's Proposed Plan.

9.9 Detailed Analysis of Alternative 6: Combined and Removal

Scope, performance, and cost summaries for Alternatives 6C and 6R are presented in Tables 9-22 and 9-23.

9.9.1 Overall Protection of Human Health and the Environment

The technology application areas and dredge removal volumes presented in Tables 9-22 and 9-23 illustrate the physical extent to which these alternatives rely on engineering controls and natural recovery to reduce risk. Alternative 6C emphasizes a combination of remedial technologies—dredging with upland disposal, capping, and ENR/*in situ*, where appropriate. Alternative 6R emphasizes removal and upland disposal of sediment from the actively remediated areas. Both alternatives actively address 302 acres of contaminated sediment. These alternatives do not employ MNR but do rely on source control to preserve risk reductions achieved by construction. Alternatives 6C and 6R have estimated construction periods of 16 and 42 years, respectively during which short-term effects to the community, workers, and the environment occur as described in Section 9.9.5 below.

The stacked bar charts in Tables 9-22 and 9-23 show the relative contributions that construction and natural recovery make toward reducing surface sediment concentrations of the four human health risk drivers (i.e., total PCBs, arsenic, cPAHs, and dioxins/furans) from the baseline concentrations. Completion of the EAAs, coupled with the 302 acres of active remediation in Alternatives 6C and 6R, are predicted to reduce the site-wide total PCB SWAC by approximately 87%. Natural recovery is predicted to contribute minimally to the further reductions of total PCB concentrations after construction. The site-wide arsenic SWAC is predicted to be reduced an estimated 42% in the long term after completion of the EAAs, construction of the active components of Alternatives 6C and 6R, and natural recovery. With this reduction, the predicted arsenic SWAC is approximately 2 mg/kg dw above the natural background concentration of 7 mg/kg dw. The site-wide cPAH SWAC is predicted to be reduced an estimated 66% after completion of the EAAs and the active components of Alternatives 6C and 6R. Natural recovery is predicted to contribute to an additional 10% reduction in the cPAH SWAC in the long term. The EAAs and active remediation together are predicted to reduce the site-wide dioxin/furan SWAC nearly 84%. As discussed in Sections 9.1.2.1 and 9.3.5, the long-term model-predicted SWACs and outcomes based on changes in SWACs (e.g., percent reduction from baseline) are approximations because of uncertainties in Green/Duwamish River inputs, the effectiveness of source control, natural recovery beyond the construction period, and the potential for contaminated subsurface sediments left in place to be exposed in the future.

Neither Alternative 6C nor 6R can achieve the total PCB and dioxin/furan PRGs for the seafood consumption scenarios (RAO 1). Alternatives 6C and 6R are predicted to achieve cleanup objectives for human health direct contact (RAO 2) with the exception of arsenic (which is set at natural background) and cPAHs at certain beaches, as discussed further below. Both alternatives achieve the SQS (RAO 3 PRG) well before the end of construction. The PRG for protection of wildlife (RAO 4) is predicted to be achieved by both alternatives.

Long-term residual risks from contaminated surface and subsurface sediment left in place are predicted to be similar for both alternatives, as discussed below in Section 9.9.3. However, Alternative 6R provides for more removal of subsurface contamination by dredging 274 acres and will require less long-term management than Alternative 6C, with 108 acres of dredging. Estimated times to achieve cleanup objectives (i.e., the PRGs associated with each RAO or long-term model-predicted concentrations/risk thresholds) and other interim risk reduction milestones are shown in the lower panels of Tables 9-22 and 9-23 and are discussed in Section 9.9.5.3

Institutional controls, including seafood consumption advisories and public outreach and education programs, are implemented to reduce seafood consumption exposures. Further, LDW-wide recovery processes are monitored to assess the reduction in long-term human health risks. Long-term monitoring, maintenance, and institutional controls are required for both alternatives. Alternative 6C has 194 acres of surface that are either capped or that undergo remediation by ENR/*in situ* where these activities will need to be applied. The level of effort associated with these activities is lower for Alternative 6R because of the low RALs, reliance on removal, and there being only 28 acres of capped surface area to manage.

9.9.2 Compliance with ARARs

Alternatives 6C and 6R have many of the same ARAR compliance limitations as the other remedial alternatives evaluated previously (see Section 9.5.2). The alternatives are unlikely to comply with the MTCA-based ARARs that require PRGs to be set at natural background when RBTCs are below natural background. These include the total PCB and dioxin/furan PRGs for human seafood consumption and the arsenic PRG for direct contact. Surface water quality is expected to improve, yet it may not comply with some water quality standard ARARs, particularly those based on human consumption of bioaccumulative contaminants (e.g., PCBs). ARAR waivers based on technical impracticability may be issued by EPA for a final remedial action that cannot practicably achieve ARARs.

In addition, the alternatives are predicted to achieve the SQS before construction is completed, 6 and 11 years for Alternatives 6C and 6R, respectively. These alternatives achieve the SQS in the same time frame as Alternatives 4 and 5 because the larger footprint alternatives build upon the smaller ones.

9.9.3 Long-term Effectiveness and Permanence

9.9.3.1 Magnitude and Type of Residual Risk

The active remedial measures of Alternatives 6C and 6R significantly reduce surface sediment contaminant concentrations (Tables 9-2a, 9-2b, and 9-3). Residual risks (where natural background cannot be achieved) from surface sediment are predicted to persist into the future subject to incremental changes tied to source control. Alternatives 6C and 6R actively remediate the same 302 acres of the site.

Physical disturbance (e.g., earthquakes, vessel scour) could expose contaminated subsurface sediment left in place after active remediation. Alternatives that remediate more area by removal through dredging or isolation through capping (with long-term monitoring and maintenance of the cap) have lower potential for residual risks from exposure of subsurface sediment by all mechanisms. Alternative 6C leaves contaminated subsurface sediment in place because it relies on more than dredging to remediate sediments (e.g., 108 acres are dredged in Alternative 6C compared to 274 acres for Alternative 6R; Tables 9-22 and 9-23). Capping (including partial dredge and cap) also has a low potential for exposing subsurface contamination because caps are engineered to ensure containment under the scour and seismic conditions assumed during design. Alternatives 6C and 6R cap 93 acres and 28 acres, respectively.

The greatest exposure potential is from areas outside of the dredge and cap footprints where subsurface contamination is expected to remain without the isolation provided by the cap. Based on the approach outlined in Section 9.1.2.1, Table 9-24 semi-quantitatively evaluates the post-construction potential to increase surface sediment concentrations from exposure of subsurface contamination. Specifically, information on core stations remaining, total PCB concentrations in core stations remaining, and areas remediated by technologies other than dredging within AOPCs 1 and 2 are presented by recovery category and depth below mudline. Recovery Category 1 areas are predicted to be more vulnerable to exposure of subsurface contaminated sediment than areas located in Recovery Categories 2 and 3. Contamination located in the 0- to 2-ft sediment depths is predicted to be more vulnerable to disturbance than deeper sediments. This information is summarized as follows:

- Core Counts – 8 cores with concentrations greater than the CSL (for Alternative 6C; none for Alternative 6R) and 8 with concentrations greater than the SQS but less than the CSL (for Alternative 6C; none for Alternative 6R) remain outside of the dredge and cap footprint following active remediation. The mean total PCB concentration in all of the remaining cores in Alternative 6C is 352 and 573 µg/kg dw in the 0- to 2-ft and in the 2- to 4-ft depth intervals (Table 9-24; upper panel).

- Areas Not Dredged or Capped – The sediment surface area that are neither dredged nor capped is 101 acres for Alternative 6C, with no area residing in Recovery Category 1 (Table 9-24, center panel).
- Total PCB Statistics – Additional descriptive statistics for total PCB concentrations in cores that remain outside of the dredge and cap footprints are illustrated in the lower panel of Table 9-24. The information is broken down by subsurface depth interval and recovery category.

Assuming that the majority of disturbances to sediment are more likely to expose buried contamination in the upper 2 ft, an area of approximately 42 acres for Alternative 6C at this mean concentration (352 µg/kg dw) would need to be disturbed and remain exposed to produce a 25% increase in the long-term model-predicted total PCB SWAC of 40 µg/kg dw (see Figure 2 in Appendix M, Part 5). Alternative 6R PCB SWAC is the basis for obtaining the long-term model-predicted concentration without disturbance effects (40 µg/kg dw), so therefore, no area of disturbance was estimated.

9.9.3.2 Adequacy and Reliability of Controls

Alternative 6C dredges less than half the area dredged by Alternative 6R. For this reason, Alternative 6C requires a less effort in the short term to manage dredge residuals than Alternative 6R, but requires more monitoring and maintenance in the long term. The 93 acres capped in Alternative 6C (including areas that are partially dredged and capped) will require long-term monitoring and maintenance, although the potential for caps requiring replacement in the future is considered to be low. The 101 acres of ENR/*in situ* addressed under Alternative 6C require more intensive monitoring, and may require contingency actions (Table 9-22). The areas managed by ENR/*in situ* are located in Recovery Categories 2 and 3; none are located in potential scour areas (Table 9-24). An important assumption underlying development of the remedial alternatives is that 15% (approximately 15 acres) of the total ENR/*in situ* area of Alternative 6C is assumed to require some form of contingency action (dredging is assumed for costing purposes although other technologies such as capping or ENR/*in situ* could be used) based on findings, either during remedial design or as a result of long-term monitoring, indicating unacceptable performance.[31] Modeling results predict that in the long term, the effectiveness of source control for the LDW and inputs from the Green/Duwamish River will be the primary factors governing surface sediment contaminant concentrations. Alternative 6C leaves a small amount and Alternative 6R leaves the least amount of contaminated subsurface sediment in place (see Section 9.9.3.1 and Table 9-24) that could be exposed at the sediment surface. Exposure of this material could be difficult to identify and manage into the future but has lowest potential to affect long-term SWAC.

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[31] Alternatives 6C and 6R do not remediate any area by MNR.

Alternatives 6C and 6R require an Institutional Controls Plan because the cleanup objectives for RAO 1 cannot be achieved. The Institutional Controls Plan will consist of, at a minimum:

- Seafood consumption advisories and public outreach and education programs (both alternatives)
- Monitoring of in-water construction permit applications, waterway uses, and notification of waterway users (only for Alternative 6C, as Alternative 6R leaves no cores behind with subsurface contamination following completion of construction)
- Environmental covenants for areas with residual contamination above levels needed to achieve cleanup objectives (both alternatives).

The public outreach and education components are intended to enhance the reliability of the seafood consumption advisories. The advisories themselves are not enforceable and therefore have limited reliability.

The combination of monitoring, maintenance, and institutional controls, 5-year reviews as required under CERCLA, and contingency actions (if required), are intended to enhance remedy integrity. As a whole, these activities are intended to allow the remedial alternatives to be adaptively managed, as needed, based on new information.

9.9.4 Reductions in Toxicity, Mobility, or Volume through Treatment

Under Alternative 6C, 50.5 of the 101 acres remediated by ENR would include an *in situ* treatment technology, which reduces the toxicity and bioavailability of contaminants due to their reduced mobility (Table 9-22). Alternative 6R contains no provisions to treat contaminated sediment.

9.9.5 Short-term Effectiveness

9.9.5.1 Community and Worker Protection

Appropriate planning and adherence to standard health and safety practices provide some protection to both workers and the community during the construction period. The construction period of Alternative 6C (16 years) is less than 40% of that for Alternative 6R (42 years). Therefore, risks to workers and the community are assumed to be proportionally higher for Alternative 6R. Also, fish and shellfish tissue concentrations are predicted to remain elevated during the additional years of construction for Alternative 6R and for some time thereafter, potentially resulting in increased seafood consumption risks.

Local transportation impacts (traffic, noise, air pollution) from implementation of these alternatives are proportional to the number of truck/train miles (Alternative 6C: 1,100,000/280,000 and Alternative 6R: 25,000,000/670,000) estimated for support of material hauling operations (Appendix L). Also, approximately 53 and 118 metric tons of particulate matter, as PM_{10}, are predicted to be emitted by the two alternatives.

9.9.5.2 Environmental Impacts

As discussed in Section 9.1.2.3, resuspension of contaminated sediment is a well-documented short-term impact that occurs during environmental dredging operations (and also occurs to a lesser degree via natural and man-made erosion events [e.g., high-flow scour and propeller scour]). For Alternative 6C, dredging over the 16 construction seasons was estimated to result in the export of 9 kg of PCBs from the LDW (see Part 2 of Appendix M). For Alternative 6R, dredging over the 42 construction seasons was estimated to result in the export of 18 kg of PCBs from the LDW. For comparison and as documented in the same part of Appendix M, estimates of PCB export from other sources (i.e., upstream, lateral, and natural erosion in the LDW) were 60, 3, and 2 kg for Alternative 6C over the 16-year construction period and 155, 8, and 3 kg for Alternative 6R over the 42-year construction period (see Figure 4 in Appendix M, Part 2). Resuspension of contaminated sediments from dredging will be reduced to the extent possible through the use of BMPs (see Section 7.4.3). Also, release of contaminated sediment that settles back onto the dredged surface or onto areas just outside the dredge footprint (i.e., dredge residuals) are assumed to be managed through application of a thin layer of sand (9 inches, with the goal of achieving a minimum of 6 inches of coverage over the area dredged for Alternatives 6C and 6R, 108 and 274 acres, respectively).

For Alternative 6C, the benthic community within approximately 99 acres of intertidal and shallow subtidal habitat areas (i.e., above -10 ft MLLW) within AOPCs 1 and 2 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-22). Within AOPCs 1 and 2, no areas above -10 ft MLLW are passively remediated. The alternative consumes regional resources primarily in the form of quarry material (sand, gravel, and rock) and landfill space. An estimated 1,100,000 cy of imported granular material are used for capping, ENR, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to their original grade is assumed. The landfill capacity consumed by this alternative is proportional to the volume of material removed and disposed of in the landfill (2,000,000 cy).

For Alternative 6R, the benthic community within approximately 99 acres of intertidal and shallow subtidal habitat area (i.e., above -10 ft MLLW) within AOPCs 1 and 2 would be impacted by active remediation, requiring time to regain ecological functions (Table 9-23). Within AOPCs 1 and 2, no areas above -10 ft MLLW are passively remediated. An estimated 1,200,000 cy of imported granular material are used for capping, management of dredge residuals, habitat restoration, and backfilling of dredged areas where restoration to their original grade is assumed. The landfill capacity consumed by the alternative is proportional to the volume of dredged material removed and disposed of in the landfill (4,700,000 cy).

Estimates of air-borne gas emissions associated with Alternative 6C are presented in Appendix L. Implementation of this alternative would result in approximately 64,000 tons of CO_2 emitted to the atmosphere. These emissions are primarily the result of using fossil fuels for activities such as dredging and transportation. Alternative 6R has estimated CO_2 emissions of 139,000 tons. As described for Alternative 2R, only small reductions in the carbon footprint are possible through the use of BMPs for these alternatives.

9.9.5.3 Time to Achieve Cleanup Objectives

The lower panels of Tables 9-22 and 9-23 summarize predicted times to achieve cleanup objectives for each RAO (expressed as the time to achieve PRGs or the time to achieve long-term model-predicted concentrations, as described in Section 9.1.2.3). These tables also report the time to achieve some interim risk reduction milestones.

All risk reduction outcomes for RAO 1 (Tables 9-22 and 9-23) are predicted to be achieved at the end of construction, 16 and 42 years for Alternatives 6C and 6R, respectively. After construction, total PCB and dioxin/furan concentrations are, by definition, consistent with long-term model-predicted concentrations site-wide.

The time to achieve cleanup objectives for RAO 2 in all exposure areas is 3 years for Alternative 6C and 6 years for Alternative 6R (except for Beach 3). These times are consistent with the sequencing assumptions in which the footprints for Alternatives 3C, 4C, and 5C, and Alternatives 3R, 4R, and 5R (i.e., alternatives designed to actively remediate areas with direct contact risk) are remediated first. Following construction within the remedial footprints for Alternatives 3, 4, and 5 (which are assumed to be remediated prior to the active footprint for Alternatives 6C and 6R), total direct contact excess cancer risks (all four risk drivers combined) are reduced to 1×10^{-5}, individual excess cancer risks from total PCBs and dioxins/furans are reduced to 1×10^{-6}, and a non-cancer hazard quotient of less than 1 for total PCBs is achieved in all areas.

For RAO 3, the PRGs are achieved within 6 years and 11 years for Alternatives 6C and 6R, respectively, assuming construction is sequenced to remediate the footprints of Alternative 3 first, Alternative 4 next, followed by Alternative 5.

The RAO 4 PRG is achieved at the end of construction, 16 and 42 years for Alternatives 6C and 6R, respectively. This is conservative because the site-wide surface sediment SWAC is predicted to be below the PRG well before the end of construction. However, disturbances of contaminated sediment during construction are predicted to elevate seafood tissue contaminant concentrations throughout construction.

As discussed previously, because predicted outcomes are based on modeling, they are approximations and therefore uncertain (see Section 9.3.5). Uncertainty bounds on time to achieve cleanup objectives associated for each RAO were not estimated.

9.9.6 Implementability

Alternatives 6C and 6R have construction periods of 16 and 42 years, respectively, actively remediate 302 acres, and are administratively implementable. Alternative 6C dredges less than half the area and sediment volume dredged by Alternative 6R. With its much longer construction period, Alternative 6R has a higher potential for technical or administrative delays. Alternative 6C utilizes ENR/*in situ*, making it more susceptible to contingency actions should ENR/*in situ* not perform adequately.

The much longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions from recontamination, are important implementability considerations for these two alternatives.

9.9.7 Cost

Total costs for Alternatives 6C and 6R are $530 million and $810 million, respectively (see Appendix I for details). Total costs include estimated O&M costs of $49 million and $41 million, respectively, and include costs for maintenance and/or contingency actions in capping and ENR/*in situ* areas. All costs are presented on a net present value basis (see Appendix I for details and cost uncertainties).

9.9.8 State, Tribal, and Community Acceptance

See Section 9.1.3 for a general discussion on how the state, tribes, and community are engaged in the RI/FS, and a summary of opinions provided by these groups on the Draft Final FS. Stakeholder comments and concerns will continue to be considered by EPA and Ecology. EPA will fully evaluate state, tribal, and community acceptance in the ROD following the public comment period on EPA’s Proposed Plan.

9.10 Summary of the Detailed Analysis of Remedial Alternatives

Table 9-25 summarizes the predicted times at which the remedial alternatives achieve several risk reduction benchmarks. Except for Alternative 1, the remedial alternatives satisfy the threshold criteria of protecting human health and the environment, although they do not do so by reducing contaminant concentrations to protective levels for human seafood consumption. Therefore, seafood consumption advisories are needed to attain protectiveness. Alternatives 2 through 6 also comply with ARARs assuming the availability of waivers premised on technical impracticability where PRGs cannot be achieved. Alternatives 2 through 6 eventually reach the same outcomes but vary significantly in the time required to achieve the cleanup objectives.

The information presented in this section serves as the basis for a comparative evaluation of the remedial alternatives presented in Section 10.

9.11 Managing COCs Other Than the Risk Drivers

In addition to the risk drivers, additional COCs, all of which are hazardous substances under CERCLA and MTCA, were identified in both the human health and ecological risk assessments (Table 3-16) (Windward 2007a and 2007b). As summarized in Section 3, COCs were defined as detected contaminants with hazard quotients greater than one (for the risk assessments) or excess cancer risk estimates greater than 1×10^{-6} (for human health). The risks associated with these other COCs were very small compared to the risks associated with the risk drivers. This section evaluates how concentrations of these other COCs would change following implementation of the various remedial alternatives and how these changes would achieve the applicable cleanup objectives for each of the RAOs.

9.11.1 Human Health

In addition to the four human health risk drivers, 3 semivolatile organic compounds (SVOCs), 2 metals, and 10 organochlorine pesticides were identified as COCs for human health seafood consumption scenarios in the RI (Windward 2010). These COCs were not designated as risk drivers for establishing PRGs in the FS because of their limited contribution to overall risk and because of uncertainties associated with the risk estimates for these contaminants (see Section 3). Table 9-26 summarizes the estimated risks associated with these COCs and the expected management of these risks through sediment remediation. In general, these contaminants are not expected to pose significant residual human health risks after remediation of LDW sediments primarily because: 1) detection frequencies in either sediment or tissue were low (e.g., less than 5%); 2) baseline total risk is within the EPA target risk range and is not expected to increase when these individual risks are added; or 3) baseline concentrations are close to background.

The three SVOC COCs not designated as human health risk drivers are bis(2-ethylhexyl)phthalate (BEHP), pentachlorophenol, and carbazole. BEHP was rarely detected in tissues and generally had low concentrations when detected. This contaminant will be reduced in sediment largely as a result of source control and removal of hot spots identified for remediation by the Alternative 2 RALs. Further, Alternatives 2 through 6 reduce BEHP concentrations over varying time frames for protection of benthic invertebrates. Pentachlorophenol was rarely detected in LDW tissue samples. Re-analyses of tissue samples suggest that the initial detections were biased high and pentachlorophenol may not have actually been present. Risks from carbazole are within the EPA target risk range.

The two metal COCs not designated as human health risk drivers are vanadium and tributyltin (TBT) (an organometal). Vanadium concentrations in LDW sediment are consistent with natural background and therefore sediment remediation is not likely to reduce concentrations in the long term. Risk estimates for TBT were driven primarily by concentrations in clams. Several clam sampling locations will be remediated as part of completing the EAAs, which may reduce TBT concentrations in clams. Finally, TBT discharges to LDW sediments peaked in the 1970s and 1980s and current industrial uses are strictly controlled. Concentrations of this compound are expected to decline as a result of natural recovery processes.

Ten organochlorine pesticides (i.e., dichlorodiphenyl-trichloroethanes [DDTs], aldrin, alpha-benzene hexachloride (alpha-BHC), beta-BHC, total chlordane, dieldrin, gamma-BHC, heptachlor, heptachlor epoxide, and hexachlorobenzene) were COCs for seafood consumption scenarios. Most of the organochlorine pesticides had low detection frequencies in sediment and tissue from the LDW (Table 9-26). Also, many of the sample results for these compounds had high reporting limits. As discussed in the RI (Windward 2010), the high reporting limits are most likely attributable to analytical interference from PCB congeners.[32] The low level of detections, while not fully independent of the analytical issue described above, aligns with the similarly low detection frequencies reported throughout the Puget Sound region. The HHRA (Windward 2007b) estimated the excess cancer risks for these organochlorine pesticides for the seafood consumption scenarios to be: 1×10^{-4} to 6×10^{-6} for the Adult Tribal RME, 1×10^{-6} to 8×10^{-6} for the Child Tribal RME, and 1×10^{-5} to 6×10^{-6} for the Adult API RME (see Table 3-4a of Section 3). Remediation of the EAAs and hot spots (Alternative 2) are expected to effectively manage the majority of sample locations with detected concentrations of total chlordane, total DDTs, TBT, beta-BHC, and dieldrin. Finally, as with PCBs, many of the organochlorine pesticides have been banned from use and therefore are expected to decline as a result of natural recovery processes.

Toxaphene is the only other contaminant that was identified in the RI (Windward 2010) as a COC for direct contact. It had a detection frequency in surface sediment of 1% (based on the RI baseline dataset) and an estimated risk of 6×10^{-6}, well within the EPA target risk range. Both detected results (2 total) were JN-qualified (estimated concentration, tentatively identified compound) because of analytical interference.

9.11.2 Ecological Health

In addition to the 41 SMS contaminants identified as risk drivers, nickel, total DDTs, and total chlordane were identified as COCs for benthic invertebrates. All of the detected exceedances for the first two COCs were located in EAAs, and all but three for total chlordane, and therefore will be managed under all alternatives (Table 9-27); hence, these contaminants are not considered to pose significant residual risks and were not identified as risk drivers.

In addition to PCBs for river otter, several other COCs were identified in the RI for ecological receptors. These COCs were not designated as risk drivers for establishing

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[32] A detailed discussion of PCB interference with quantitation of organochlorine pesticides is given in Section B.6.1.1.3 of the HHRA (Windward 2007a) and summarized here.

PRGs in the FS because of uncertainties in exposure and effects data, comparisons to regional natural background concentrations in sediment, and the likely magnitude of residual risks following planned sediment remediation within EAAs in the LDW.

Table 9-27 summarizes the estimated risks associated with these COCs and the expected management of these risks through sediment remediation.

Many of the ecological COCs are metals (chromium, copper, lead, mercury, and vanadium) and present a risk to the spotted sandpiper only in specific sandpiper exposure areas. All lowest-observed-adverse-effect level (LOAEL)-based hazard quotients for these metals were less than 2.0, except for a LOAEL-based hazard quotient of 5.5 for lead in one area. The hazard quotients for several metals (copper, lead [one of two areas], and mercury) are expected to be reduced to less than 1.0 in these habitat areas as a result of completing the planned actions in the EAAs. LOAEL-based hazard quotients for cadmium and fish are also expected to be reduced to less than 1.0 as a result of planned actions in the EAAs. In the case of vanadium, existing concentrations are consistent with Puget Sound Ambient Monitoring Program rural Puget Sound background, and therefore sediment remediation is not likely to reduce vanadium concentrations in the long term.

Table 9-1 National Contingency Plan Evaluation Criteria for Detailed Analysis of LDW Remedial Alternatives

Criteria		FS Evaluation Factors
Threshold	1. Overall Protection of Human Health and the Environment	Controls used to reduce risks
		Effectiveness summary
	2. Compliance with ARARs	Location, chemistry, and action
Balancing	3. Long-Term Effectiveness and permanence	Magnitude and type of residual risk
		Adequacy and reliability of controls
	4. Reduction in Toxicity, Mobility, or Volume Through Treatment (applies only to Alternative 5R-Treatment)	Treatment process used
		Amount of hazardous material destroyed or treated
		Reduction in toxicity, mobility, or volume
		Treatment irreversibility
		Nature and quantity of post-treatment residuals
	5. Short-Term Effectiveness	Community protection
		Protection of workers
		Environmental impacts
		Time to achieve cleanup objectives (PRGs, risk targets, or long-term model predicted concentrations when PRGs cannot be achieved)
	6. Implementability	Ability to construct and operate technology
		Reliability of the technology
		Ease of undertaking additional remedial actions
		Monitoring considerations
		Ability to coordinate and obtain approval from agencies
		Availability of transloading and offsite disposal services and capacity
		Availability of technology, equipment, and specialists
	7. Cost	Capital
		Operations, maintenance, and monitoring
		Total net present value
Modifying	8/9. State, Tribal, and Community Acceptance	Will be evaluated in the ROD following the public comment period on the RI/FS

Source: Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA, EPA 1988

Table 9-2a Effectiveness Evaluation – Predicted Post-Construction Arsenic, Total PCB, cPAH, and Dioxin/Furan Concentrations (SWACs)

Arsenic (mg/kg dw) (RAO 2)

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Netfishing Direct Contact Baseline = 16 10^{-6} RBTC = 3.7 PRG = Background = 7.0										Tribal Clamming Direct Contact Baseline = 13 10^{-6} RBTC = 1.3 PRG = Background = 7.0										Beach Play Direct Contact Baseline = 9.1 10^{-6} RBTC = 2.8 PRG = Background = 7.0									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	16	12	11	10	10	9.7	9.7	9.5	9.5	9.5	13	11	11	11	11	11	11	10	10	10	9.1	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 3C	58	3	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	13	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 4C	107	6	16	10	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.1	13	9.5	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.4	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5C	157	7	16	10	9.6	9.4	9.2	9.2	9.2	9.1	9.1	9.1	13	9.6	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.6	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 6C	302	16	16	10	9.5	9.2	9.1	9.1	9.1	9.1	9.1	9.1	13	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.2	9.1	9.1	9.6	9.4	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 2R	32	4	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	9.1	13	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 3R	58	6	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	13	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.1	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 4R	107	11	16	10	9.7	9.3	9.2	9.2	9.2	9.2	9.1	9.1	13	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1	9.3	9.4	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5R	157	17	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	9.1	13	9.4	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.1	9.3	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 6R	302	42	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	9.1	13	9.4	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.3	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2

Total PCBs (µg/kg dw) (RAOs 1, 2 and 4)

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Site-wide Baseline = 346 Netfishing Direct Contact: PRG = 10^{-6} RBTC = 1,300 Seafood Consumption – Human: PRG = Background = 2 Seafood Consumption – Ecological (otter): PRG = 128 - 159										Tribal Clamming Direct Contact Baseline = 540 10^{-6} RBTC = 500 PRG = 500										Beach Play Direct Contact Baseline = 286 10^{-6} RBTC = 1,700 PRG = 1,700									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	180	103	73	56	52	49	48	45	45	43	190	95	68	55	52	50	49	47	47	46	270	110	69	51	49	47	47	45	45	42
Alternative 3C	58	3	180	86	65	52	49	46	45	44	43	42	190	66	56	50	48	47	46	45	45	44	270	61	53	47	45	45	45	44	44	42
Alternative 4C	107	6	180	79	61	50	47	45	45	43	43	41	190	61	53	48	46	45	45	44	44	43	270	54	49	45	44	44	45	44	44	42
Alternative 5C	157	7	180	70	56	48	46	44	44	43	43	41	190	59	52	48	46	45	45	44	44	43	270	54	49	45	44	44	45	44	44	42
Alternative 6C	302	16	180	70	48	39	40	40	41	41	41	40	190	59	49	41	42	42	42	42	42	41	270	54	47	43	43	43	44	44	44	42
Alternative 2R	32	4	180	91	68	54	50	48	47	45	44	42	190	71	59	52	49	48	47	45	45	44	270	66	55	48	46	45	45	44	44	42
Alternative 3R	58	6	180	86	65	52	49	46	45	44	43	42	190	66	56	50	48	47	46	45	45	44	270	61	53	47	45	45	45	44	44	42
Alternative 4R	107	11	180	86	62	50	47	45	45	43	43	41	190	66	54	48	46	45	45	44	44	43	270	61	50	45	44	44	45	44	44	42
Alternative 5R	157	17	180	86	62	50	47	45	44	43	43	41	190	66	54	49	46	45	45	44	44	43	270	61	50	47	45	44	45	44	44	42
Alternative 6R	302	42	180	86	62	50	44	41	41	40	39	39	190	66	54	49	44	43	43	41	41	40	270	61	50	47	44	44	45	43	43	42

Table 9-2a Effectiveness Evaluation – Predicted Post-Construction Arsenic, Total PCB, cPAH, and Dioxin/Furan Concentrations (SWACs) (continued)

cPAHs (µg TEQ/kg dw) (RAO 2)

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Netfishing Direct Contact Baseline = 390 10^{-6} RBTC = 380 PRG = 380										Tribal Clamming Direct Contact Baseline = 380 10^{-6} RBTC = 150 PRG = 150										Beach Play Direct Contact Baseline = 331 10^{-6} RBTC = 90 PRG = 90									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	360	220	160	130	120	110	110	107	107	99	300	190	150	130	120	120	120	110	110	107	310	200	160	130	130	120	120	120	120	110
Alternative 3C	58	3	360	180	140	120	109	105	106	104	104	97	300	130	120	107	106	106	106	103	105	99	310	150	130	120	120	120	120	120	120	109
Alternative 4C	107	6	360	170	140	110	106	104	106	103	103	96	300	130	120	107	106	105	106	103	105	99	310	140	130	120	120	120	120	120	120	109
Alternative 5C	157	7	360	160	130	110	105	103	105	103	103	96	300	130	120	107	106	105	107	104	105	99	310	140	130	120	120	120	120	120	120	109
Alternative 6C	302	16	360	160	130	103	101	100	103	102	102	95	300	130	120	106	105	105	106	103	105	99	310	140	130	120	120	120	120	120	120	109
Alternative 2R	32	4	360	200	150	120	110	107	108	105	105	98	300	170	140	120	110	110	110	106	107	101	310	170	150	120	120	120	120	120	120	110
Alternative 3R	58	6	360	180	140	120	109	105	106	104	104	97	300	130	120	107	106	106	106	103	105	99	310	150	130	120	120	120	120	120	120	109
Alternative 4R	107	11	360	180	140	110	107	104	106	103	103	96	300	130	120	106	106	105	106	103	105	99	310	150	130	120	120	120	120	120	120	109
Alternative 5R	157	17	360	180	140	110	107	104	106	103	103	96	300	130	120	110	108	106	107	104	105	99	310	150	130	120	120	120	120	120	120	109
Alternative 6R	302	42	360	180	140	110	107	103	105	103	102	96	300	130	120	110	107	106	106	105	106	99	310	150	130	120	120	120	120	120	120	110

Dioxins/Furans (ng TEQ/kg dw) (RAOs 1 and 2)

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Site-wide Baseline = 26 Netfishing Direct Contact: PRG = 10^{-6} RBTC = 37 Seafood Consumption – Human: PRG = 2										Tribal Clamming Direct Contact Baseline = 32 10^{-6} RBTC = 13 PRG = 13										Beach Play Direct Contact Baseline = 18 10^{-6} RBTC = 28 PRG = 28									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	24	13	7.9	5.5	4.9	4.6	4.6	4.5	4.4	4.3	30	15	8.5	5.6	4.9	4.6	4.6	4.5	4.4	4.3	14	7.7	5.8	5.0	4.8	4.7	4.7	4.6	4.6	4.5
Alternative 3C	58	3	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	30	5.4	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	14	5.0	4.8	4.6	4.6	4.6	4.6	4.6	4.6	4.5
Alternative 4C	107	6	24	5.5	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	30	5.3	4.9	4.5	4.4	4.4	4.4	4.4	4.4	4.3	14	4.8	4.8	4.5	4.6	4.6	4.6	4.6	4.6	4.5
Alternative 5C	157	7	24	4.9	4.7	4.4	4.4	4.4	4.4	4.4	4.4	4.3	30	4.9	4.7	4.4	4.4	4.4	4.4	4.3	4.4	4.3	14	4.7	4.7	4.5	4.5	4.5	4.6	4.6	4.6	4.5
Alternative 6C	302	16	24	4.9	4.6	4.2	4.3	4.3	4.3	4.3	4.4	4.3	30	4.9	4.7	4.2	4.3	4.3	4.3	4.3	4.3	4.2	14	4.7	4.6	4.4	4.5	4.5	4.6	4.5	4.6	4.4
Alternative 2R	32	4	24	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	4.3	30	5.7	5.2	4.7	4.5	4.5	4.4	4.4	4.4	4.3	14	5.2	5.0	4.7	4.6	4.6	4.6	4.6	4.6	4.5
Alternative 3R	58	6	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	30	5.4	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	14	5.0	4.8	4.6	4.6	4.6	4.6	4.6	4.6	4.5
Alternative 4R	107	11	24	5.9	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	30	5.4	4.9	4.5	4.4	4.4	4.4	4.4	4.4	4.3	14	5.0	4.7	4.6	4.6	4.6	4.6	4.6	4.6	4.5
Alternative 5R	157	17	24	5.9	5.0	4.4	4.4	4.4	4.4	4.4	4.4	4.3	30	5.4	4.9	4.4	4.4	4.4	4.4	4.3	4.4	4.3	14	5.0	4.7	4.5	4.5	4.5	4.6	4.6	4.6	4.5
Alternative 6R	302	42	24	5.9	5.0	4.4	4.4	4.3	4.3	4.3	4.3	4.3	30	5.4	4.9	4.4	4.4	4.3	4.3	4.3	4.3	4.2	14	5.0	4.7	4.5	4.5	4.5	4.6	4.5	4.5	4.4

Notes:

▨ BCM output used as approximation (estimate) of concentrations after construction.

1. BCM predictions use base case STM outputs revised June 2010 (Appendix C) and FS dataset.
2. Arsenic BCM inputs (mg/kg dw): upstream 9, lateral 13, and post-remedy bed sediment replacement value 10 (AOPC 1) and 9 (AOPC 2).
3. Total PCB BCM inputs (µg/kg dw): upstream 35, lateral 300, and post-remedy bed sediment replacement value 60 (AOPC 1) and 20 (AOPC 2).
4. cPAH BCM inputs (µg TEQ/kg dw): upstream 70, lateral 1,400, and post-remedy bed sediment replacement value 140 (AOPC 1) and 100 (AOPC 2).
5. Dioxin/furan BCM inputs (ng TEQ/kg dw): upstream 4, lateral 20, and post-remedy bed sediment replacement value 4.
6. BCM model area = 430 acres and FS study area = 441 acres.

a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6. BCM SWAC output shown for Alternative 1 after EAA construction is completed.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EAA = early action area; FS = feasibility study; kg = kilogram; µg = microgram; mg = milligram; ng = nanogram; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RBTC = risk-based threshold concentration; STM = sediment transport model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 9-2b Effectiveness Evaluation – Predicted Post-Construction Exceedances of SMS Criteria (CSL and SQS) (RAO 3)

Remaining CSL Exceedances Station Counts; Total Baseline Station Count = 1,395

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Time from Beginning of Construction																						10 Years Following End of Construction		
			0 yr[a]			5 yr			10 yr			15 yr			20 yr			25 yr			30 yr					
			Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL	Number of Stations	% of Stations < CSL	% of Area < CSL
Alternative 1	29	0	63	95%	96%	34	98%	98%	24	98%	99%	11	99%	>99%	8	99%	>99%	10	99%	>99%	13	99%	>99%	24	98%	99%
Alternative 3C	58	3	63	95%	96%	7	99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	2	>99%	>99%
Alternative 4C	107	6	63	95%	96%	6	>99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	2	>99%	>99%
Alternative 5C	157	7	63	95%	96%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6C	302	16	63	95%	96%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 2R	32	4	63	95%	96%	13	99%	99%	10	99%	>99%	6	>99%	>99%	3	>99%	>99%	5	>99%	>99%	7	99%	>99%	6	>99%	>99%
Alternative 3R	58	6	63	95%	96%	7	99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	2	>99%	>99%
Alternative 4R	107	11	63	95%	96%	7	99%	>99%	3	>99%	>99%	2	>99%	>99%	1	>99%	>99%	1	>99%	>99%	2	>99%	>99%	1	>99%	>99%
Alternative 5R	157	17	63	95%	96%	7	99%	>99%	3	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6R	302	42	63	95%	96%	7	99%	>99%	3	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%

Remaining SQS Exceedances Station Counts; PRG = compliance with SQS; Total Baseline Station Count = 1,395

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Time from Beginning of Construction																						10 Years Following End of Construction		
			0 yr[a]			5 yr			10 yr			15 yr			20 yr			25 yr			30 yr					
			Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS	Number of Stations	% of Stations < SQS	% of Area < SQS
Alternative 1	29	0	224	84%	82%	106	92%	92%	67	95%	96%	46	97%	97%	34	98%	98%	29	98%	99%	34	98%	98%	67	95%	96%
Alternative 3C	58	3	224	84%	82%	39	97%	96%	24	98%	98%	17	99%	99%	12	99%	99%	9	99%	>99%	10	99%	>99%	17	99%	99%
Alternative 4C	107	6	224	84%	82%	24	98%	98%	15	99%	99%	13	99%	99%	8	99%	>99%	5	>99%	>99%	6	>99%	>99%	13	99%	99%
Alternative 5C	157	7	224	84%	82%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6C	302	16	224	84%	82%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 2R	32	4	224	84%	82%	60	96%	94%	37	97%	97%	30	98%	98%	23	98%	99%	20	99%	99%	22	98%	99%	30	98%	98%
Alternative 3R	58	6	224	84%	82%	39	97%	96%	24	98%	98%	17	99%	99%	12	99%	99%	9	99%	>99%	10	99%	>99%	17	99%	99%
Alternative 4R	107	11	224	84%	82%	39	97%	96%	15	99%	99%	13	99%	99%	8	99%	>99%	5	>99%	>99%	6	>99%	>99%	8	99%	>99%
Alternative 5R	157	17	224	84%	82%	39	97%	96%	15	99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%
Alternative 6R	302	42	224	84%	82%	39	97%	96%	15	99%	99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%	0	>99%	>99%

▨ = Predicted percentage of baseline stations or LDW surface area below CSL or SQS is ≥ 98%

Notes:

1. FS study area = 441 acres. BCM model area = 430 acres.
2. Concentration predictions use BCM input parameters for SMS contaminants are described in Section 5.
3. Stations falling within the actively remediated footprint of each remedial alternative are not counted after construction is completed for that alternative. However, recontamination potential analysis shows that 23 STM grid cells (out of >700) have the potential to recontaminate above the SQS for bis 2-ethylhexyl phthalate (BEHP) 10 years after remedy completion. These counts do not factor into the recontamination potential.
4. In some locations, the BCM predicts point concentrations above the SQS, but recent chemical data and trend analysis suggest sediment concentrations are below the SQS. Therefore, the assignment of remedial technologies may not be consistent with BCM point-counts. This apparent discrepancy will be resolved during remedy implementation through design sampling, monitoring, and adaptive management.
5. Many of the predicted SQS exceedances remaining 10 years after construction of Alternative 3 (BCM Year 15) are located on the edges of areas to be actively remediated and will likely be recharacterized during remedial design sampling. Other locations are in areas expected to recover (based on other factors used to define the recovery categories) and were assigned to MNR using best professional judgment.
6. The percent of LDW area below SMS criteria is calculated by dividing the polygon-derived areas associated with predicted exceedances by the total area of the LDW (441 acres).
7. The percent of stations below SMS criteria is calculated by dividing the predicted number of station exceedances by the number of FS baseline stations (n = 1,395 points).
8. Station-specific TOC values were used to oc-normalize dry weight concentrations for non-polar organic compounds, with TOC values between 0.5 and 4%. For samples with a TOC outside this range, oc-normalization did not occur, and the dry weight concentration was compared to the LAET and 2LAET criteria.
9. The convention of 98% stations or LDW surface area below the SMS criteria is used in the FS for point count and area estimation purposes only. It does not represent a standard to be applied to compliance monitoring.
10. Estimated construction period for Alternative 6R is 42 years; results are only shown through 30 years.

a. The 5-year model-predicted intervals associated with the BCM output are indexed to the start of construction for Alternatives 2 through 6. BCM output shown for Alternative 1 is after EAA construction is completed.

BCM = bed composition model; C = combined; CSL = cleanup screening level; EAA = early action area; FS = feasibility study; LAET = lowest apparent effect threshold; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; oc = organic carbon; PRG = preliminary remediation goal; R = removal; RAO = remedial action objective; SMS = Sediment Management Standards; SQS = sediment quality standard; STM = sediment transport model; TOC = total organic carbon; yr = year

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches

Arsenic (mg/kg dw), Beach Play Direct Contact, PRG = 7, 10-6 RBTC = 2.8

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 1 Baseline = 8.9										Beach 2 Baseline = 13										Beach 3 Baseline = 11									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	8.9	8.7	8.9	9.1	9.1	9.1	9.1	9.1	9.1	9.1	13	11	11	9.9	9.5	9.3	9.3	9.2	9.1	9.1	11	10	9.9	9.7	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 3C	58	3	8.9	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	9.1	13	10	10	9.6	9.4	9.3	9.2	9.2	9.1	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 4C	107	6	8.9	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	9.1	13	11	10	9.8	9.4	9.3	9.2	9.2	9.1	9.1	11	10	10	9.8	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 5C	157	7	8.9	9.0	9.1	9.2	9.1	9.1	9.1	9.1	9.1	9.1	13	11	10	9.9	9.5	9.3	9.3	9.2	9.1	9.1	11	10	10	9.8	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 6C	302	16	8.9	9.0	9.1	9.2	9.1	9.1	9.1	9.1	9.1	9.1	13	11	10	9.3	9.1	9.1	9.1	9.1	9.1	9.0	11	10	10	9.8	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 2R	32	4	8.9	8.7	8.9	9.1	9.1	9.1	9.1	9.1	9.1	9.1	13	11	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 3R	58	6	8.9	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	9.1	13	10	10	9.6	9.4	9.3	9.2	9.2	9.1	9.1	11	10	9.8	9.7	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 4R	107	11	8.9	8.0	8.5	8.9	9.0	9.1	9.1	9.1	9.1	9.1	13	10	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	11	10	10	10	9.8	9.8	9.8	9.7	9.7	9.6
Alternative 5R	157	17	8.9	8.0	8.5	9.4	9.2	9.2	9.2	9.2	9.2	9.1	13	10	10	10	9.6	9.4	9.3	9.2	9.2	9.1	11	10	10	10	10	9.8	9.8	9.7	9.7	9.6
Alternative 6R	302	42	8.9	8.0	8.5	9.4	9.2	9.2	9.2	9.2	9.1	9.1	13	10	10	10	9.6	9.4	9.3	9.1	9.1	9.0	11	10	10	10	10	9.8	9.8	9.7	9.7	9.6

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 4[b] Baseline = 7.5										Beach 5[b] Baseline = 9.1										Beach 6 Baseline = 12									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	7.5	8.7	9.0	9.1	9.1	9.1	9.0	9.1	9.1	9.1	9.1	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	12	9.5	9.1	9.1	9.1	9.1	9.1	9.0	9.0	9.0
Alternative 3C	58	3	7.5	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	8.7	8.7	8.7	8.7	8.7	8.8	8.7	8.7	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 4C	107	6	7.5	9.2	9.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.9	8.9	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 5C	157	7	7.5	9.4	9.2	9.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.2	9.0	8.9	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 6C	302	16	7.5	9.4	9.2	9.2	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.2	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 2R	32	4	7.5	9.0	9.1	9.1	9.1	9.1	9.0	9.1	9.1	9.1	9.1	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	8.7	12	9.5	9.1	9.1	9.1	9.1	9.1	9.0	9.0	9.0
Alternative 3R	58	6	7.5	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	8.7	8.7	8.7	8.7	8.7	8.8	8.7	8.7	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 4R	107	11	7.5	9.0	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	9.0	8.9	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 5R	157	17	7.5	9.0	9.3	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	9.0	9.0	8.9	8.9	8.9	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0
Alternative 6R	302	42	7.5	9.0	9.3	9.3	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.8	9.0	9.0	9.0	8.9	9.0	8.9	8.9	8.9	12	10	9.3	9.2	9.1	9.1	9.1	9.1	9.1	9.0

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 7 Baseline = 9.1										Beach 8 Baseline = 8.0									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 3C	58	3	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 4C	107	6	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 5C	157	7	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 6C	302	16	9.1	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 2R	32	4	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 3R	58	6	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 4R	107	11	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 5R	157	17	9.1	9.0	9.1	9.1	9.1	9.1	9.2	9.1	9.1	9.1	8.0	9.0	9.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0
Alternative 6R	302	42	9.1	9.0	9.1	9.1	9.1	9.1	9.1	9.1	9.1	9.1	8.0	9.0	9.0	9.1	9.0	9.0	9.0	9.0	9.0	9.0

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches (continued)

Total PCBs (µg/kg dw), Beach Play Direct Contact, PRG = 10-6 RBTC = 1,700)

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 1 Baseline = 51										Beach 2 Baseline = 280										Beach 3 Baseline = 170									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	51	49	47	44	43	43	42	43	44	43	280	190	130	86	64	54	49	45	43	40	104	93	80	66	64	63	65	65	65	60
Alternative 3C	58	3	51	47	46	45	43	43	43	44	44	43	280	110	86	66	53	48	45	43	41	39	104	88	77	65	63	63	65	65	65	60
Alternative 4C	107	6	51	47	46	45	43	43	43	44	44	43	280	85	69	57	47	44	43	41	40	39	104	71	69	62	62	63	65	65	65	60
Alternative 5C	157	7	51	55	51	48	44	43	44	44	44	43	280	82	67	56	47	44	42	41	40	39	104	71	69	63	62	63	65	65	65	60
Alternative 6C	302	16	51	55	51	44	42	42	43	44	44	43	280	82	67	37	36	36	37	37	37	37	104	71	69	60	61	62	65	65	65	60
Alternative 2R	32	4	51	49	47	44	43	43	42	43	44	43	280	140	104	74	57	50	47	44	42	40	104	88	77	65	63	63	65	65	65	60
Alternative 3R	58	6	51	47	46	45	43	43	43	44	44	43	280	110	86	66	53	48	45	43	41	39	104	88	77	65	63	63	65	65	65	60
Alternative 4R	107	11	51	47	46	45	43	43	43	44	44	43	280	110	70	56	48	44	43	41	40	39	104	88	70	62	62	63	65	65	65	60
Alternative 5R	157	17	51	47	46	50	45	44	44	45	45	43	280	110	70	57	48	45	43	41	40	39	104	88	70	65	64	64	66	66	65	60
Alternative 6R	302	42	51	47	46	50	45	44	44	45	42	42	280	110	70	57	48	45	43	32	34	34	104	88	70	65	64	64	66	65	63	59

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 4 [b] Baseline = 1,100										Beach 5 [b] Baseline = 120										Beach 6 Baseline = 450									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	1,100	290	110	55	56	51	44	43	44	41	120	70	60	59	58	58	58	54	55	55	450	120	67	55	57	53	46	41	40	40
Alternative 3C	58	3	1,100	69	51	43	44	44	40	42	43	41	120	64	58	58	57	57	57	53	54	55	450	60	43	41	39	39	39	38	38	37
Alternative 4C	107	6	1,100	61	48	43	43	43	40	42	43	41	120	59	53	52	52	51	51	49	50	50	450	60	43	41	39	39	39	38	38	37
Alternative 5C	157	7	1,100	59	48	43	43	43	41	42	43	41	120	59	52	52	51	51	51	48	49	49	450	60	43	41	39	39	39	38	38	37
Alternative 6C	302	16	1,100	59	44	43	43	43	42	43	43	41	120	59	43	44	44	44	44	43	43	43	450	60	43	41	39	39	39	38	38	37
Alternative 2R	32	4	1,100	70	51	43	44	44	39	42	43	41	120	69	60	59	58	58	58	54	55	55	450	120	67	55	57	53	46	41	40	40
Alternative 3R	58	6	1,100	69	51	43	44	44	40	42	43	41	120	64	58	58	57	57	57	53	54	55	450	60	43	41	39	39	39	38	38	37
Alternative 4R	107	11	1,100	69	51	43	43	43	40	42	43	41	120	64	54	52	52	51	51	49	50	50	450	60	43	41	39	39	39	38	38	37
Alternative 5R	157	17	1,100	69	51	45	44	43	41	42	43	41	120	64	54	54	51	51	51	48	49	49	450	60	43	41	39	39	39	38	38	37
Alternative 6R	302	42	1,100	69	51	45	44	40	41	42	43	41	120	64	54	54	43	43	44	43	43	43	450	60	43	41	39	39	39	38	38	37

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 7 Baseline = 46										Beach 8 Baseline = 49									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	46	41	42	40	41	41	46	41	41	40	49	35	35	35	36	35	35	35	35	35
Alternative 3C	58	3	46	41	42	40	41	41	46	41	41	40	49	37	35	35	35	35	35	35	35	35
Alternative 4C	107	6	46	41	42	40	41	41	46	41	41	40	49	37	35	35	35	35	35	35	35	35
Alternative 5C	157	7	46	41	42	40	41	41	46	41	41	40	49	39	35	35	35	35	35	35	35	35
Alternative 6C	302	16	46	41	37	39	41	40	43	41	41	39	49	39	35	35	35	35	35	35	35	35
Alternative 2R	32	4	46	41	42	40	41	41	46	41	41	40	49	35	35	35	36	35	35	35	35	35
Alternative 3R	58	6	46	41	42	40	41	41	46	41	41	40	49	37	35	35	35	35	35	35	35	35
Alternative 4R	107	11	46	41	42	40	41	41	46	41	41	40	49	37	35	35	35	35	35	35	35	35
Alternative 5R	157	17	46	41	42	40	41	41	46	41	41	40	49	37	35	38	35	35	35	35	35	35
Alternative 6R	302	42	46	41	42	40	37	40	43	41	41	39	49	37	35	38	35	35	35	35	35	35

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches (continued)

cPAHs (µg TEQ/kg dw), Beach Play Direct Contact, PRG = 10-6 RBTC = 90

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 1 Baseline = 400										Beach 2 Baseline = 750										Beach 3 Baseline = 510									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	400	300	220	160	130	120	110	120	120	109	750	490	320	200	140	120	107	99	93	87	380	340	290	240	240	240	250	240	240	220
Alternative 3C	58	3	400	110	120	110	106	108	107	110	120	108	750	130	110	102	92	89	89	87	86	84	380	320	280	240	240	240	250	240	240	220
Alternative 4C	107	6	400	110	120	110	106	108	107	110	120	108	750	130	120	105	93	90	89	88	87	84	380	320	290	240	240	240	250	240	240	220
Alternative 5C	157	7	400	130	130	120	108	110	110	120	120	109	750	140	120	108	94	90	90	88	87	84	380	270	260	230	230	240	250	240	240	220
Alternative 6C	302	16	400	130	130	110	107	109	110	120	120	109	750	140	120	107	93	90	90	88	87	84	380	270	260	230	230	240	250	240	240	220
Alternative 2R	32	4	400	300	220	160	130	120	110	120	120	109	750	260	190	140	110	100	96	92	89	85	380	320	290	240	240	240	250	240	240	220
Alternative 3R	58	6	400	110	120	110	106	108	107	110	120	108	750	130	110	102	92	89	89	87	86	84	380	320	280	240	240	240	250	240	240	220
Alternative 4R	107	11	400	110	120	110	106	108	107	110	120	108	750	130	120	104	94	90	90	88	87	84	380	320	290	240	240	240	250	240	240	220
Alternative 5R	157	17	400	110	120	120	110	110	110	120	120	109	750	130	120	110	98	93	92	89	88	84	380	320	290	240	240	240	250	240	240	220
Alternative 6R	302	42	400	110	120	120	110	110	110	120	120	109	750	130	120	110	98	93	92	95	91	88	380	320	290	240	240	240	250	240	240	220

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 4 [b] Baseline = 380										Beach 5 [b] Baseline = 380										Beach 6 Baseline = 530									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	380	170	130	103	110	110	87	104	110	99	380	170	120	103	107	104	100	95	96	92	530	190	130	120	120	110	98	91	92	90
Alternative 3C	58	3	380	150	120	103	108	109	91	105	110	99	380	110	105	98	99	97	98	94	96	93	530	140	96	90	87	86	87	83	84	81
Alternative 4C	107	6	380	130	120	103	107	109	93	105	110	99	380	110	106	99	101	100	102	97	99	96	530	140	96	90	87	86	87	83	84	81
Alternative 5C	157	7	380	140	120	104	108	109	99	107	110	99	380	120	104	100	102	101	102	98	100	97	530	140	96	90	87	86	87	83	84	81
Alternative 6C	302	16	380	140	120	104	107	109	103	108	110	99	380	120	104	97	99	98	100	96	98	95	530	140	96	90	87	86	87	83	84	81
Alternative 2R	32	4	380	160	130	103	109	110	89	104	110	99	380	160	120	103	104	101	100	95	96	92	530	190	130	120	120	110	98	91	92	90
Alternative 3R	58	6	380	150	120	103	108	109	91	105	110	99	380	110	105	98	99	97	98	94	96	93	530	140	96	90	87	86	87	83	84	81
Alternative 4R	107	11	380	150	120	102	108	109	93	105	110	99	380	110	108	99	102	100	102	97	99	96	530	140	96	90	88	86	87	83	84	81
Alternative 5R	157	17	380	150	120	107	109	110	100	107	110	99	380	110	108	105	102	101	102	98	100	97	530	140	96	90	88	86	87	83	84	81
Alternative 6R	302	42	380	150	120	107	109	109	103	108	110	99	380	110	108	105	103	99	100	96	98	95	530	140	96	90	88	86	87	83	84	81

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 7 Baseline = 97										Beach 8 Baseline = 180									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	97	97	97	93	97	98	96	96	95	93	180	76	74	72	73	73	72	71	71	70
Alternative 3C	58	3	97	97	97	93	97	98	96	96	95	93	180	81	74	72	73	73	72	71	71	70
Alternative 4C	107	6	97	97	97	93	97	98	96	96	95	93	180	81	74	72	73	73	72	71	71	70
Alternative 5C	157	7	97	97	97	93	97	98	96	96	95	93	180	88	74	72	73	73	72	71	71	70
Alternative 6C	302	16	97	97	97	88	97	98	96	96	95	93	180	88	74	72	73	73	72	71	71	70
Alternative 2R	32	4	97	97	97	93	97	98	96	96	95	93	180	76	74	72	73	73	72	71	71	70
Alternative 3R	58	6	97	97	97	93	97	98	96	96	95	93	180	81	74	72	73	73	72	71	71	70
Alternative 4R	107	11	97	97	97	93	97	98	96	96	95	93	180	81	74	72	73	73	72	71	71	70
Alternative 5R	157	17	97	97	97	93	97	98	96	96	95	93	180	81	74	79	73	73	72	71	71	70
Alternative 6R	302	42	97	97	97	93	97	98	96	96	95	93	180	81	74	79	73	73	72	71	71	70

Table 9-3 Effectiveness Evaluation – Predicted Post-Construction Risk Driver Concentrations (SWACs) at Individual Beaches (continued)

Dioxins/Furans (ng TEQ/kg dw), Beach Play Direct Contact, PRG = 10^{-6} RBTC = 28

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 1 Baseline = 5.3										Beach 2 Baseline = 23										Beach 3 Baseline = 30									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	<5	5.3	5.1	4.8	4.6	4.5	4.5	4.4	4.5	4.5	4.5	23	16	11	7.7	6.0	5.3	5.0	4.7	4.5	4.3	7.2	6.8	6.4	5.8	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 3C	58	3	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	4.5	23	7.7	6.5	5.5	4.9	4.7	4.5	4.4	4.3	4.2	7.2	5.9	6.0	5.7	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 4C	107	6	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	4.5	23	7.1	6.1	5.2	4.8	4.6	4.5	4.4	4.3	4.2	7.2	5.8	6.0	5.6	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 5C	157	7	5.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.5	23	6.1	5.5	4.9	4.6	4.5	4.4	4.3	4.3	4.2	7.2	5.6	5.8	5.6	5.7	5.8	6.0	5.9	5.9	5.6
Alternative 6C	302	16	5.3	4.3	4.4	4.3	4.4	4.4	4.5	4.5	4.6	4.5	23	6.1	5.5	4.0	4.1	4.1	4.2	4.2	4.2	4.1	7.2	5.6	5.8	5.5	5.7	5.8	6.0	5.9	5.9	5.6
Alternative 2R	32	4	5.3	5.1	4.8	4.6	4.5	4.5	4.4	4.5	4.5	4.5	23	8.5	7.0	5.7	5.1	4.7	4.6	4.5	4.4	4.3	7.2	6.4	6.2	5.7	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 3R	58	6	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	4.5	23	7.7	6.5	5.5	4.9	4.7	4.5	4.4	4.3	4.2	7.2	5.9	6.0	5.7	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 4R	107	11	5.3	4.6	4.6	4.5	4.4	4.5	4.4	4.5	4.5	4.5	23	7.7	6.1	5.2	4.8	4.6	4.5	4.4	4.3	4.2	7.2	5.9	5.9	5.6	5.8	5.8	5.9	5.9	5.9	5.6
Alternative 5R	157	17	5.3	4.6	4.6	4.3	4.4	4.4	4.5	4.5	4.5	4.5	23	7.7	6.1	4.9	4.6	4.4	4.4	4.3	4.3	4.2	7.2	5.9	5.9	5.5	5.7	5.8	6.0	5.9	5.9	5.6
Alternative 6R	302	42	5.3	4.6	4.6	4.3	4.4	4.4	4.5	4.5	4.5	4.4	23	7.7	6.1	4.9	4.6	4.4	4.4	4.1	4.1	4.1	7.2	5.9	5.9	5.5	5.7	5.8	6.0	5.9	5.9	5.6

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 4 [b] Baseline = 47										Beach 5 [b] Baseline = 5.8										Beach 6 Baseline = 8.3									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	47	14	7.2	4.9	5.0	4.8	4.4	4.5	4.5	4.4	5.8	4.2	4.0	3.8	3.8	3.8	3.8	3.9	3.9	3.8	8.3	5.4	5.1	5.1	5.1	5.1	4.6	4.4	4.5	4.5
Alternative 3C	58	3	47	5.1	4.7	4.4	4.5	4.5	4.3	4.4	4.5	4.4	5.8	3.5	3.7	3.6	3.6	3.6	3.6	3.7	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 4C	107	6	47	4.8	4.6	4.4	4.5	4.5	4.3	4.4	4.5	4.4	5.8	3.5	3.7	3.5	3.6	3.6	3.7	3.7	3.7	3.6	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 5C	157	7	47	4.6	4.6	4.3	4.5	4.5	4.4	4.4	4.5	4.4	5.8	3.5	3.6	3.5	3.6	3.6	3.7	3.8	3.8	3.6	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 6C	302	16	47	4.6	4.4	4.3	4.4	4.5	4.4	4.5	4.5	4.4	5.8	3.5	3.8	3.7	3.8	3.8	3.9	3.9	3.9	3.8	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 2R	32	4	47	5.2	4.7	4.4	4.5	4.5	4.2	4.4	4.5	4.4	5.8	4.1	3.9	3.8	3.8	3.8	3.8	3.9	3.9	3.8	8.3	5.4	5.1	5.1	5.1	5.1	4.6	4.4	4.5	4.5
Alternative 3R	58	6	47	5.1	4.7	4.4	4.5	4.5	4.3	4.4	4.5	4.4	5.8	3.5	3.7	3.6	3.6	3.6	3.6	3.7	3.7	3.7	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 4R	107	11	47	5.1	4.6	4.4	4.5	4.5	4.3	4.4	4.5	4.4	5.8	3.5	3.6	3.6	3.6	3.6	3.7	3.7	3.7	3.6	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 5R	157	17	47	5.1	4.6	4.3	4.5	4.5	4.4	4.4	4.5	4.4	5.8	3.5	3.6	3.5	3.6	3.6	3.7	3.8	3.8	3.6	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1
Alternative 6R	302	42	47	5.1	4.6	4.3	4.5	4.4	4.4	4.4	4.5	4.4	5.8	3.5	3.6	3.5	3.8	3.8	3.9	3.9	3.9	3.8	8.3	4.0	4.1	4.1	4.1	4.1	4.2	4.1	4.2	4.1

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Beach 7 Baseline = 4.5										Beach 8 Baseline = 3.8									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 3C	58	3	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 4C	107	6	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 5C	157	7	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 6C	302	16	4.5	4.2	4.3	4.1	4.3	4.3	4.4	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 2R	32	4	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 3R	58	6	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 4R	107	11	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 5R	157	17	4.5	4.2	4.3	4.2	4.3	4.3	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Alternative 6R	302	42	4.5	4.2	4.3	4.2	4.3	4.2	4.3	4.4	4.4	4.3	3.8	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0

▨ BCM output used as approximation (estimate) of concentrations after construction.

Notes:

1. BCM predictions use base case STM outputs revised June 2010 (Appendix C) and FS dataset.
2. Arsenic BCM inputs (mg/kg dw): upstream 9, lateral 13, and post-remedy bed sediment replacement value 10 (AOPC 1) and 9 (AOPC 2).
3. Total PCB BCM inputs (µg/kg dw): upstream 35, lateral 300, and post-remedy bed sediment replacement value 60 (AOPC 1) and 20 (AOPC 2).
4. cPAH BCM inputs (µg TEQ/kg dw): upstream 70, lateral 1,400, and post-remedy bed sediment replacement value 140 (AOPC 1) and 100 (AOPC 2).
5. Dioxin/Furan BCM inputs (ng TEQ/kg dw): upstream 4, lateral 20, and post-remedy bed sediment replacement value 4 (AOPC 1).
6. BCM model area = 430 acres and FS study area = 441 acres.

a. Baseline SWACs are based on the FS baseline dataset. Year 0 SWACs are based on post-remediation of EAAs for all remedial alternatives. Year 0 represents the start of construction for Alternatives 2 through 6.

b. SWAC calculations for Beaches 4 and 5 included the entire areas. However, two of the highest concentrations of total PCBs (2,900,000 and 230,000 µg/kg dw) at RM 2.2 (Trotsky Inlet) were removed from the total PCB dataset as outliers for the purposes of IDW interpolation. These samples remain in the FS baseline dataset, but were excluded from the interpolation and any reported SWACs. The modified areas for Beach 4 and Beach 5 [Area 4-inlet only and -without inlet, and Area 5-north and -south] were assessed in Section 3 and Appendix B to clarify which portions of these beach play areas are causing most of the risk and therefore, facilitate remedial decision-making. Beach 4 is actively remediated by Alternative 2.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EAA = early action area; FS = feasibility study; IDW = inverse distance weighted; kg = kilogram; µg = microgram; mg = milligram; ng = nanogram; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RBTC = risk-based threshold concentration; RM = river mile; STM = sediment transport model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 9-4 Sensitivity of LDW Arsenic, Total PCB, cPAH, and Dioxin/Furan SWACs to BCM Input Values

Arsenic Site-Wide Predicted SWACs (mg/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Arsenic SWAC = 16 mg/kg dw

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Recommended (Mid, Mid, Mid)										Sensitivity (Low, Low, Low)										Sensitivity (High, High, High)										Sensitivity (Mid (Bed), Mid (Up), High (Lat))									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	16	12	11	10	10	9.7	9.7	9.5	9.5	9.5	16	11	9.2	8.3	8.1	7.8	7.8	7.6	7.5	7.5	16	13	12	11	11	11	11	11	11	11	16	12	11	10	10	10	10	9.9	9.9	9.8
Alternative 3C	58	3	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	16	9.0	8.0	7.6	7.4	7.3	7.2	7.2	7.1	7.1	16	11	11	10	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5	9.4
Alternative 4C	107	6	16	10	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.1	16	8.9	8.0	7.6	7.4	7.3	7.2	7.2	7.1	7.1	16	11	11	10	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5	9.4
Alternative 5C	157	7	16	10	9.6	9.4	9.2	9.2	9.2	9.1	9.1	9.1	16	8.9	8.0	7.6	7.4	7.3	7.2	7.2	7.1	7.1	16	11	11	11	10	10	10	10	10	10	16	10	9.8	9.6	9.5	9.5	9.5	9.5	9.5	9.4
Alternative 6C	302	16	16	10	9.5	9.2	9.1	9.1	9.1	9.1	9.1	9.1	16	8.9	8.0	7.6	7.3	7.2	7.2	7.1	7.1	7.1	16	11	11	10	10	10	10	10	10	10	16	10	9.7	9.4	9.4	9.4	9.5	9.5	9.5	9.4
Alternative 2R	32	4	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	9.1	16	9.1	8.2	7.6	7.4	7.3	7.3	7.2	7.2	7.1	16	11	11	11	10	10	10	10	10	10	16	11	10	9.7	9.6	9.5	9.6	9.5	9.5	9.4
Alternative 3R	58	6	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	16	9.0	8.0	7.6	7.4	7.3	7.2	7.2	7.1	7.1	16	11	11	10	10	10	10	10	10	10	16	10	9.9	9.6	9.5	9.5	9.5	9.5	9.5	9.4
Alternative 4R	107	11	16	10	9.7	9.3	9.2	9.2	9.2	9.2	9.1	9.1	16	9.0	8.1	7.6	7.4	7.3	7.2	7.2	7.1	7.1	16	11	11	10	10	10	10	10	10	10	16	10	10	9.6	9.5	9.5	9.5	9.5	9.5	9.4
Alternative 5R	157	17	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	9.1	16	9.0	8.1	7.7	7.4	7.3	7.3	7.2	7.2	7.1	16	11	11	11	10	10	11	10	10	10	16	10	10	9.6	9.5	9.5	9.6	9.5	9.5	9.4
Alternative 6R	302	42	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	9.1	16	9.0	8.1	7.7	7.5	7.4	7.3	7.3	7.2	7.2	16	11	11	11	10	10	10	10	10	10	16	10	10	9.6	9.5	9.5	9.5	9.5	9.4	9.4

BCM input parameters (mg/kg dw arsenic)
low: upstream = 7; lateral = 9; replacement value = 9 (AOPC 1), 8 (AOPC 2)
mid: upstream = 9; lateral = 13; replacement value = 10 (AOPC 1), 9 (AOPC 2)
high: upstream = 10; lateral = 30; replacement value = 11 (AOPC 1), 10 (AOPC 2)

Total PCBs Site-Wide Predicted SWACs (µg/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Total PCB SWAC = 346 µg/kg dw

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Recommended (Mid, Mid, Mid)										Sensitivity (Low, Low, Low)										Sensitivity (High, High, High)										Sensitivity (Mid (Bed), Mid (Up), High (Lat))									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	180	103	73	56	52	49	48	45	45	43	180	83	46	27	22	17	16	13	12	11	180	140	120	106	104	103	104	103	103	98	180	110	86	67	64	61	63	60	60	55
Alternative 3C	58	3	180	86	65	52	49	46	45	44	43	42	180	64	37	23	18	14	13	11	10	9.3	180	120	110	101	101	100	102	101	102	97	180	100	76	62	60	59	60	59	59	54
Alternative 4C	107	6	180	79	61	50	47	45	45	43	43	41	180	55	32	20	16	13	12	10	10	8.9	180	110	108	99	100	100	101	101	101	97	180	92	72	60	59	58	59	58	58	54
Alternative 5C	157	7	180	70	56	48	46	44	44	43	43	41	180	45	26	18	15	12	11	10	9.3	8.7	180	104	103	97	99	99	101	101	101	97	180	81	67	58	58	57	59	58	58	53
Alternative 6C	302	16	180	70	48	39	40	40	41	41	41	40	180	45	22	12	10	8.9	8.9	8.2	8.1	7.6	180	104	91	83	90	94	98	99	100	96	180	81	58	47	51	52	56	56	57	52
Alternative 2R	32	4	180	91	68	54	50	48	47	45	44	42	180	69	40	25	20	16	14	12	11	10	180	120	110	103	102	102	103	102	102	98	180	106	80	64	62	60	61	60	60	55
Alternative 3R	58	6	180	86	65	52	49	46	45	44	43	42	180	64	37	23	18	14	13	11	10	9.3	180	120	110	101	101	100	102	101	102	97	180	100	76	62	60	59	60	59	59	54
Alternative 4R	107	11	180	86	62	50	47	45	45	43	43	41	180	64	34	20	16	13	12	10	10	8.9	180	120	107	99	100	100	101	101	101	97	180	100	82	60	59	58	59	58	58	54
Alternative 5R	157	17	180	86	62	50	47	45	44	43	43	41	180	64	34	19	16	13	12	10	9.4	8.7	180	120	107	97	99	99	101	101	101	97	180	100	82	69	58	57	59	58	58	53
Alternative 6R	302	42	180	86	62	50	44	41	41	40	39	39	180	64	34	19	14	11	10	9.0	8.5	7.8	180	120	107	97	94	93	94	94	93	93	180	100	82	69	54	53	54	54	53	51

BCM input parameters (µg/kg dw total PCBs)
low: upstream = 5; lateral = 100; replacement value = 30 (AOPC 1), 10 (AOPC 2)
mid: upstream = 35; lateral = 300; replacement value = 60 (AOPC 1), 20 (AOPC 2)
high: upstream = 80; lateral = 1,000; replacement value = 90 (AOPC 1), 40 (AOPC 2)

Table 9-4 Sensitivity of LDW Arsenic, Total PCB, cPAH, and Dioxin/Furan SWACs to BCM Input Values (continued)

cPAHs Site-Wide Predicted SWACs (µg TEQ/kg dw) Based on Range of BCM Parameter Value Sets; Baseline cPAH SWAC = 390 µg TEQ/kg dw

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Recommended (Mid, Mid, Mid)										Sensitivity (Low, Low, Low)										Sensitivity (High, High, High)										Sensitivity (Mid (Bed), Mid (Up), High (Lat))									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	360	220	160	130	120	110	110	107	107	99	350	190	120	85	73	66	64	59	57	54	360	360	350	330	330	330	340	340	340	320	360	250	200	160	150	150	150	150	150	130
Alternative 3C	58	3	360	180	140	120	109	105	106	104	104	97	350	150	101	73	65	60	59	55	54	51	360	310	330	310	320	320	330	340	340	320	360	200	180	140	140	140	150	150	150	130
Alternative 4C	107	6	360	170	140	110	106	104	106	103	103	96	350	130	90	68	62	58	57	54	54	51	360	290	320	310	320	320	330	330	340	320	360	190	170	140	140	140	150	150	150	130
Alternative 5C	157	7	360	160	130	110	105	103	105	103	103	96	350	110	81	64	60	56	56	54	53	51	360	270	310	300	320	320	330	330	340	320	360	170	160	140	140	140	150	150	150	130
Alternative 6C	302	16	360	160	130	103	101	100	103	102	102	95	350	110	76	55	53	52	53	52	52	50	360	270	280	270	300	310	330	330	330	320	360	170	150	130	130	140	150	140	150	130
Alternative 2R	32	4	360	200	150	120	110	107	108	105	105	98	350	170	110	79	69	62	61	57	55	53	360	330	340	320	320	330	330	340	340	320	360	220	190	150	150	140	150	150	150	130
Alternative 3R	58	6	360	180	140	120	109	105	106	104	104	97	350	150	101	73	65	60	59	55	54	51	360	310	330	310	320	320	330	340	340	320	360	200	180	140	140	140	150	150	150	130
Alternative 4R	107	11	360	180	140	110	107	104	106	103	103	96	350	150	91	68	62	58	57	54	54	51	360	310	310	310	320	320	330	330	340	320	360	200	170	140	140	140	150	150	150	130
Alternative 5R	157	17	360	180	140	110	107	104	106	103	103	96	350	150	91	66	61	57	57	54	53	51	360	310	310	290	310	320	330	330	340	320	360	200	170	140	140	140	150	150	150	130
Alternative 6R	302	42	360	180	140	110	107	103	105	103	102	96	350	150	91	66	59	55	55	53	52	50	360	310	310	290	300	310	310	310	310	310	360	200	170	140	140	140	140	140	140	130

BCM input parameters (µg TEQ/kg dw cPAHs)
low: upstream = 40; lateral = 500; replacement value = 70 (AOPC 1), 50 (AOPC 2)
mid: upstream = 70; lateral = 1,400; replacement value = 140 (AOPC 1), 100 (AOPC 2)
high: upstream = 270; lateral = 3,400; replacement value = 200 (AOPC 1), 140 (AOPC 2)

Dioxin/Furan Site-Wide Predicted SWACs (ng TEQ/kg dw) Based on Range of BCM Parameter Value Sets; Baseline Dioxin/Furan SWAC = 26 ng TEQ/kg dw

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Recommended (Mid, Mid, Mid)										Sensitivity (Low, Low, Low)										Sensitivity (High, High, High)										Sensitivity (Mid (Bed), Mid (Up), High (Lat))									
			Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
			0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[a]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	24	13	7.9	5.5	4.9	4.6	4.6	4.5	4.4	4.3	24	11	6.2	3.6	2.9	2.6	2.5	2.4	2.3	2.2	24	15	11	9.2	8.8	8.7	8.7	8.7	8.7	8.5	24	13	8.3	5.8	5.2	5.0	5.0	4.9	4.9	4.7
Alternative 3C	58	3	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	24	4.4	3.4	2.7	2.5	2.4	2.4	2.3	2.3	2.2	24	8.4	8.6	8.4	8.4	8.5	8.6	8.6	8.6	8.5	24	6.1	5.5	4.9	4.9	4.8	4.9	4.8	4.8	4.7
Alternative 4C	107	6	24	5.5	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	24	4.0	3.2	2.6	2.5	2.4	2.3	2.3	2.2	2.2	24	8.0	8.4	8.3	8.4	8.5	8.6	8.6	8.6	8.5	24	5.7	5.4	4.8	4.8	4.8	4.9	4.8	4.8	4.6
Alternative 5C	157	7	24	4.9	4.7	4.4	4.4	4.4	4.4	4.4	4.4	4.3	24	3.3	2.8	2.4	2.4	2.3	2.3	2.2	2.2	2.2	24	7.3	8.1	8.1	8.3	8.4	8.5	8.6	8.6	8.5	24	5.1	5.0	4.7	4.7	4.7	4.8	4.8	4.8	4.6
Alternative 6C	302	16	24	4.9	4.6	4.2	4.3	4.3	4.3	4.3	4.4	4.3	24	3.3	2.6	2.2	2.2	2.2	2.2	2.2	2.2	2.1	24	7.3	7.7	7.6	8.1	8.3	8.5	8.6	8.6	8.5	24	5.1	4.8	4.4	4.6	4.6	4.8	4.8	4.8	4.6
Alternative 2R	32	4	24	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	4.3	24	4.8	3.6	2.8	2.6	2.5	2.4	2.3	2.3	2.2	24	8.7	8.7	8.5	8.5	8.5	8.6	8.6	8.7	8.5	24	6.4	5.7	5.0	4.9	4.9	4.9	4.9	4.9	4.7
Alternative 3R	58	6	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	24	4.4	3.4	2.7	2.5	2.4	2.4	2.3	2.3	2.2	24	8.4	8.6	8.4	8.4	8.5	8.6	8.6	8.6	8.5	24	6.1	5.5	4.9	4.9	4.8	4.9	4.8	4.8	4.7
Alternative 4R	107	11	24	5.9	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	24	4.4	3.2	2.6	2.5	2.4	2.3	2.3	2.2	2.2	24	8.4	8.3	8.3	8.4	8.5	8.6	8.6	8.6	8.5	24	6.1	5.3	4.9	4.8	4.8	4.9	4.8	4.8	4.6
Alternative 5R	157	17	24	5.9	5.0	4.4	4.4	4.4	4.4	4.4	4.4	4.3	24	4.4	3.2	2.4	2.4	2.3	2.3	2.2	2.2	2.2	24	8.4	8.3	7.9	8.2	8.4	8.5	8.6	8.6	8.5	24	6.1	5.3	4.6	4.7	4.7	4.8	4.8	4.8	4.6
Alternative 6R	302	42	24	5.9	5.0	4.4	4.4	4.3	4.3	4.3	4.3	4.3	24	4.4	3.2	2.4	2.3	2.2	2.2	2.2	2.2	2.1	24	8.4	8.3	7.9	8.1	8.2	8.3	8.3	8.3	8.3	24	6.1	5.3	4.6	4.7	4.7	4.7	4.7	4.7	4.6

BCM input parameters (ng TEQ/kg dw dioxins/furans)
low: upstream = 2; lateral = 10; replacement value = 2 (AOPC 1)
mid: upstream = 4; lateral = 20; replacement value = 4 (AOPC 1)
high: upstream = 8; lateral = 40; replacement value = 6 (AOPC 1)

▨ BCM output used as approximation (estimate) of concentrations after construction.

Notes:

1. BCM predictions use base case STM outputs revised June 2010 (Appendix C) and FS dataset.
2. BCM model area = 430 acres and FS study area = 441 acres.

a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6. BCM SWAC output shown for Alternative 1 after EAA construction is completed.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EAA = early action area; FS = feasibility study; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; ng = nanogram; PCB = polychlorinated biphenyl; replacement value = post-remedy bed sediment replacement value; STM = sediment transport model; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 9-5 Site-wide Arsenic, Total PCB, cPAH, and Dioxin/Furan Predicted SWACs Compared to Alternative 6 Predicted SWAC

Total PCBs (µg/kg dw)

	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
Alternative	0[b]	5	10	15	20	25	30	35	40	45	0[b]	5	10	15	20	25	30	35	40	45
Alternative 3C	180	86	65	52	49	46	45	44	43	42	78%	55%	40%	25%	20%	15%	13%	11%	9%	7%
Alternative 4C	180	79	61	50	47	45	45	43	43	41	78%	51%	36%	22%	17%	13%	13%	9%	9%	5%
Alternative 5C	180	70	56	48	46	44	44	43	43	41	78%	44%	30%	19%	15%	11%	11%	9%	9%	5%
Alternative 6C	180	70	48	39	40	40	41	41	41	40	78%	44%	19%	0%	3%	3%	5%	5%	5%	3%
Alternative 2R	180	91	68	54	50	48	47	45	44	42	78%	57%	43%	28%	22%	19%	17%	13%	11%	7%
Alternative 3R	180	86	65	52	49	46	45	44	43	42	78%	55%	40%	25%	20%	15%	13%	11%	9%	7%
Alternative 4R	180	86	62	50	47	45	45	43	43	41	78%	55%	37%	22%	17%	13%	13%	9%	9%	5%
Alternative 5R	180	86	62	50	47	45	44	43	43	41	78%	55%	37%	22%	17%	13%	11%	9%	9%	5%
Alternative 6R	180	86	62	50	44	41	41	40	39	39	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Arsenic (mg/kg dw)

	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
Alternative	0[b]	5	10	15	20	25	30	35	40	45	0[b]	5	10	15	20	25	30	35	40	45
Alternative 3C	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	43%	9%	6%	3%	1%	1%	1%	0%	0%	0%
Alternative 4C	16	10	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.1	43%	9%	5%	3%	1%	1%	1%	1%	0%	0%
Alternative 5C	16	10	9.6	9.4	9.2	9.2	9.2	9.1	9.1	9.1	43%	9%	5%	3%	1%	1%	1%	0%	0%	0%
Alternative 6C	16	10	9.5	9.2	9.1	9.1	9.1	9.1	9.1	9.1	43%	9%	4%	1%	0%	0%	0%	0%	0%	0%
Alternative 2R	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	9.1	43%	9%	7%	3%	2%	1%	1%	1%	1%	0%
Alternative 3R	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1	43%	9%	6%	3%	1%	1%	1%	0%	0%	0%
Alternative 4R	16	10	9.7	9.3	9.2	9.2	9.2	9.2	9.1	9.1	43%	9%	6%	2%	1%	1%	1%	1%	0%	0%
Alternative 5R	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	9.1	43%	9%	6%	3%	2%	1%	1%	1%	0%	0%
Alternative 6R	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	9.1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Table 9-5 Site-wide Arsenic, Total PCB, cPAH, and Dioxin/Furan Predicted SWACs Compared to Alternative 6 Predicted SWAC (continued)

cPAHs (µg TEQ/kg dw)

	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
Alternative	0[b]	5	10	15	20	25	30	35	40	45	0[b]	5	10	15	20	25	30	35	40	45
Alternative 3C	360	180	140	120	109	105	106	104	104	97	73%	47%	31%	20%	12%	9%	9%	8%	8%	1%
Alternative 4C	360	170	140	110	106	104	106	103	103	96	73%	44%	31%	13%	9%	8%	9%	7%	7%	0%
Alternative 5C	360	160	130	110	105	103	105	103	103	96	73%	40%	26%	13%	9%	7%	9%	7%	7%	0%
Alternative 6C	360	160	130	103	101	100	103	102	102	95	73%	40%	26%	7%	5%	4%	7%	6%	6%	-1%
Alternative 2R	360	200	150	120	110	107	108	105	105	98	73%	52%	36%	20%	13%	10%	11%	9%	9%	2%
Alternative 3R	360	180	140	120	109	105	106	104	104	97	73%	47%	31%	20%	12%	9%	9%	8%	8%	1%
Alternative 4R	360	180	140	110	107	104	106	103	103	96	73%	47%	31%	13%	10%	8%	9%	7%	7%	0%
Alternative 5R	360	180	140	110	107	104	106	103	103	96	73%	47%	31%	13%	10%	8%	9%	7%	7%	0%
Alternative 6R	360	180	140	110	107	103	105	103	102	96	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Dioxin/Furan (ng TEQ/kg dw)

	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
Alternative	0[b]	5	10	15	20	25	30	35	40	45	0[b]	5	10	15	20	25	30	35	40	45
Alternative 3C	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	82%	27%	17%	9%	4%	4%	4%	2%	2%	0%
Alternative 4C	24	5.5	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	82%	22%	14%	7%	4%	2%	2%	2%	2%	0%
Alternative 5C	24	4.9	4.7	4.4	4.4	4.4	4.4	4.4	4.4	4.3	82%	12%	9%	2%	2%	2%	2%	2%	2%	0%
Alternative 6C	24	4.9	4.6	4.2	4.3	4.3	4.3	4.3	4.4	4.3	82%	12%	7%	-2%	0%	0%	0%	0%	2%	0%
Alternative 2R	24	6.1	5.3	4.7	4.6	4.5	4.5	4.4	4.4	4.3	82%	30%	19%	9%	7%	4%	4%	2%	2%	0%
Alternative 3R	24	5.9	5.2	4.7	4.5	4.5	4.5	4.4	4.4	4.3	82%	27%	17%	9%	4%	4%	4%	2%	2%	0%
Alternative 4R	24	5.9	5.0	4.6	4.5	4.4	4.4	4.4	4.4	4.3	82%	27%	14%	7%	4%	2%	2%	2%	2%	0%
Alternative 5R	24	5.9	5.0	4.4	4.4	4.4	4.4	4.4	4.4	4.3	82%	27%	14%	2%	2%	2%	2%	2%	2%	0%
Alternative 6R	24	5.9	5.0	4.4	4.4	4.3	4.3	4.3	4.3	4.3	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

▨ Percent reduction in SWAC from alternative to Year 45 Alternative 6R SWAC equal to or less than 25%

Notes:

1. SWACs reported are base case (mid input values) BCM outputs (Table 9-2a).

a. Percent reduction of site-wide SWAC is calculated using Alternative 6 Removal at year 45 as follows:

$$\text{Percent reduction (Alt. X; year Y)} = \frac{\text{SWAC (Alt.X; year Y) - SWAC (Alt.6R; year 45)}}{\text{SWAC (Alt. X; year Y)}}$$

b. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; kg = kilogram; µg = microgram; mg = milligram; n/a = not applicable; ng = nanogram; PCB = polychlorinated biphenyl; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 9-6 Predicted Total PCB Tissue Concentrations (mg/kg ww)

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Clam FS Baseline = 110										Dungeness Crab Whole-Body FS Baseline = 1,117										Dungeness Crab Edible Meat[a] FS Baseline = 155									
			Time from Beginning of Construction (years)[b]										Time from Beginning of Construction (years)[b]										Time from Beginning of Construction (years)[b]									
			0	5	10	15	20	25	30	35	40	45	0	5	10	15	20	25	30	35	40	45	0	5	10	15	20	25	30	35	40	45
Alternative 1	29	0[c]	62	42	29	25	24	23	23	22	22	22	654	479	329	290	281	274	272	265	265	261	91	67	46	40	39	38	38	37	37	36
Alternative 3C	58	3		33	27	24	23	22	22	22	22	21		358	311	281	274	267	265	263	261	258		50	43	39	38	37	37	36	36	36
Alternative 4C	107	6		31	26	23	23	22	22	22	22	21		343	302	277	270	265	265	261	261	256		48	42	38	37	37	37	36	36	36
Alternative 5C	157	7		28	25	23	22	22	22	22	22	21		322	290	272	267	263	263	261	261	256		45	40	38	37	36	36	36	36	36
Alternative 6C	300	16				21	21	21	21	21	21	21				251	254	254	256	256	256	254				35	35	35	36	36	36	35
Alternative 2R	32	4		34	28	24	23	23	23	22	22	21		370	318	286	277	272	270	265	263	258		51	44	40	38	38	37	37	36	36
Alternative 3R	58	6		33	27	24	23	22	22	22	22	21		358	311	281	274	267	265	263	261	258		50	43	39	38	37	37	36	36	36
Alternative 4R	107	11			26	23	23	22	22	22	22	21			304	277	270	265	265	261	261	256			42	38	37	37	37	36	36	36
Alternative 5R	157	17				23	23	22	22	22	22	21				277	270	265	263	261	261	256				38	37	37	36	36	36	36
Alternative 6R	300	42									21	21									251	251									35	35

Alternative	Active Area in FS Study Area (acres)	Construc-tion Period (years)	Perch FS Baseline = 1,436										Sole Whole-Body FS Baseline = 2,282										Sole Fillet[a] FS Baseline = 1,200									
			Time from Beginning of Construction (years)[b]										Time from Beginning of Construction (years)[b]										Time from Beginning of Construction (years)[b]									
			0	5	10	15	20	25	30	35	40	45	0	5	10	15	20	25	30	35	40	45	0	5	10	15	20	25	30	35	40	45
Alternative 1	29	0[c]	802	538	374	315	301	292	288	277	277	271	1245	797	557	458	434	418	412	393	393	383	655	419	293	241	228	220	217	207	207	201
Alternative 3C	58	3		418	346	301	292	281	277	274	271	267		631	510	434	418	399	393	387	383	377		332	268	228	220	210	207	204	201	198
Alternative 4C	107	6		395	333	295	284	277	277	271	271	264		592	488	423	405	393	393	383	383	371		312	256	223	213	207	207	201	201	195
Alternative 5C	157	7		363	315	288	281	274	274	271	271	264		539	458	412	399	387	387	383	383	371		284	241	217	210	204	204	201	201	195
Alternative 6C	300	16				257	261	261	264	264	264	261				359	365	365	371	371	371	365				189	192	192	195	195	195	192
Alternative 2R	32	4		436	357	309	295	288	284	277	274	267		662	528	447	423	412	405	393	387	377		348	278	235	223	217	213	207	204	198
Alternative 3R	58	6		418	346	301	292	281	277	274	271	267		631	510	434	418	399	393	387	383	377		332	268	228	220	210	207	204	201	198
Alternative 4R	107	11			336	295	284	277	277	271	271	264			493	423	405	393	393	383	383	371			259	223	213	207	207	201	201	195
Alternative 5R	157	17				295	284	277	274	271	271	264				423	405	393	387	383	383	371				223	213	207	204	201	201	195
Alternative 6R	300	42									257	257									359	359									189	189

Notes:

1. Tissue concentrations were estimated with the FWM (Windward 2010) using the alternative-specific total PCB SWACs in sediment and assumed surface water dissolved total PCB concentrations of 0.6 ng/L (except 0.9 ng/L at Years 0 and 5 for Alternative 1). For comparative purposes, baseline risk estimates were calculated using the FWM and total PCB SWACs using the FS baseline dataset. These differ from the HHRA baseline risk estimates, which were based on actual tissue data (RI) and UCL95.
2. Tissue concentrations were not estimated for construction period because of uncertainties in total PCB tissue concentrations during construction. Fish/shellfish tissue concentrations are expected to remain elevated in total PCBs for up to 2 years as a result of construction impacts (e.g., sediment resuspension).

a. The FWM estimated total PCB concentrations in whole-body organisms. In the HHRA, some of the seafood ingestion scenarios included the consumption of edible meat (crabs) or fillet (English sole). Therefore, conversion factors were developed. The conversion factors used to convert total PCB concentrations in whole-body organisms to lower concentrations in edible meat or fillet concentrations were 0.139 for Dungeness crabs and 0.526 for English sole. These conversion factors were based on the ratio of whole-body to edible-meat concentrations detected in individual LDW fish tissue samples and detected in composite crab edible meat and hepatopancreas samples collected as part of the LDW RI.

b. The 5-year model-predicted intervals associated with the BCM SWAC output (for tissue estimation) are indexed to the start of construction for Alternatives 2 through 6. Tissue estimation for Alternative 1 uses the BCM SWAC output after EAA construction is completed.

c. EAA construction is assumed to be complete by the time the ROD is finalized. Construction time is estimated to be less than 5 years and is complete for the start of Alternative 1.

22 Gray indicates alternative under construction. Red font indicates tissue estimate based on the end of construction PCB SWAC.

BCM = bed composition model; C = combined; EAA = early action area; FS = feasibility study; FWM = food web model; HHRA = human health risk assessment; kg = kilogram; L = liter; LDW = Lower Duwamish Waterway; µg = microgram; ng = nanogram; PCB = polychlorinated biphenyl; R = removal; RI = remedial investigation; ROD = record of decision; SWAC = spatially-weighted average concentration; UCL95 = 95 percent upper confidence limit on the mean; ww = wet weight

Table 9-7a Excess Cancer Risks for RME Seafood Consumption Scenarios Associated with Residual Surface Sediment Total PCB SWACs over Time

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Adult Tribal RME (Tulalip data) Baseline HHRA Risk = 2 x 10^{-3}										Child Tribal RME (Tulalip data) Baseline HHRA = 3 x 10^{-4}										Adult API RME Baseline HHRA Risk = 5 x 10^{-4}									
			Time from Beginning of Construction (years)[a]										*Time from Beginning of Construction (years)*[a]										*Time from Beginning of Construction (years)*[a]									
			0 [b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0* [b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0* [b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	5 x 10^{-4}	4 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	7 x 10^{-5}	5 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	1 x 10^{-4}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}
Alternative 3C	58	3	5 x 10^{-4}	3 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	5 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	8 x 10^{-5}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 4C	107	6	5 x 10^{-4}	3 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	5 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	8 x 10^{-5}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 5C	157	7	5 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 6C	302	16	5 x 10^{-4}			2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}			3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}			5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 2R	32	4	5 x 10^{-4}	3 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	5 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	9 x 10^{-5}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 3R	58	6	5 x 10^{-4}	3 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}	5 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}	8 x 10^{-5}	7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 4R	107	11	5 x 10^{-4}		2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}		4 x 10^{-5}	4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}		7 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 5R	157	17	5 x 10^{-4}			2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}			4 x 10^{-5}	4 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}			6 x 10^{-5}	6 x 10^{-5}	6 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}	5 x 10^{-5}
Alternative 6R	302	42	5 x 10^{-4}								2 x 10^{-4}	2 x 10^{-4}	1 x 10^{-4}								3 x 10^{-5}	3 x 10^{-5}	2 x 10^{-4}								5 x 10^{-5}	5 x 10^{-5}

Notes:

1. Excess cancer risks estimated using tissue concentrations predicted by the FWM (Windward 2010) with alternative-specific total PCB SWACs in surface sediment (Table 9-2a) and assumed surface water dissolved total PCB concentrations of 0.6 ng/L, except 0.9 ng/L for Year 0 for all alternatives and Year 5 for Alternative 1.
2. Significant figures are displayed in accordance with the conventions established in the HHRA.
3. Risks were not estimated for construction period because of uncertainties in total PCB tissue concentrations during construction. Fish/shellfish tissue total PCB concentrations are expected to remain elevated for up to 2 years as a result of construction impacts (e.g., sediment resuspension).
4. Residual excess cancer risks associated with non-RME seafood consumption scenarios are provided in Appendix M.

a. The 5-year model-predicted intervals associated with the BCM SWAC output (for risk estimation) are indexed to the start of construction for Alternatives 2 through 6. Risk estimation for Alternative 1 uses the BCM SWAC output after EAA construction is completed.

b. Risk estimates for time 0 (post-EAA/Alternative 1) use the BCM-predicted SWACs after constructions of the EAAs. While baseline HHRA seafood consumption risks were based on tissue data collected from the LDW, seafood consumption risks at time 0 (post-EAA construction) were estimated using tissue concentrations predicted by the FWM.

10^{-3}
10^{-4}
10^{-5}
Colored cells indicate residual excess cancer risk rounded to the nearest order of magnitude.

5 x 10^{-4}
Gray indicates alternative under construction. Red font indicates risk estimate based on the end of construction PCB SWAC.

BCM Input Values (mid)			
Contaminant	Post-remedy Bed Sediment Replacement	Lateral	Upstream
PCB (µg/kg dw)	60 (AOPC 1) / 20 (AOPC 2)	300	35

AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; dw = dry weight; EAA = early action area; FS = feasibility study; FWM = Food Web Model; HHRA = human health risk assessment; kg = kilogram; L = liter; LDW = Lower Duwamish Waterway; µg = microgram; ng = nanogram; PCB = polychlorinated biphenyl; R = removal; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration

Table 9-7b Non-Cancer Hazard Quotients for RME Seafood Consumption Scenarios Associated with Residual Sediment Total PCB SWACs for Human Health and River Otter over Time

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Adult Tribal RME (Tulalip data) Baseline HHRA HQ = 40										Child Tribal RME (Tulalip data) Baseline HHRA HQ = 86										Adult API RME Baseline HHRA HQ = 29									
			Time from Beginning of Construction (years)[a]										*Time from Beginning of Construction (years)*[a]										*Time from Beginning of Construction (years)*[a]									
			0[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	13	9	6	5	5	5	5	5	5	5	29	19	13	11	11	10	10	10	10	10	9	6	4	4	3	3	3	3	3	3
Alternative 3C	58	3	13	7	6	5	5	5	5	5	5	4	29	15	12	11	10	10	10	10	10	10	9	5	4	3	3	3	3	3	3	3
Alternative 4C	107	6	13	7	6	5	5	5	5	5	5	4	29	14	12	11	10	10	10	10	10	9	9	5	4	3	3	3	3	3	3	3
Alternative 5C	157	7	13	6	5	5	5	5	5	5	5	4	29	13	11	10	10	10	10	10	10	9	9	4	4	3	3	3	3	3	3	3
Alternative 6C	302	16	13			4	4	4	4	4	4	4	29			9	9	9	9	9	9	9	9			3	3	3	3	3	3	3
Alternative 2R	32	4	13	7	6	5	5	5	5	5	5	4	29	16	13	11	11	10	10	10	10	10	9	5	4	4	3	3	3	3	3	3
Alternative 3R	58	6	13	7	6	5	5	5	5	5	5	4	29	15	12	11	10	10	10	10	10	10	9	5	4	3	3	3	3	3	3	3
Alternative 4R	107	11	13		6	5	5	5	5	5	5	4	29		12	11	10	10	10	10	10	9	9		4	3	3	3	3	3	3	3
Alternative 5R	157	17	13			5	5	5	5	5	5	4	29			11	10	10	10	10	10	9	9			3	3	3	3	3	3	3
Alternative 6R	302	42	13								4	4	29								9	9	9								3	3

Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	Otter LOAEL-based HQ – with Juvenile Fish Baseline HHRA HQ = 2.9										Otter LOAEL-based HQ – without Juvenile Fish[c]									
			Time from Beginning of Construction (years)[a]										*Time from Beginning of Construction (years)*[a]									
			0[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0*[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	1.1	0.7	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.9	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
Alternative 3C	58	3	1.1	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Alternative 4C	107	6	1.1	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.6	0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Alternative 5C	157	7	1.1	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4	0.4
Alternative 6C	302	16	1.1			0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3			0.4	0.4	0.4	0.4	0.4	0.4	0.4
Alternative 2R	32	4	1.1	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.7	0.6	0.5	0.5	0.5	0.5	0.4	0.4	0.4
Alternative 3R	58	6	1.1	0.6	0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3	0.7	0.6	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Alternative 4R	107	11	1.1		0.5	0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3		0.5	0.5	0.5	0.4	0.4	0.4	0.4	0.4
Alternative 5R	157	17	1.1			0.4	0.4	0.4	0.4	0.4	0.4	0.4	1.3			0.5	0.5	0.4	0.4	0.4	0.4	0.4
Alternative 6R	302	42	1.1								0.4	0.4	1.3								0.4	0.4

Notes:

1. Non-cancer hazard quotients were estimated using tissue concentrations predicted by the FWM (Windward 2010) with alternative-specific total PCB SWACs in surface sediment (Table 9-2a) and assumed surface water dissolved total PCBs concentrations of 0.6 ng/L, except 0.9 ng/L at Year 0 for all alternatives at Years 0 and 5 for Alternative 1.
2. All tabulated values are hazard quotients.
3. Hazard quotients were not estimated for construction period because of uncertainties in total PCB tissue concentrations during construction. Fish/shellfish tissue total PCB concentrations are expected to remain elevated for up to 2 years as a result of construction impacts (e.g., sediment resuspension).
4. Residual non-cancer hazard quotients associated with non-RME seafood consumption scenarios are provided in Appendix M.

a. The 5-year model-predicted intervals associated with the BCM SWAC output (for risk estimation) are indexed to the start of construction for Alternatives 2 through 6. Risk estimation for Alternative 1 uses the BCM SWAC output after EAA construction is completed.

b. Risk estimates for time 0 (post-EAA/Alternative 1) use the BCM-predicted SWACs after constructions of the EAAs. While baseline HHRA seafood consumption risks were based on tissue data collected from the LDW, seafood consumption risks at time 0 (post-EAA construction) were estimated using tissue concentrations predicted by the FWM.

c. Otter LOAEL-based HQ without Juvenile Fish was not estimated in the ERA (Windward 2007a).

HQ >1
HQ ≤1
0.4

Colored cells indicate residual non-cancer hazard quotient.

Gray indicates alternative under construction. Red font indicates hazard quotient estimate based on the end of construction PCB SWAC.

BCM Input Values (mid)			
Contaminant	Post-remedy Bed Sediment Replacement	Lateral	Upstream
PCB (µg/kg dw)	60 (AOPC 1) / 20 (AOPC 2)	300	35

AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; dw = dry weight; EAA = early action area; ERA = ecological risk assessment; FS = feasibility study; FWM = Food Web Model; HHRA = human health risk assessment; HQ = hazard quotient; kg = kilogram; L = liter; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; ng = nanogram; µg = microgram; PCB = polychlorinated biphenyl; R = removal; RME = reasonable maximum exposure; SWAC = spatially-weighted average concentration

Table 9-8 Total Excess Cancer Risks for Direct Contact Based on Predicted SWACs

Combined Alternatives

		Risk for Each Alternative																													
		Alternative 1										Alternative 3 Combined (3 years[b])										Alternative 4 Combined (6 years[b])									
		Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*										*Time from Beginning of Construction (years)*									
Receptor Group	**Baseline Risk[a]**	*0[c]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[c]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[c]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Site-wide Netfishing	3 x 10^{-5}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
Tribal Clamming	2 x 10^{-4}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	1 x 10^{-5}	9 x 10^{-6}	9 x 10^{-6}	9 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}
Beach 1	9 x 10^{-6}	9 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 2	9 x 10^{-5}	9 x 10^{-5}	1 x 10^{-5}	8 x 10^{-6}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 3	1 x 10^{-5}	6 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}
Beach 4	6 x 10^{-4}	6 x 10^{-4}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 5	3 x 10^{-5}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 6	1 x 10^{-4}	1 x 10^{-4}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 7	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}
Beach 8	6 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}

		Risk for Each Alternative																			
		Alternative 5 Combined (7 years[b])										Alternative 6 Combined (16 years[b])									
		Time from Beginning of Construction (years)										*Time from Beginning of Construction (years)*									
Receptor Group	**Baseline Risk[a]**	*0[c]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*	*0[c]*	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Site-wide Netfishing	3 x 10^{-5}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
Tribal Clamming	2 x 10^{-4}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}
Beach 1	9 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 2	9 x 10^{-5}	9 x 10^{-5}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 3	1 x 10^{-5}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}
Beach 4	6 x 10^{-4}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 5	3 x 10^{-5}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 6	1 x 10^{-4}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 7	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}
Beach 8	6 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}

Table 9-8 Total Excess Cancer Risks for Direct Contact Based on Predicted SWACs (continued)

Removal Alternatives

		Risk for Each Alternative																													
		Alternative 2 Removal (4 years[b])										Alternative 3 Removal (6 years[b])										Alternative 4 Removal (11 years[b])									
		Time from Beginning of Construction (years)										Time from Beginning of Construction (years)										Time from Beginning of Construction (years)									
Receptor Group	**Baseline Risk[a]**	0[c]	5	10	15	20	25	30	35	40	45	0[c]	5	10	15	20	25	30	35	40	45	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	3 x 10^{-5}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
Tribal Clamming	2 x 10^{-4}	1 x 10^{-5}	9 x 10^{-6}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}
Beach 1	9 x 10^{-6}	9 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 2	9 x 10^{-5}	9 x 10^{-5}	7 x 10^{-6}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 3	1 x 10^{-5}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}
Beach 4	6 x 10^{-4}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 5	3 x 10^{-5}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 6	1 x 10^{-4}	1 x 10^{-4}	6 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 7	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}
Beach 8	6 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}

		Risk for Each Alternative																			
		Alternative 5 Removal (17 years[b])										Alternative 6 Removal (42 years[b])									
		Time from Beginning of Construction (years)										Time from Beginning of Construction (years)									
Receptor Group	**Baseline Risk[a]**	0[c]	5	10	15	20	25	30	35	40	45	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	3 x 10^{-5}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	6 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}	3 x 10^{-6}
Tribal Clamming	2 x 10^{-4}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	1 x 10^{-5}	9 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}	8 x 10^{-6}
Beach 1	9 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	9 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 2	9 x 10^{-5}	9 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	9 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 3	1 x 10^{-5}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	8 x 10^{-6}	7 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	7 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}	6 x 10^{-6}
Beach 4	6 x 10^{-4}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	6 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}
Beach 5	3 x 10^{-5}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	3 x 10^{-5}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 6	1 x 10^{-4}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	1 x 10^{-4}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}
Beach 7	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	5 x 10^{-6}	4 x 10^{-6}
Beach 8	6 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	6 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}	4 x 10^{-6}

Notes:

1. Total excess cancer risks include only the risk drivers (total PCBs, arsenic, cPAHs, and dioxins/furans).
2. Significant figures are displayed in accordance with the conventions established in the HHRA.
3. The BCM input values used in the predicted future concentrations after start of construction are as follows:

Contaminant	Unit	Upstream	Lateral	Post-remedy Bed Sediment Replacement Value
Total PCBs	µg/kg dw	35	300	60 (AOPC 1), 20 (AOPC 2)
Arsenic	mg/kg dw	9	13	10 (AOPC 1), 9 (AOPC 2)
cPAHs	µg TEQ /kg dw	70	1,400	140 (AOPC 1), 100 (AOPC 2)
Dioxins/Furans	ng TEQ /kg dw	4	20	4

4. Baseline risks are used as the post-EAA risk at time 0 for the beaches (with the exception of beach 3).

a. Baseline risks for the direct contact scenarios are reported in Section 3 (Table 3-6a for netfishing and tribal clamming scenarios, and Table 3-6b for beach play scenarios).

b. Construction period.

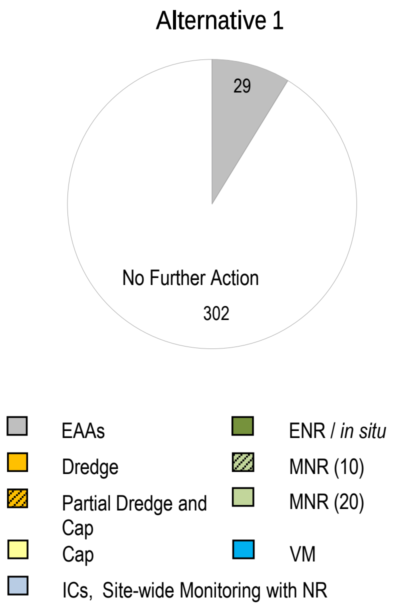
c. The 5-year model-predicted intervals associated with the BCM SWAC output (used in the risk estimation) are indexed to the start of construction for Alternatives 2 through 6. Risk estimation for Alternative 1 uses the BCM SWAC output after EAA construction is completed.

AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EAA = early action area; HHRA = human health risk assessment; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; ng = nanogram; PCB = polychlorinated biphenyl; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

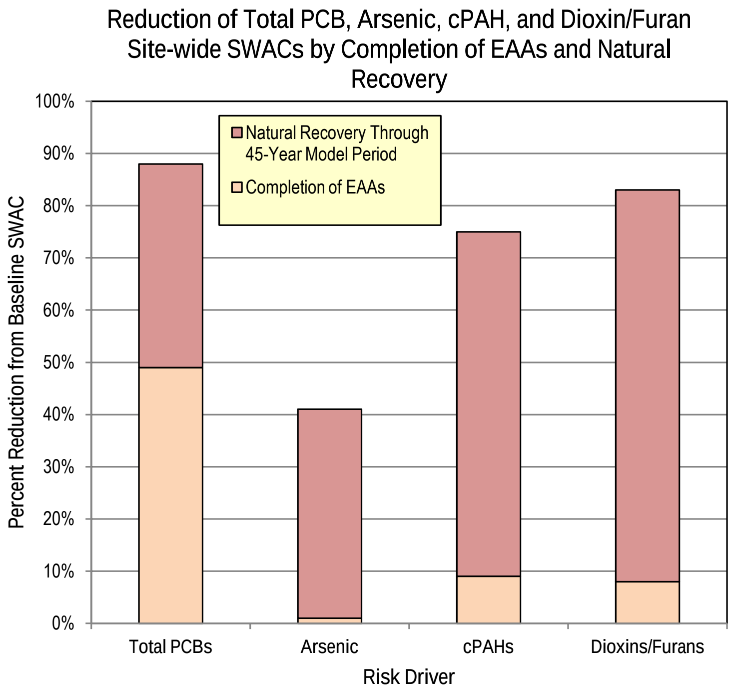
Table 9-9 Remedial Alternative 1: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Early Action Areas (acres)		29
Actively Remediated Area (acres)	Dredge	n/a
	Partial Dredge and Cap	n/a
	Cap	n/a
	ENR / *in situ*	n/a
	Habitat Area	n/a
Passively Remediated Area (acres)	MNR(10)	n/a
	MNR(20)	n/a
	Verification Monitoring	n/a
	Habitat Area	n/a
Active/Passive/Total Managed Area (acres)		n/a
ICs, Site-wide Monitoring with NR (acres)		n/a
Total Dredge Volume (cy)		n/a
Construction Time (years)		n/a

Cost Summary		
Costs ($)[a]	Completion of EAA Construction	95,000,000
	Alternative 1	9,000,000
	Total	104,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[b]	🟦	🟦	🟦	🟦	🟦	🟦																					25
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[b]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦											
	Total PCBs in sediment reach long-term model-predicted concentration ranges site-wide[c]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
	Dioxins/Furans in sediment reach long-term model-predicted concentration ranges site-wide[c]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦						
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦	🟦																					25
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas [d]	🟦	🟦	🟦	🟦	🟦	🟦																					
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦	🟦																					
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦	🟦																					
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3 [e]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [f]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦						20
RAO 4	River Otter LOAEL-based HQ <1 [b]	🟦	🟦	🟦	🟦	🟦	🟦																					5

End of EAA Construction

🟦 Estimated period of time to reach indicated risk outcome.

Notes:

1. Alternative 1 outcomes have high uncertainty because BCM model is applied to all areas of site regardless of recovery category or scour potential.
2. Time periods are referenced to a starting point that assumes construction of all EAAs has been completed.
3. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting. The costs for EAA in-water construction are shown for completeness. The EAA cleanup action costs are provided for informational purposes, and are not included in the cost of other alternatives or used in the comparison of alternatives.

b. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.

c. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw, and a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.

d. The total PCB SWAC for Beach 4 is below the PRG for the direct contact exposure scenario. Based on the HHRA, this beach is expected to have 6 x 10^{-6} excess cancer risk for total PCBs at the end of construction (no active remediation in this beach in Alternative 1).

e. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.

f. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

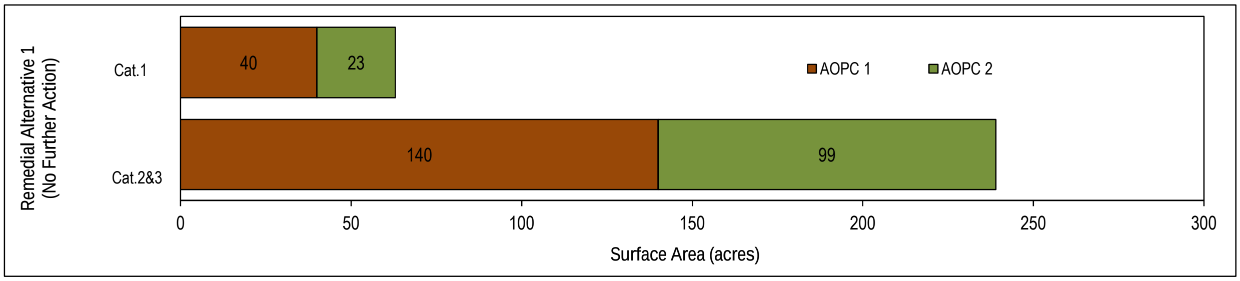
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yards; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; HHRA = human health risk assessment; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MNR = monitored natural recovery; n/a = not applicable; ng=nanogram; NR = natural recovery; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-10 Post-Construction Sediment Conditions for Alternative 1

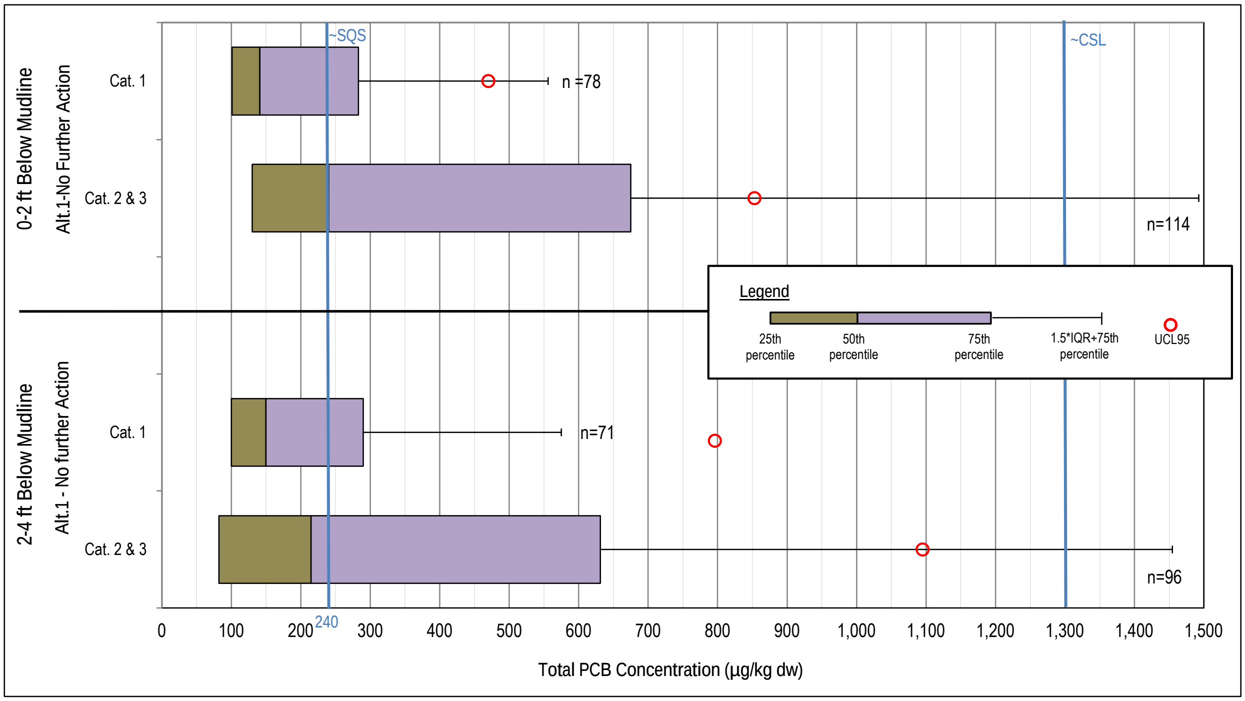
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA Footprint for Alternative 1

		Located within AOPC 1 and AOPC 2 Outside of EAAs							
		Core Station Counts		Total PCB Concentration (µg/kg dw)					
				0 to 2 ft depth			2 to 4 ft depth		
Remedial Alternative 1	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95
No Further Action	1	25	na	78	270	470	71	375	796
	2 and 3	45	na	114	542	853	96	568	1095
	All	70	na	192	431	637	167	486	838

Surface Areas Outside the EAA Footprint Corresponding to Areas of Potential Concern for Alternative 1



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA Footprint for Alternative 1



Notes:

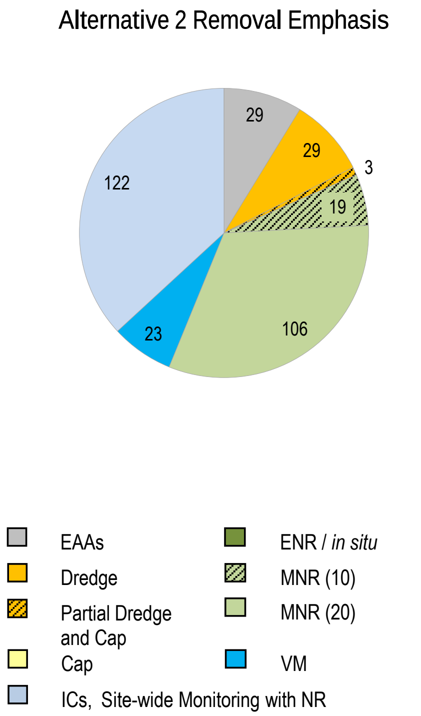
1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

Alt. = alternative; AOPC = area of potential concern; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; n = number of cores; na = not available; PCB = polychlorinated biphenyl; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean

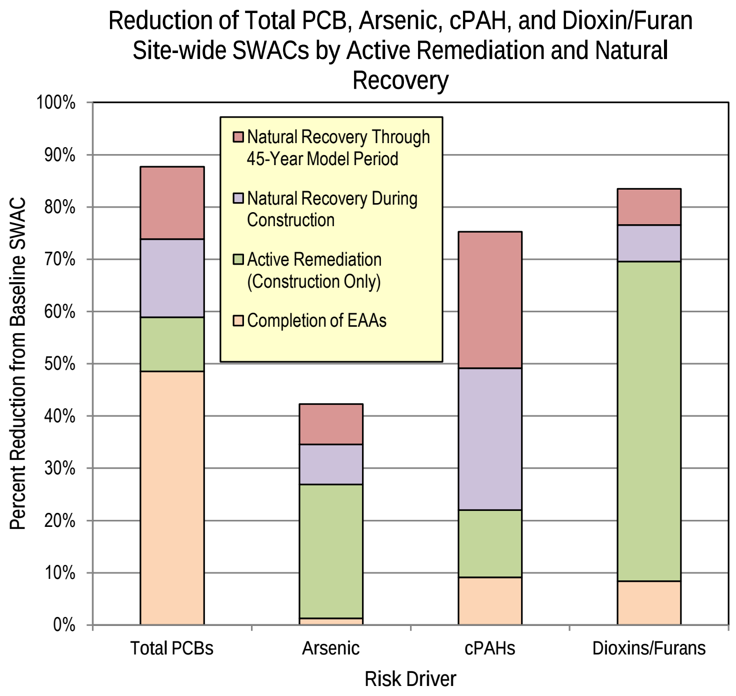
Table 9-11 Remedial Alternative 2R and 2R-CAD: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	29
	Partial Dredge and Cap	3
	Cap	0
	ENR / *in situ*	0
	Habitat Area[a]	13
Passively Remediated Area (acres)	MNR(10)[b]	19
	MNR(20)[c]	106
	Verification Monitoring	23
	Habitat Area[a]	61
Active/Passive/Total Managed Area (acres)[d]		32/148/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		580,000
Construction Time (years)		4

Cost Summary		
Costs ($)[g]	Capital (Alternative 2R/2R-CAD)	169,000,000/148,000,000
	OM&M (Alternative 2R/2R-CAD)	46,000,000/48,000,000
	Total (Alternative 2R/2R-CAD)	220,000,000/200,000,000


Alternative 2 Removal Emphasis

Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.


Reduction of Total PCB, Arsenic, cPAH, and Dioxin/Furan Site-wide SWACs by Active Remediation and Natural Recovery

Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟩	🟩																				24
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																	
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																	
RAO 2	$\le 1 \times 10^{-5}$ total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦																						19
	$\le 1 \times 10^{-6}$ direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦	🟦																						
	$\le 1 \times 10^{-5}$ and $> 1 \times 10^{-6}$ direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦																						
	$< 1 \times 10^{-6}$ direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦																						
	$\le 1 \times 10^{-6}$ direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦							
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦	🟦																						
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦												14
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟩	🟩																				4

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternatives 2R and 2R-CAD are as follows: arsenic: 93 mg/kg dw; total PCBs: 2,200 µg/kg dw; cPAHs: 5,500 µg TEQ/kg dw, dioxins/furans: 50 ng TEQ/kg dw, and benthic SMS (41 contaminants): CSL 10 (achieve CSL within 10 years).
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. MNR(10) is the area expected to be less than CSL (Alternative 2) within 10 years.
c. MNR(20) is the area expected to be less than SQS within 20 years (applicable to areas below the RALs).
d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.
e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.
f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.
g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.
h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.
i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.
j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.
k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.
l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

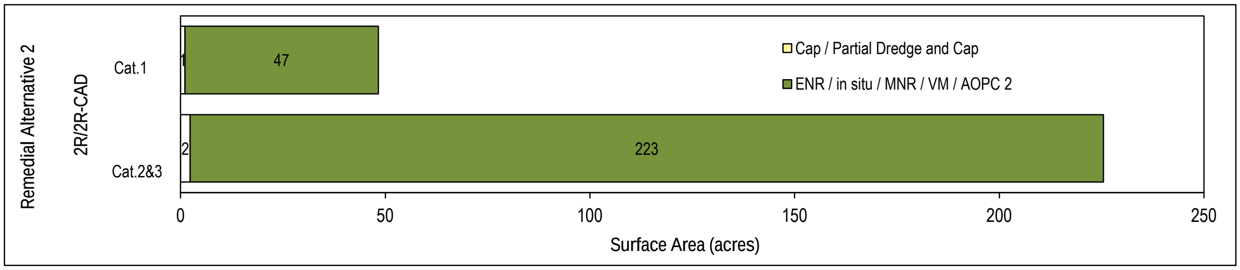
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal; RAL = remedial action level; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-12 Post-Construction Sediment Conditions for Alternative 2

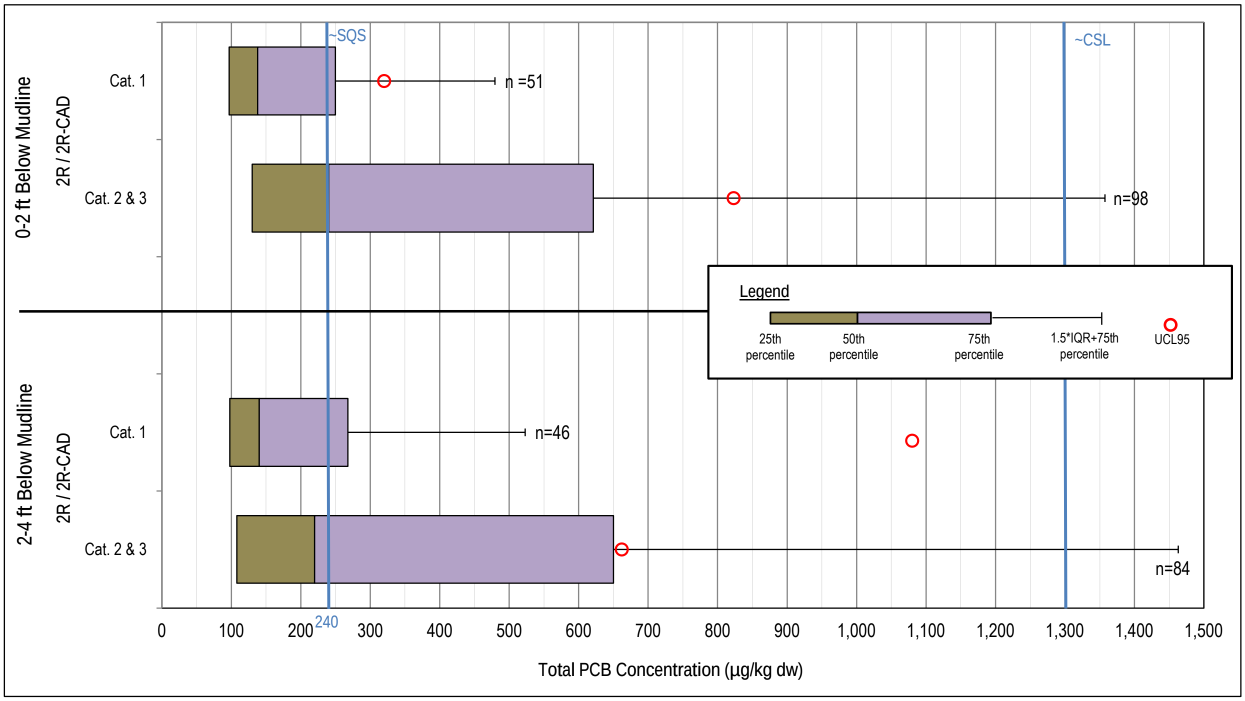
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 2

		Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint								Cap / Partial Dredge and Cap			
		Core Station Counts		Total PCB Concentration (µg/kg dw)						Core Station Counts		Total PCB Concentration (µg/kg dw)	
				0 to 2 ft depth			2 to 4 ft depth					0 to 4 ft depth	
Remedial Alternative 2	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95	> CSL	< CSL, > SQS	n	Mean
Removal / Removal w/CAD	1	4	19	51	192	320	46	338	1,080	0	0	0	-
	2 and 3	33	28	98	500	823	84	511	662				
	All	37	47	149	395	617	130	450	742				

Surface Areas Outside the EAA and Dredge Footprint Corresponding to Technology Assignment Groups for Alternative 2



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA, Dredge and Cap Footprint for Alternative 2



Notes:

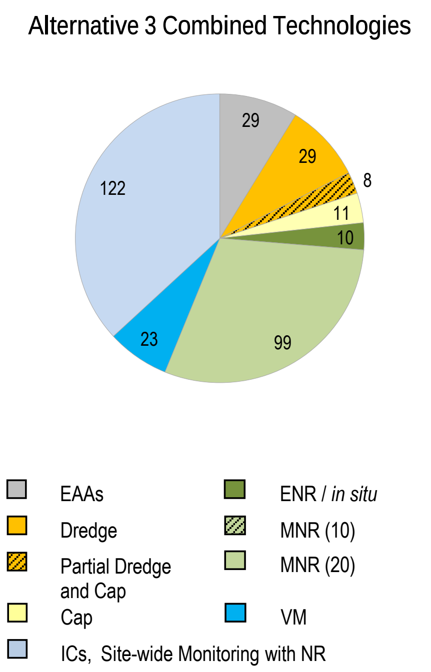
1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. Alternatives 2R and 2R-CAD include 29 acres of dredged areas, not shown in center panel. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4-ft interval (shown in top table) is the vertical average of the combination of clean capping material (0 to 2 ft [with an assumed total PCB concentration of 40 µg/kg dw]), and the native sediment (0 to 2 ft in areas to be capped, and 2 to 4 ft in areas to be partially dredged/capped [with the total PCB concentration from those intervals in the subsurface FS baseline dataset]). However, a sediment cap is designed to be 3 ft thick.
7. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

AOPC = area of potential concern; CAD = contained aquatic disposal; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; MNR = monitored natural recovery; n = number of cores; PCB = polychlorinated biphenyl; R = removal; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean; VM = verification monitoring

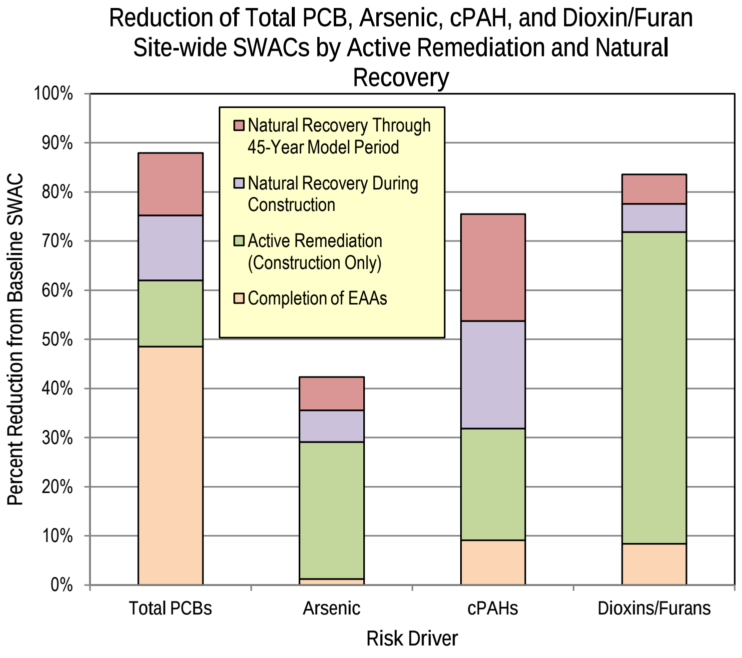
Table 9-13 Remedial Alternative 3C: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	29
	Partial Dredge and Cap	8
	Cap	11
	ENR / *in situ*	5 / 5
	Habitat Area[a]	28
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	99
	Verification Monitoring	23
	Habitat Area[a]	46
Active/Passive/Total Managed Area (acres)[d]		58/122/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		490,000
Construction Time (years)		3

Cost Summary		
Costs ($)[g]	Capital	156,000,000
	OM&M	45,000,000
	Total	200,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary

Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟩	🟩																					18
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																		
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦								
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																		
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦																							3
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦																							
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦																							
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas[l]	🟦	🟦	🟦	🟦																							
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																		8
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟩	🟩																					3

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 3C are as follows: arsenic: 93 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 1,300 µg/kg dw; cPAHs: 3,800 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 35 (site-wide) and 28 (intertidal) ng TEQ/kg dw, and benthic SMS (41 contaminants): CSL toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

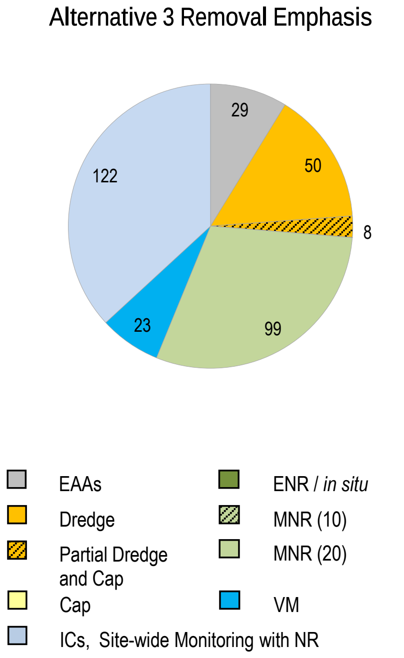
a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. Not applicable for Alternative 3C.
c. MNR(20) is the area expected to be less than the SQS within 20 years (applicable to areas below the RALs).
d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.
e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.
f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.
g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.
h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.
i. Based on achieving a site-wide total SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.
j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.
k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.
l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = insittutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAL = remedial action level; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

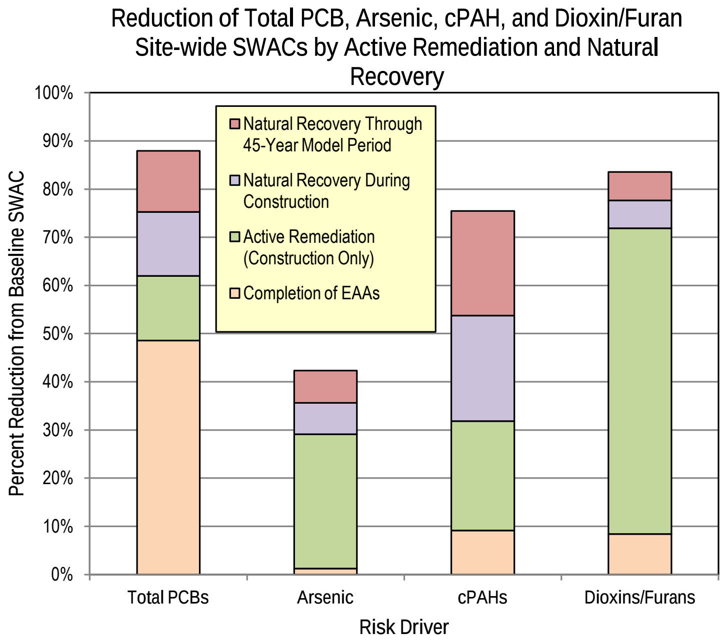
Table 9-14 Remedial Alternative 3R: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	50
	Partial Dredge and Cap	8
	Cap	0
	ENR / *in situ*	0
	Habitat Area[a]	28
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	99
	Verification Monitoring	23
	Habitat Area[a]	46
Active/Passive/Total Managed Area (acres)[d]		58/122/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		760,000
Construction Time (years)		6

Cost Summary		
Costs ($)[g]	Capital	224,000,000
	OM&M	43,000,000
	Total	270,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																		21
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦																						6
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦																						
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦	🟦																						
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															11
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																		6

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 3R are as follows: arsenic: 93 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 1,300 µg/kg dw; cPAHs: 3,800 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 35 (site-wide) and 28 (intertidal) ng TEQ/kg dw, and benthic SMS (41 contaminants): CSL toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. Not applicable for Alternative 3R.
c. MNR(20) is the area expected to be less than the SQS within 20 years (applicable to areas below the RALs).
d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.
e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.
f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.
g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.
h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.
i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.
j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.
k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.
l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

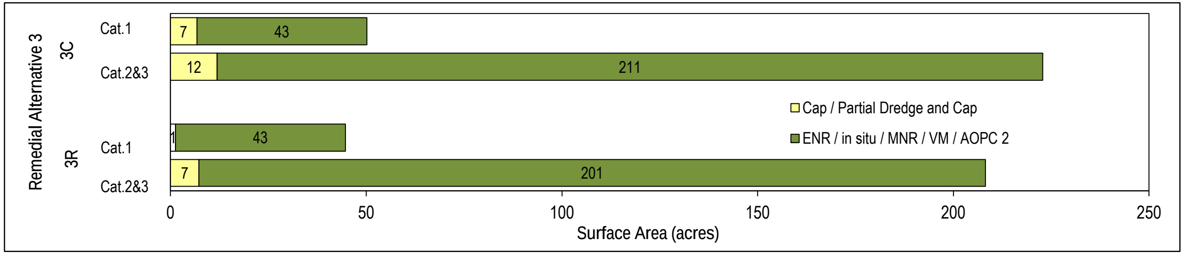
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal; RAL = remedial action level; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-15 Post-Construction Sediment Conditions for Alternative 3

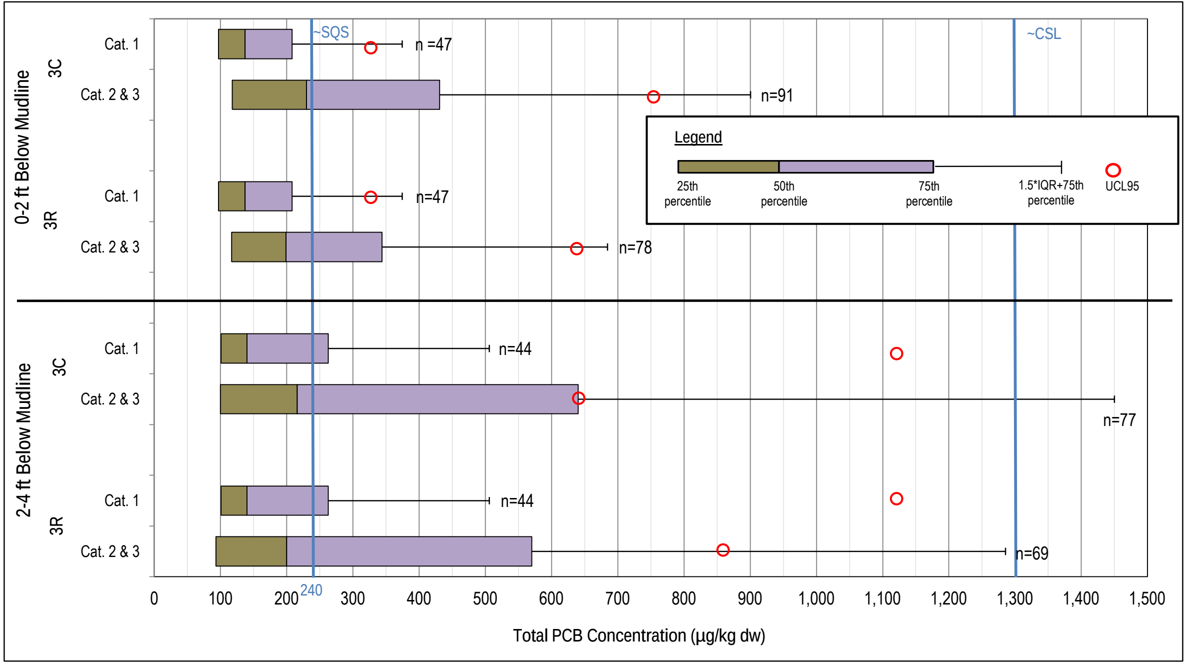
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 3

		Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint								Cap / Partial Dredge and Cap			
		Core Station Counts		Total PCB Concentration (µg/kg dw)						Core Station Counts		Total PCB Concentration (µg/kg dw)	
				0 to 2 ft depth			2 to 4 ft depth					0 to 4 ft depth	
Remedial Alternative 3	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95	> CSL	< CSL, > SQS	n	Mean
Combined	1	4	16	47	190	327	44	347	1,121	15	1	16	770
	2 and 3	28	27	91	441	754	77	486	641				
	All	32	43	138	356	571	121	436	736				
Removal	1	4	16	47	190	327	44	347	1,121	1	0	1	240
	2 and 3	20	25	78	366	638	69	470	859				
	All	24	41	125	300	480	113	422	739				

Surface Areas Outside the EAA and Dredge Footprint Corresponding to Technology Assignment Groups for Alternative 3



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA, Dredge and Cap Footprint for Alternative 3



Notes:

1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. Alternatives 3C and 3R include 29 and 50 acres, respectively, of dredged areas, not shown in center panel. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4-ft interval (shown in top table) is the vertical average of the combination of clean capping material (0- to 2-ft [with an assumed total PCB concentration of 40 µg/kg dw]), and the native sediment (0 to 2 ft in areas to be capped, and 2 to 4 ft in areas to be partially dredged/capped [with the total PCB concentration from those intervals in the subsurface FS baseline dataset]). However, a sediment cap is designed to be 3 ft thick.
7. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

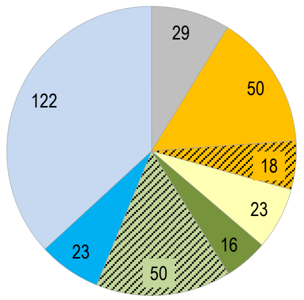
AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; MNR = monitored natural recovery; n = number of cores; PCB = polychlorinated biphenyl; R = removal; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean; VM = verification monitoring

Table 9-16 Remedial Alternative 4C: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	50
	Partial Dredge and Cap	18
	Cap	23
	ENR / *in situ*	8 / 8
	Habitat Area[a]	42
Passively Remediated Area (acres)	MNR(10)[b]	50
	MNR(20)[c]	0
	Verification Monitoring	23
	Habitat Area[a]	32
Active/Passive/Total Managed Area (acres)[d]		107/73/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		690,000
Construction Time (years)		6

Cost Summary		
Costs ($)[g]	Capital	221,000,000
	OM&M	41,000,000
	Total	260,000,000

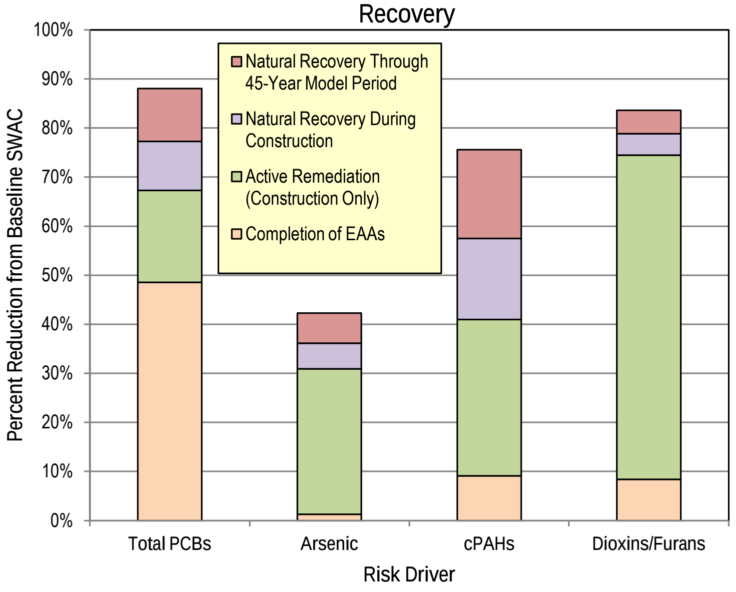
Alternative 4 Combined Technologies



⬜	EAAs	🟩	ENR / *in situ*
🟧	Dredge	▨	MNR (10)
▨	Partial Dredge and Cap	🟩	MNR (20)
🟨	Cap	🟦	VM
🟦	ICs, Site-wide Monitoring with NR		

Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.

Reduction of Total PCB, Arsenic, cPAH, and Dioxin/Furan Site-wide SWACs by Active Remediation and Natural Recovery



Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																		21
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦																							3
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦																							
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦																							
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦																							
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				6
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																		6

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 4C are as follows: arsenic: 57 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 700 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS 10 (achieve SQS within 10 years).
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.

b. MNR(10) is the area expected to be less than the SQS (Alternative 4) within 10 years.

c. Not applicable for Alternative 4C.

d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.

e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.

f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.

g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.

i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.

j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.

k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.

l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

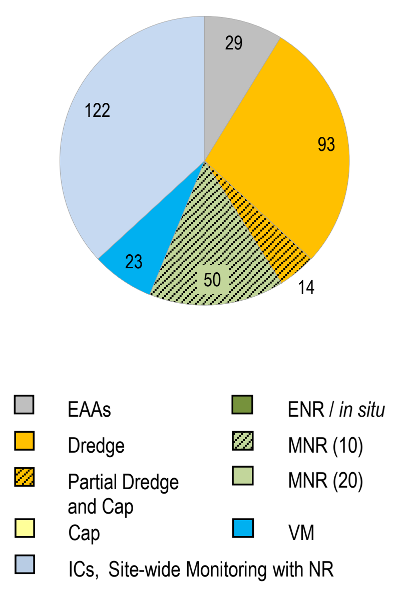
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-17 Remedial Alternative 4R: Scope, Costs, and Risk Performance Summary

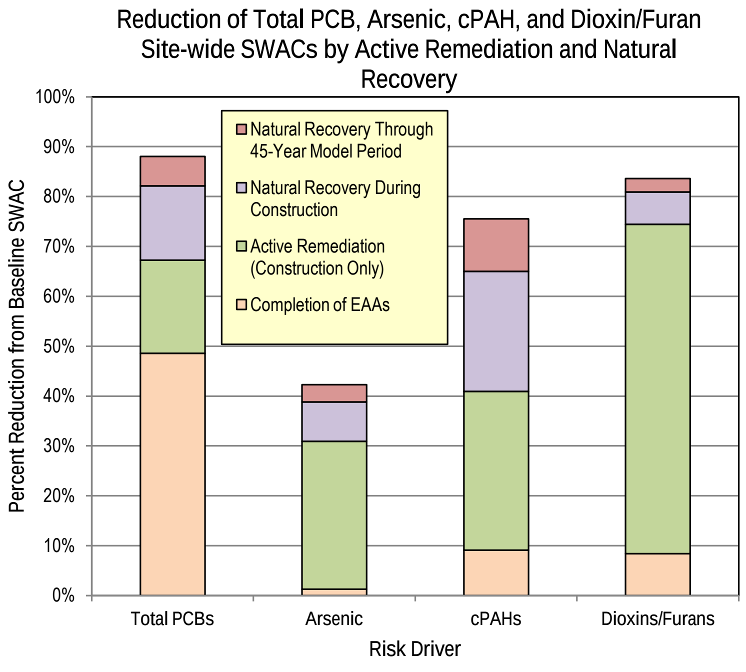
Technology Application Summary		
Actively Remediated Area (acres)	Dredge	93
	Partial Dredge and Cap	14
	Cap	0
	ENR / *in situ*	0
	Habitat Area[a]	42
Passively Remediated Area (acres)	MNR(10)[b]	50
	MNR(20)[c]	0
	Verification Monitoring	23
	Habitat Area[a]	32
Active/Passive/Total Managed Area (acres)[d]		107/73/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		1,200,000
Construction Time (years)		11

Cost Summary		
Costs ($)[g]	Capital	324,000,000
	OM&M	38,000,000
	Total	360,000,000

Alternative 4 Removal Emphasis



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary

Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩													21
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩													
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦					
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦																						6
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦																						
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦	🟦																						
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															11
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩													11

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 4R are as follows: arsenic: 57 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 700 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS 10 (achieve SQS within 10 years).
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.

b. MNR(10) is the area expected to be less than the SQS (Alternative 4) within 10 years.

c. Not applicable for Alternative 4R.

d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.

e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.

f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.

g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.

i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.

j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.

k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.

l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

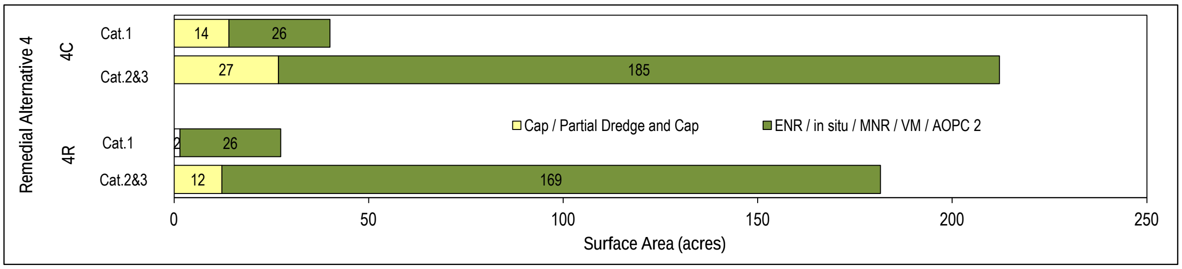
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-18 Post-Construction Sediment Conditions for Alternative 4

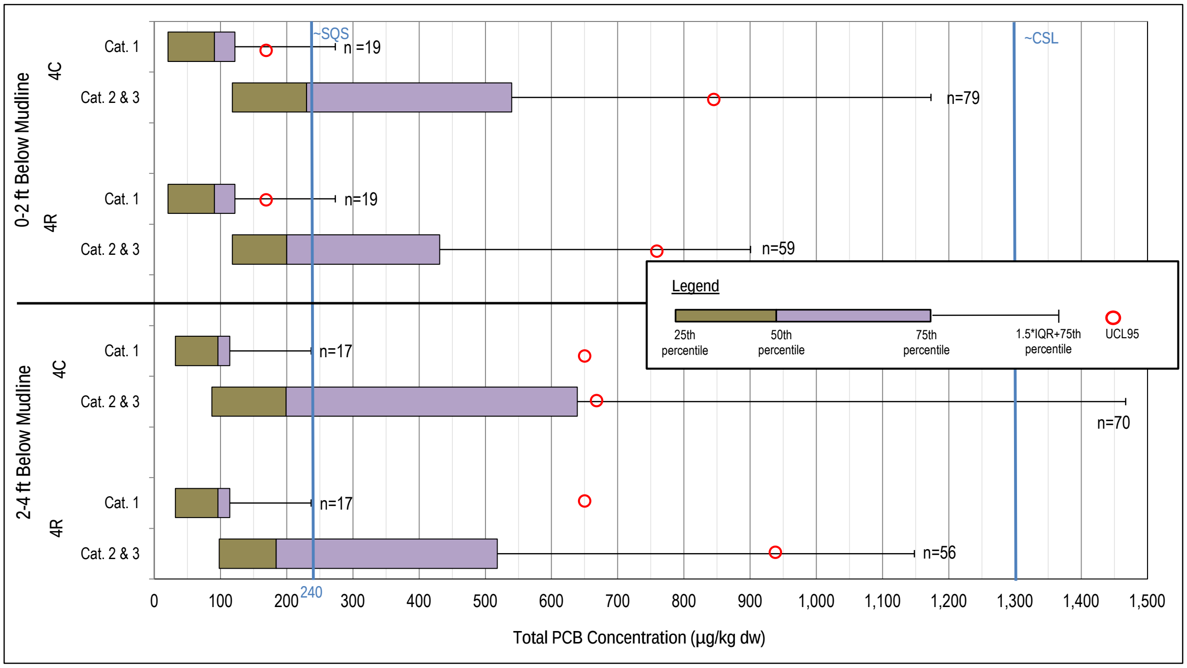
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 4

		Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint								Cap / Partial Dredge and Cap			
		Core Station Counts		Total PCB Concentration (µg/kg dw)						Core Station Counts		Total PCB Concentration (µg/kg dw)	
				0 to 2 ft depth			2 to 4 ft depth					0 to 4 ft depth	
Remedial Alternative 4	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95	> CSL	< CSL, > SQS	n	Mean
Combined	1	0	4	19	91	169	17	136	650	18	4	29	582
	2 and 3	26	22	79	485	845	70	494	668				
	All	26	26	98	409	707	87	424	748				
Removal	1	0	4	19	91	169	17	136	650	1	0	1	240
	2 and 3	14	19	59	409	759	56	481	938				
	All	14	23	78	332	605	73	401	762				

Surface Areas Outside the EAA and Dredge Footprint Corresponding to Technology Assignment Groups for Alternative 4



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA, Dredge and Cap Footprint for Alternative 4



Notes:

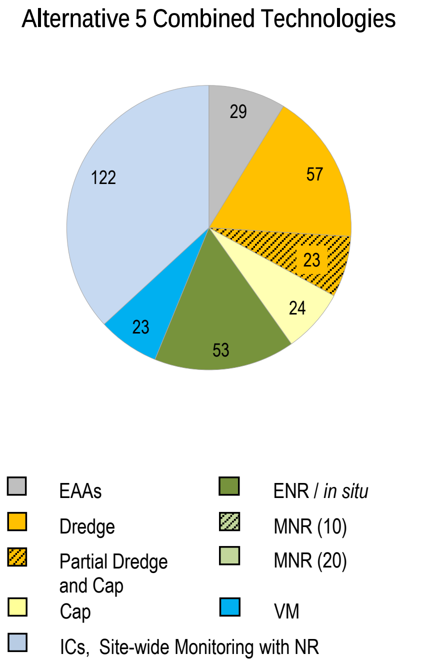
1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. Alternatives 4C and 4R include 50 and 93 acres, respectively, of dredged areas, not shown in center panel. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4-ft interval (shown in top table) is the vertical average of the combination of clean capping material (0 to 2 ft [with an assumed total PCB concentration of 40 µg/kg dw]), and the native sediment (0 to 2 ft in areas to be capped, and 2 to 4 ft in areas to be partially dredged/capped [with the total PCB concentration from those intervals in the subsurface FS baseline dataset]). However, a sediment cap is designed to be 3 ft thick.
7. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; MNR = monitored natural recovery; n = number of cores; PCB = polychlorinated biphenyl; R = removal; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean; VM = verification monitoring

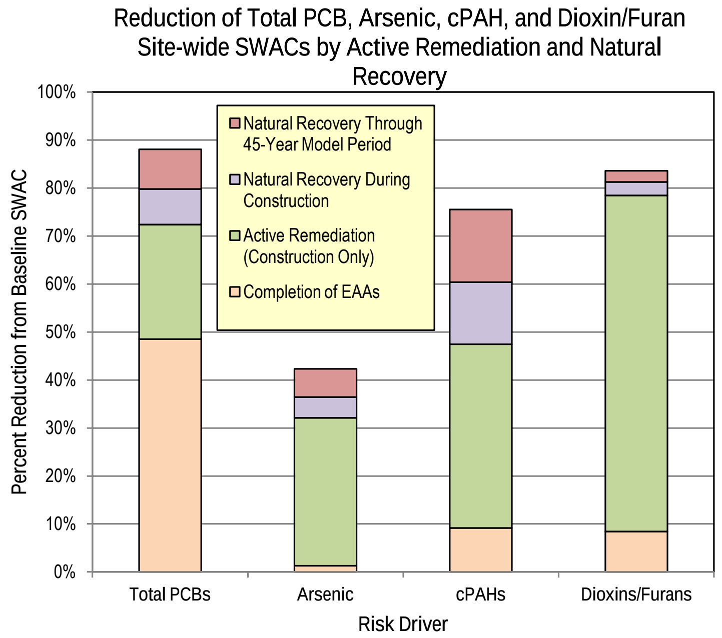
Table 9-19 Remedial Alternative 5C: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	57
	Partial Dredge and Cap	23
	Cap	24
	ENR / *in situ*	26.5 / 26.5
	Habitat Area[a]	59
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	0
	Verification Monitoring	23
	Habitat Area[a]	15
Active/Passive/Total Managed Area (acres)[d]		157/23/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		750,000
Construction Time (years)		7

Cost Summary		
Costs ($)[g]	Capital	250,000,000
	OM&M	41,000,000
	Total	290,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary

Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																	17
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																	
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦									
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦																			
RAO 2	$\leq 1 \times 10^{-5}$ total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦																							3
	$\leq 1 \times 10^{-6}$ direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦																							
	$\leq 1 \times 10^{-5}$ and $> 1 \times 10^{-6}$ direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦																							
	$< 1 \times 10^{-6}$ direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦																							
	$\leq 1 \times 10^{-6}$ direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦																							
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas[l]	🟦	🟦	🟦	🟦																							
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				6
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩																	7

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 5C are as follows: arsenic: 57 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 240 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.

b. Not applicable for Alternative 5C.

c. Not applicable for Alternative 5C.

d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.

e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.

f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.

g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.

i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.

j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.

k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.

l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

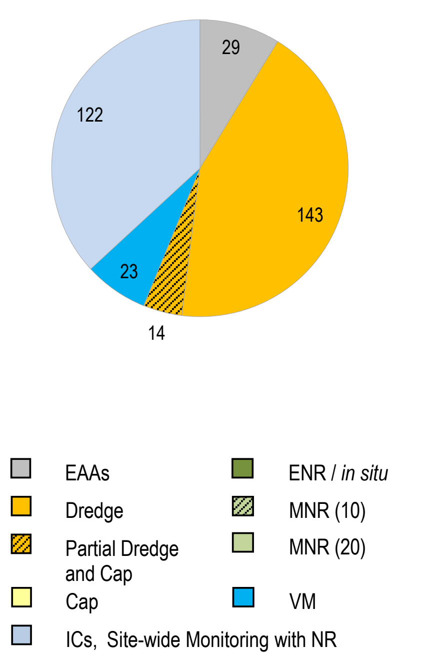
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-20 Remedial Alternative 5R and 5R-T: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	143
	Partial Dredge and Cap	14
	Cap	0
	ENR / *in situ*	0
	Habitat Area[a]	59
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	0
	Verification Monitoring	23
	Habitat Area[a]	15
Active/Passive/Total Managed Area (acres)[d]		157/23/180
ICs, Site-wide Monitoring with NR (acres)[e]		122
Total Dredge Volume (cy)[f]		1,600,000
Construction Time (years)		17

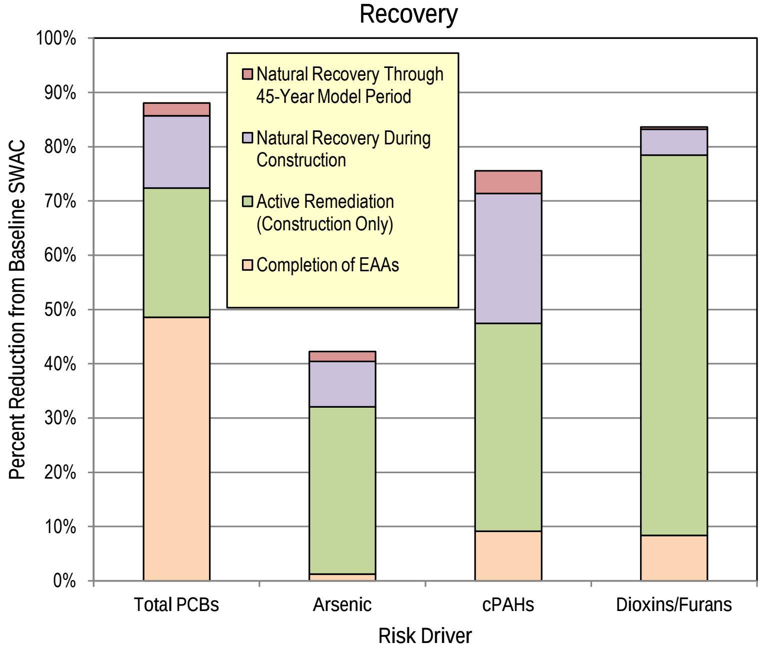
Cost Summary		
Costs ($)[g]	Capital (Alternative 5R/5R-T)	430,000,000/ 474,000,000
	OM&M	36,000,000
	Total (Alternative 5R/5R-T)	470,000,000/ 510,000,000

Alternative 5 Removal Emphasis

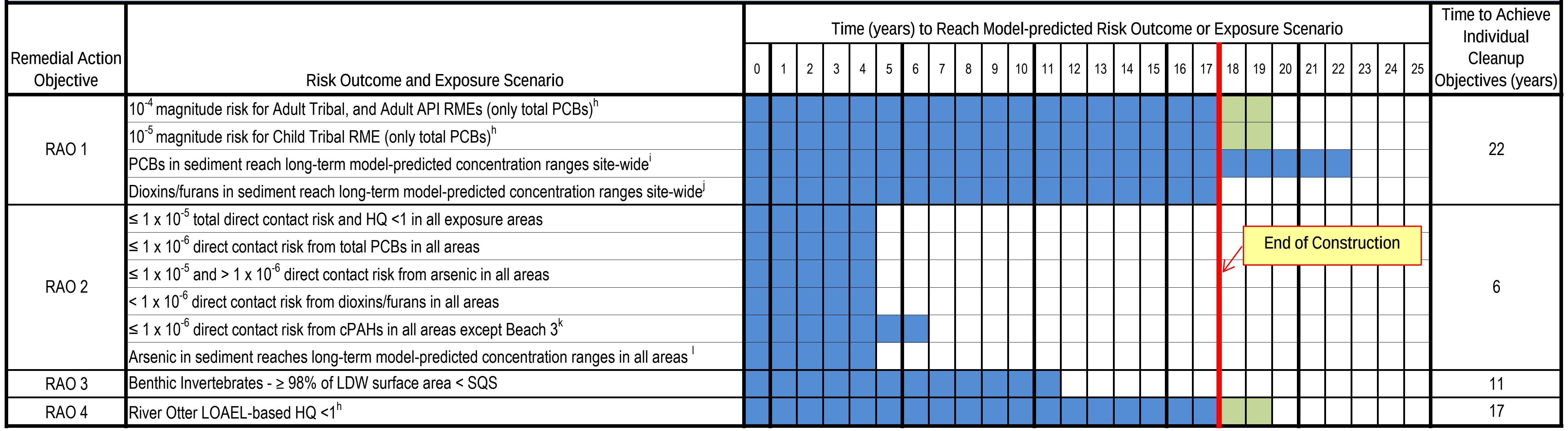


Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.

Reduction of Total PCB, Arsenic, cPAH, and Dioxin/Furan Site-wide SWACs by Active Remediation and Natural Recovery



Risk Performance Summary



Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal, and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩							22
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩							
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦				
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦									
RAO 2	$\leq 1 \times 10^{-5}$ total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦																						6
	$\leq 1 \times 10^{-6}$ direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦	🟦																						
	$\leq 1 \times 10^{-5}$ and $> 1 \times 10^{-6}$ direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦																						
	$< 1 \times 10^{-6}$ direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦																						
	$\leq 1 \times 10^{-6}$ direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas[l]	🟦	🟦	🟦	🟦	🟦																						
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															11
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩							17

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 5R/5R-T are as follows: arsenic: 57 (site-wide) and 28 (intertidal) mg/kg dw; total PCBs: 240 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 25 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. Not applicable for Alternative 5R/5R-T.
c. Not applicable for Alternative 5R/5R-T.
d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.
e. Acres in AOPC 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.
f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.
g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.
h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.
i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.
j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.
k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.
l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.4 mg/kg dw.

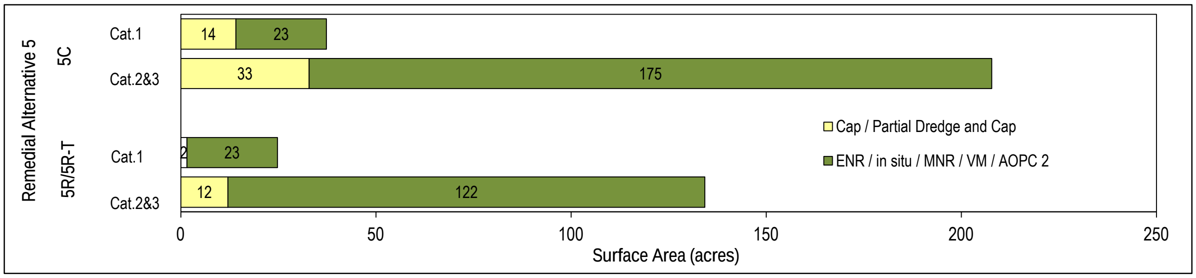
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; R = removal; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; T = treatment; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-21 Post-Construction Sediment Conditions for Alternative 5

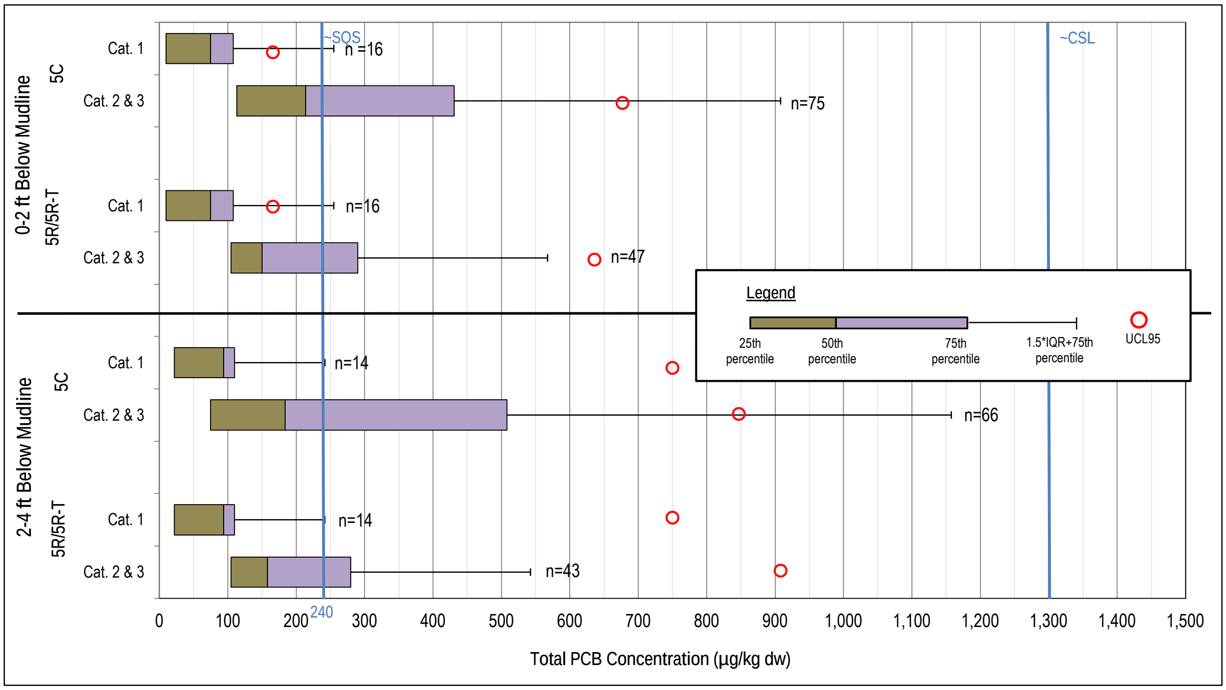
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 5

		Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint								Cap / Partial Dredge and Cap			
		Core Station Counts		Total PCB Concentration (µg/kg dw)						Core Station Counts		Total PCB Concentration (µg/kg dw)	
				0 to 2 ft depth			2 to 4 ft depth					0 to 4 ft depth	
Remedial Alternative 5	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95	> CSL	< CSL, > SQS	n	Mean
Combined	1	0	2	16	80	166	14	133	750	20	4	31	610
	2 and 3	22	22	75	399	677	66	451	847				
	All	22	24	91	343	579	80	395	730				
Removal	1	0	2	16	80	166	14	133	750	1	0	1	240
	2 and 3	5	16	47	313	636	43	363	908				
	All	5	18	63	253	501	57	306	606				

Surface Areas Outside the EAA and Dredge Footprint Corresponding to Technology Assignment Groups for Alternative 5



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA, Dredge and Cap Footprint for Alternative 5



Notes:

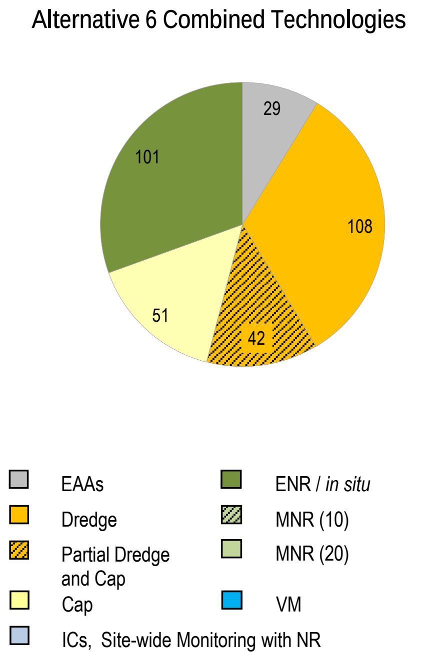
1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. Alternatives 5C and 5R/5R-T include 57 and 143 acres, respectively, of dredged areas, not shown in center panel. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4-ft interval (shown in top table) is the vertical average of the combination of clean capping material (0 to 2 ft [with an assumed total PCB concentration of 40 µg/kg dw]), and the native sediment (0 to 2 ft in areas to be capped, and 2 to 4 ft in areas to be partially dredged/capped [with the total PCB concentration from those intervals in the subsurface FS baseline dataset]). However, a sediment cap is designed to be 3 ft thick.
7. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; MNR = monitored natural recovery; n = number of cores; PCB = polychlorinated biphenyl; R = removal; R-T = removal with treatment; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean; VM = verification monitoring

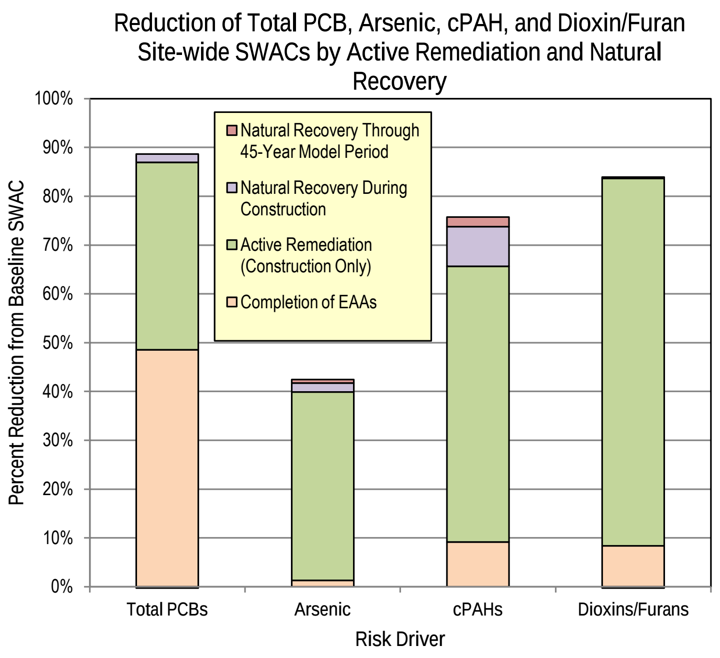
Table 9-22 Remedial Alternative 6C: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	108
	Partial Dredge and Cap	42
	Cap	51
	ENR / *in situ*	50.5 / 50.5
	Habitat Area[a]	99
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	0
	Verification Monitoring	0
	Habitat Area[a]	0
Active/Passive/Total Managed Area (acres)[d]		302/0/302
ICs, Site-wide Monitoring with NR (acres)[e]		0
Total Dredge Volume (cy)[f]		1,600,000
Construction Time (years)		16

Cost Summary		
Costs ($)[g]	Capital	476,000,000
	OM&M	51,000,000
	Total	530,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	
RAO 1	10^{-4} magnitude risk for Adult Tribal and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩								16
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩								
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦										
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦										
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦																							3
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦																							
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦																							
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦																							
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦																							
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				6
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟩	🟩								16

End of Construction

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 6C are as follows: arsenic: 15 mg/kg dw; total PCBs: 100 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 15 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.

b. Not applicable for Alternative 6C.

c. Not applicable for Alternative 6C.

d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.

e. Alternative 6C is comprised of AOPCs 1 and 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.

f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.

g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.

h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.

i. Based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw.

j. Based on achieving a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw.

k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.

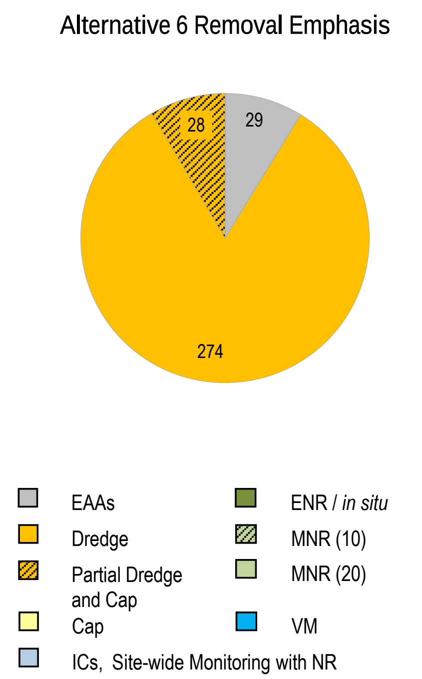
l. Based on achieving a site-wide arsenic SWAC within 25% (≤ 11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

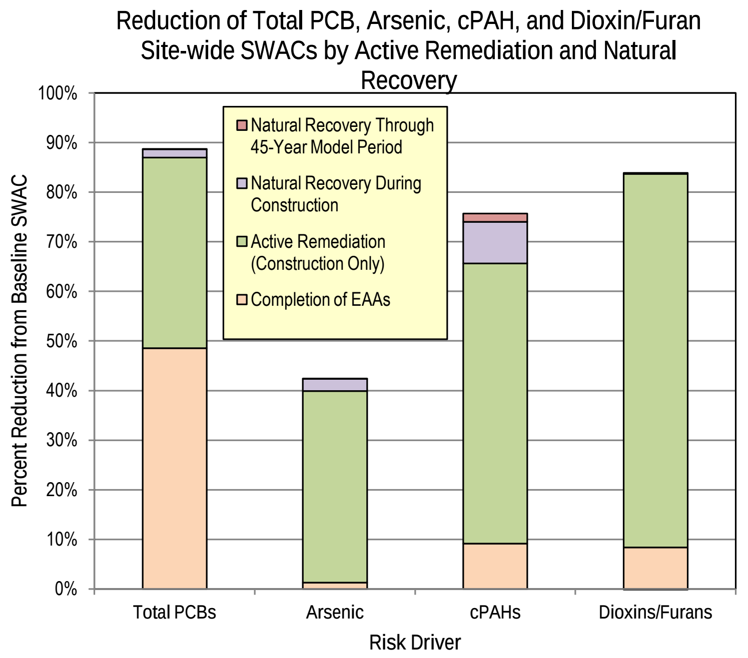
Table 9-23 Remedial Alternative 6R: Scope, Costs, and Risk Performance Summary

Technology Application Summary		
Actively Remediated Area (acres)	Dredge	274
	Partial Dredge and Cap	28
	Cap	0
	ENR / *in situ*	0
	Habitat Area[a]	99
Passively Remediated Area (acres)	MNR(10)[b]	0
	MNR(20)[c]	0
	Verification Monitoring	0
	Habitat Area[a]	0
Active/Passive/Total Managed Area (acres)[d]		302/0/302
ICs, Site-wide Monitoring with NR (acres)[e]		0
Total Dredge Volume (cy)[f]		3,900,000
Construction Time (years)		42

Cost Summary		
Costs ($)[g]	Capital	771,000,000
	OM&M	42,000,000
	Total	810,000,000



Note: Numbers in pie chart represent acres; total area is 331 acres, comprised of EAAs and AOPCs 1 and 2.



Risk Performance Summary																												
Remedial Action Objective	Risk Outcome and Exposure Scenario	Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										Time to Achieve Individual Cleanup Objectives (years)
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17			40	41	42	43	44	45	
RAO 1	10^{-4} magnitude risk for Adult Tribal and Adult API RMEs (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦	🟩	🟩		42
	10^{-5} magnitude risk for Child Tribal RME (only total PCBs)[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦	🟩	🟩		
	PCBs in sediment reach long-term model-predicted concentration ranges site-wide[i]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦				
	Dioxins/furans in sediment reach long-term model-predicted concentration ranges site-wide[j]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦				
RAO 2	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	🟦	🟦	🟦	🟦	🟦																						6
	≤ 1 x 10^{-6} direct contact risk from total PCBs in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-5} and > 1 x 10^{-6} direct contact risk from arsenic in all areas	🟦	🟦	🟦	🟦	🟦																						
	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	🟦	🟦	🟦	🟦	🟦																						
	≤ 1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3[k]	🟦	🟦	🟦	🟦	🟦	🟦	🟦																				
	Arsenic in sediment reaches long-term model-predicted concentration ranges in all areas [l]	🟦	🟦	🟦	🟦	🟦																						
RAO 3	Benthic Invertebrates - ≥ 98% of LDW surface area < SQS	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦															11
RAO 4	River Otter LOAEL-based HQ <1[h]	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			🟦	🟦	🟦	🟩	🟩		42

End of Construction

Results between 17 and 40 years are the same for all the RAOs.

🟦 Estimated period of time to reach indicated risk outcome.

🟩 Period of up to 2 years following construction during which fish/shellfish tissue concentrations remain elevated due to construction impacts (e.g., sediment resuspension).

Notes:

1. Remedial action levels for Alternative 6R are as follows: arsenic: 15 mg/kg dw; total PCBs: 100 µg/kg dw; cPAHs: 1,000 (site-wide) and 900 (intertidal) µg TEQ/kg dw, dioxins/furans: 15 ng TEQ/kg dw, and benthic SMS (41 contaminants): SQS toxicity or chemistry.
2. Predicted outcomes using the BCM include natural recovery processes during construction. Time periods are referenced to a starting point that assumes construction of all EAAs is completed.
3. None of the remedial alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios.
4. None of the remedial alternatives are expected to achieve PRGs based on natural background sediment: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - all direct contact scenarios (RAO 2).
5. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. Not applicable for Alternative 6R.
c. Not applicable for Alternative 6R.
d. The area remediated in the EAAs (29 acres) is not included in the active and total managed areas.
e. Alternative 6R is comprised of AOPCs 1 and 2. Institutional controls and site-wide monitoring with natural recovery would apply to an additional 110 acres outside of AOPCs 1 and 2.
f. The total dredge volume is the neat-line volume multiplied by a factor representing multiple influences, plus additional volume for technology assignment and performance-based contingency assumptions.
g. Capital and OM&M costs are rounded to three significant figures, and total costs are rounded to two significant figures. The EAA costs and the costs of upland cleanup and source control are not included in cost estimates.
h. Risk outcomes correspond to calculated total PCB SWACs in surface sediment immediately after construction. However, 1 to 2 years post-construction will likely be required for fish/shellfish tissue to recover from construction impacts.
i. Alternative 6R is designed to achieve the total PCB long-term model-predicted concentration at the end of construction.
j. Alternative 6R is designed to achieve the dioxin/furan long-term model-predicted concentration at the end of construction.
k. Modeling of surface sediment concentrations at Beach 3 is influenced by a lateral source (outfall). Source control may be of particular importance in achieving sufficient reductions in cPAH concentrations.
l. Alternative 6R is designed to achieve the arsenic long-term model-predicted concentration at the end of construction.

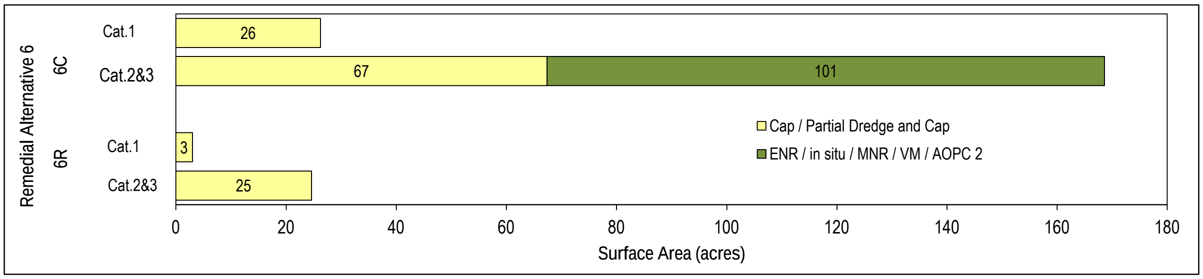
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest observed adverse effect level; µg = microgram; mg = milligram; MLLW = mean lower low water; MNR = monitored natural recovery; ng = nanogram; NR = natural recovery; OM&M = operation, maintenance and monitoring; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; VM = verification monitoring; yr = year.

Table 9-24 Post-Construction Sediment Conditions for Alternative 6

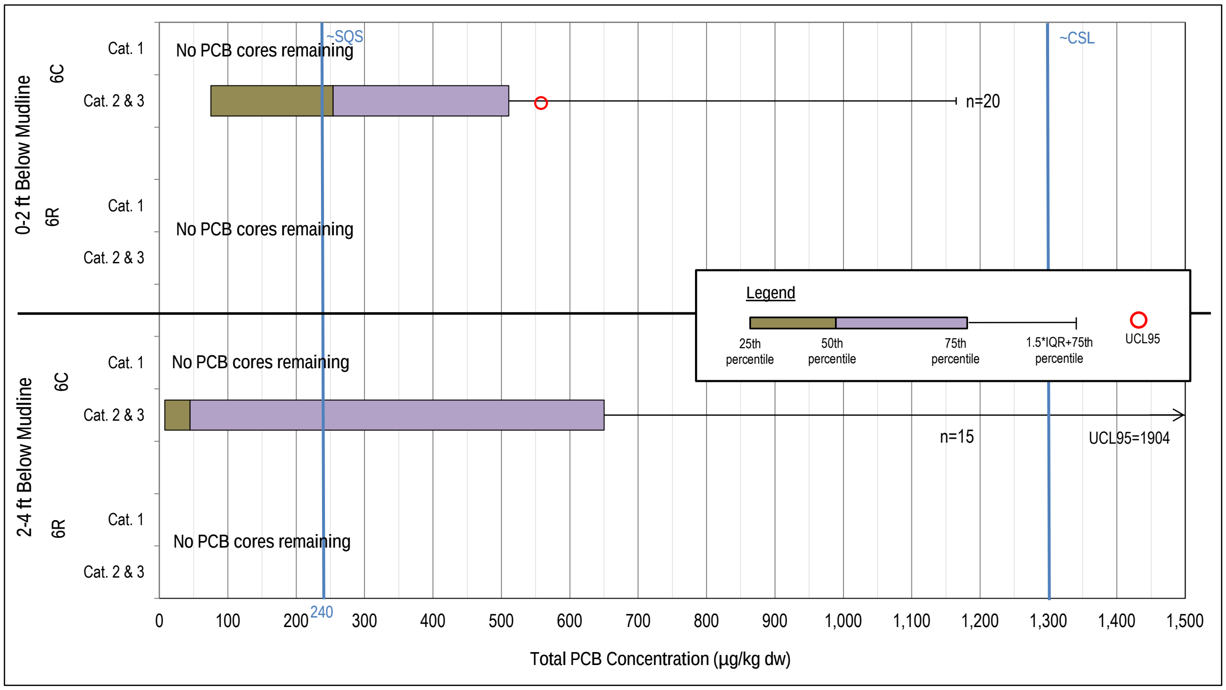
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 6

		Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint								Cap / Partial Dredge and Cap			
		Core Station Counts		Total PCB Concentration (µg/kg dw)						Core Station Counts		Total PCB Concentration (µg/kg dw)	
				0 to 2 ft depth			2 to 4 ft depth					0 to 4 ft depth	
Remedial Alternative 6	Recovery Category	> CSL	< CSL, > SQS	n	Mean	UCL95	n	Mean	UCL95	> CSL	< CSL, > SQS	n	Mean
Combined	1	0	0	0	—	—	0	—	—	27	8	56	426
	2 and 3	8	8	20	352	558	15	573	1,904				
	All	8	8	20	352	558	15	573	1,904				
Removal	1	0	0	0	—	—	0	—	—	1	1	4	109
	2 and 3	0	0	0	—	—	0	—	—				
	All	0	0	0	—	—	0	—	—				

Surface Areas Outside the EAA and Dredge Footprint Corresponding to Technology Assignment Groups for Alternative 6



Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 and Outside the EAA, Dredge and Cap Footprint for Alternative 6



Notes:

1. Recovery Category 1, 2, and 3 designations were assigned to any area of the LDW (excluding EAAs), regardless of AOPC or RAL status, and based on a specific recovery assessment (see Section 6). Recovery in Category 1 areas is presumed to be limited. Recovery in Category 2 areas is less certain. Category 3 areas are predicted to recover.
2. Core counts may be conservative because some of the material at these locations may have been previously dredged. In such cases, it is unconfirmed whether all contamination was removed and, in some instances, whether dredging actually occurred at these locations. Therefore, all remaining cores were included in the core counts.
3. Areas in the center panel reflect designations made in developing the remedial alternatives and should not be assumed to contain subsurface contaminants at concentrations represented in the table.
4. Alternatives 6C and 6R include 108 and 274 acres, respectively, of dredged areas, not shown in center panel. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.
5. Summary statistics for the 0- to 2-ft and 2- to 4-ft intervals (top table and lower panel) are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than the 1.5*IQR+75th percentile are shown in the lower panel.
6. The mean PCB concentration for capped and partially dredged/capped areas in the 0- to 4 -ft interval (shown in top table) is the vertical average of the combination of clean capping material (0 to 2 ft [with an assumed total PCB concentration of 40 µg/kg dw]), and the native sediment (0 to 2 ft in areas to be capped, and 2 to 4 ft in areas to be partially dredged/capped [with the total PCB concentration from those intervals in the subsurface FS baseline dataset]). However, a sediment cap is designed to be 3 ft thick.
7. The mean and UCL95 total PCB concentrations in the 0- to 4-ft interval outside of AOPCs 1 and 2 (i.e., rest of the waterway–110 acres) are 68 and 120 µg/kg dw, respectively (52 cores).

AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; MNR = monitored natural recovery; n = number of cores; PCB = polychlorinated biphenyl; R = removal; RAL = remedial action level; SD = standard deviation; SMS = Sediment Management Standards; SQS = sediment quality standard; UCL95 = 95% upper confidence limit on the mean; VM = verification monitoring

Table 9-25 Remedial Alternatives, Remedial Action Levels, and Model-Predicted Long-term Outcomes

			Evaluation Criteria and Estimated Times to Reach Model-Predicted Outcomes for Each RAO (years[a])										
			RAO 1: Human Health – Seafood Consumption[c, d, e] (see Tables 9-5 and 9-7a)					**RAO 2: Human Health – Direct Contact[f] (see Tables 9-3, 9-8, and M-5 series)**				**RAO 3: Ecological Health: Benthic; study area estimated to be <SQS (see Table 9-2b)[k]**	**RAO 4: Ecological Health: Seafood Consumption; HQ<1 – River Otter (see Table 9-7b)[d]**
					Total PCBs and dioxins/furans reach LTMPC ranges site-wide								
Remedial Alternative [b]	**Construction Period**	**Remedial Action Levels**	10^{-4} total PCB risk for Adult Tribal, Child Tribal and Adult API	10^{-5} total PCB risk for Child Tribal[g]	Total PCBs	Dioxins/Furans	10^{-6} risk and non-cancer risk (HI <1) or natural background PRG	Multiple risk reduction outcomes[h]	< 1 x 10^{-6} direct contact risk from dioxins/furans in all areas	≤1 x 10^{-6} direct contact risk from cPAHs in all areas except Beach 3 [i]	Arsenic reaches LTMPC range site-wide[j]		
Alternative 1: No Further Action after removal or capping of EAAs	0	n/a	0 (child tribal & adult API); 5 (adult tribal)	15	25	20		5	5	25	10	20	< 5
Alternative 2R: dredge w/ upland disposal/MNR **Alternative 2R-CAD:** dredge emphasis with contained aquatic disposal/MNR	4	**Total PCBs:** 1,300 to 2,200 µg/kg dw **Arsenic:** 93 mg/kg dw **cPAHs:** 5,500 µg TEQ/kg dw **Dioxins/Furans:** 50 ng TEQ/kg dw **SMS contaminants:** CSL w/i 10 years	4	9	24	9	Unlikely to be achieved by any of the remedial alternatives	4	4	19	4	14	4
Alternative 3C: ENR/*in situ*/cap/MNR where appropriate, otherwise dredge with upland disposal	3	**Total PCBs:** 1,300 µg/kg dw[l] **Arsenic:** 93 mg/kg dw (site-wide); 28 mg/kg dw (intertidal) **cPAHs:** 3,800 µg TEQ/kg dw (site-wide); 900 µg TEQ/kg dw (intertidal) **Dioxins/Furans:** 35 ng TEQ/kg dw (site-wide); 28 ng TEQ/kg dw (intertidal) **SMS contaminants:** CSL toxicity or chemistry	3	8	18	8		3	3	3	3	8	3
Alternative 3R: dredge with upland disposal/MNR	6		6	11	21	11		4	4	6	4	11	6
Alternative 4C: ENR/*in situ*/cap/MNR where appropriate, otherwise dredge w/ upland disposal	6	**Total PCBs:** 240 to 700 µg/kg dw **Arsenic:** 57 mg/kg dw (site-wide); 28 mg/kg dw (intertidal) **cPAHs:** 1,000 µg TEQ/kg dw (site-wide); 900 µg TEQ/kg dw (intertidal) **Dioxins/Furans:** 25 ng TEQ/kg dw **SMS contaminants:** SQS w/i 10 years	6	11	21	11		3	3	3	3	6	6
Alternative 4R: dredge with upland disposal/MNR	11		11	11	21	11		4	4	6	4	11	11
Alternative 5C: ENR/*in situ*/cap where appropriate, otherwise dredge w/ upland disposal	7	**Total PCBs:** 240 µg/kg dw[l] **Arsenic:** 57 mg/kg dw (site-wide); 28 mg/kg dw (intertidal) **cPAHs:** 1,000 µg TEQ/kg dw (site-wide); 900 µg TEQ/kg dw (intertidal) **Dioxins/Furans:** 25 ng TEQ/kg dw **SMS contaminants:** SQS toxicity or chemistry	7	7	17	7		3	3	3	3	6	7
Alternative 5R: dredge w/ upland disposal & **Alternative 5R-T:** dredge with soil washing treatment and disposal/re-use	17		17	17	22	17		4	4	6	4	11	17
Alternative 6C: ENR/*in situ*/cap where appropriate, otherwise dredge w/ upland disposal	16	**Total PCBs:** 100 µg/kg dw **Arsenic:** 15 mg/kg dw **cPAHs:** 1,000 µg TEQ/kg dw (site-wide); 900 µg TEQ/kg dw (intertidal) **Dioxins/furans:**15 ng TEQ/kg dw **SMS contaminants:** SQS toxicity or chemistry	16	16	16	16		3	3	3	3	6	16
Alternative 6R: dredge w/ upland disposal	42		42	42	42	42		4	4	6	4	11	42

Notes:

a. If an evaluation criterion is reached prior to construction, the time to reach the evaluation criterion is based on the construction period of the smallest alternative that achieves that criterion (e.g., because Alternative 2R achieves "multiple risk outcomes" for RAO 2 in 4 years, it is assumed that Alternatives 3R, 4R, 5R, and 6R also achieve that criterion in 4 years). If an evaluation criterion is reached immediately after construction, the time to reach the evaluation criterion is the end of the construction period. If an evaluation criterion is not reached until sometime after construction, then the time to reach the evaluation criterion is at a 5-year increment after construction (i.e., the time to reach a criterion could be the construction time +5 years, construction time +10 years, etc.), because the bed composition model provides output every 5 years.

b. All alternatives include seafood consumption advisories; Alternatives 2 through 6 include additional institutional controls. Predicted outcomes using the BCM include natural recovery processes during construction. All time periods are referenced to the start of construction, except for Alternative 1, which is keyed to the completion of the EAAs. Alternative 1 outcomes have high uncertainty because the BCM is applied to all the site regardless of recovery category or scour potential.

c. Only risks from total PCBs are discussed for human health seafood consumption because sediment to tissue relationships could not be developed for arsenic, cPAHs, and dioxins/furans. No alternative is expected to achieve the PRGs based on natural background, but they all are predicted to achieve the LTMPC (42 years). These concentrations, site-wide, are approximately: 49 µg/kg dw (total PCBs) and 5.4 ng TEQ/kg dw (dioxins/furans) (based on achieving a site-wide SWAC within 25% of the 45-yr Alternative 6R SWAC: 39 µg/kg dw for total PCBs and 4.3 ng TEQ/kg dw for dioxins/furans).

d. Risks from total PCBs are elevated above food web model-predicted values during construction and up to 1 to 2 years following construction due to releases during dredging that enter the food chain. Thus, the end of construction is the soonest that the 10^{-4} risk magnitude (human health) and HQ<1 (ecological) outcomes can be achieved.

e. See Tables 9-7a and 9-7b for specific predicted times to achieve seafood consumption excess cancer risk of 2×10^{-4} and non-cancer hazard quotients of 4 to 5.

f. Alternatives 3 through 6 have the same indicated times for direct contact risk reduction because of the remedial action sequencing assumptions. Alternative 3 is designed to accomplish direct contact risk reduction and the FS assumes that Alternatives 4 through 6 build upon Alternative 3.

g. The 10^{-5} risk magnitude for Adult Tribal is not predicted to be achieved by any of the alternatives.

h. $\leq 1 \times 10^{-5}$ total excess cancer risk and HQ <1 for netfishing (site-wide), clamming, and beach play areas (each beach). $\leq 1 \times 10^{-5}$ and $>1 \times 10^{-6}$ arsenic in all areas. $\leq 1 \times 10^{-6}$ risk total PCBs in all areas (except Beach 4; Beach 4 is actively remediated by Alternative 2R).

i. The BCM model output for Beach 3 is influenced by a lateral source (outfall). All hot spots in beaches are actively remediated to achieve RAO 2 at the end of construction. Some beaches are shown to have excess cancer risks that slightly exceed the 1×10^{-6} threshold at the end of construction. This is an artifact of using a post-remedy bed sediment replacement value of 140 µg TEQ/kg dw. Given the uncertainty in this value and the fact that the beaches are actively remediated, the FS assumes that direct contact risks from cPAHs at these beaches will be $\leq 1 \times 10^{-6}$ following construction.

j. No alternative is expected to achieve the arsenic PRG based on natural background, but they all are predicted to achieve the LTMPC site-wide arsenic concentration of approximately 11.4 mg/kg dw, based on achieving a site-wide arsenic SWAC within 25% (≤11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic SWAC of 9.1 mg/kg dw.

k. For FS purposes, compliance with the SMS is assumed when ≥98% of the study area is below the SQS; it does not represent a standard to be applied to compliance monitoring. Reducing SQS exceedances sufficient to achieve RAO 3 cleanup objectives depends on adequate source control and natural recovery during construction. Achievement may take a little longer if these two factors are not considered. Localized recontamination is expected (see Appendix J) but is not accounted for in this table's results. The SMS expects compliance with standards within 10 years after construction. Alternatives 1 and 2 may not achieve the SQS 10 years after construction.

l. Dry weight equivalents of the SQS and the 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.

API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbons; C = combined-technology alternative emphasis; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CSL = cleanup screening level; dw = dry weight; ENR = enhanced natural recovery; FS = feasibility study; HI = hazard index; HQ = hazard quotient; kg = kilograms; LTMPC = long-term model-predicted concentration; µg = micrograms; mg = milligrams; MNR = monitored natural recovery; n/a = not applicable; ng = nanograms; oc = organic carbon; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal-emphasis alternative; RAL = remedial action level; RAO = remedial action objective; R-T = removal-emphasis alternative with treatment technology; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; TOC = total organic carbon; w/ = with; w/i = within; yr = year

Table 9-26 Remaining Human Health Contaminants of Concern for Consideration in FS and Expected Risk Outcomes

Human Health Contaminant of Concern		Risk Estimate[a]	Additional Considerations[b]	Expected Outcome
Semivolatile Organics	bis(2-ethylhexyl) phthalate (BEHP)	6×10^{-6}	Infrequently detected (15%) in LDW tissue samples. RLs were elevated in the initial analysis because of sample dilution requirements. A subset of samples was reanalyzed, and lower RLs were achieved, suggesting that initial analysis results were biased high. Approximately 80% of the surface sediment locations with BEHP concentrations above the SQS also had PCB concentrations above the SQS. Thus, remediation of PCBs in areas with these SQS exceedances will reduce BEHP concentrations in surface sediment.	Baseline risk is within EPA target risk range.
	Pentachlorophenol	9×10^{-5}	Rarely detected (6%) in LDW tissue samples. A subset of samples was reanalyzed, and much lower RLs were achieved. Also, the only two original detected results that were reanalyzed were not confirmed, suggesting that the results of the initial analysis were biased high and pentachlorophenol may not have been present. Also rarely detected (2%) in sediment samples.	Baseline risk is within EPA target risk range.
	Carbazole	5×10^{-5}	Not detected in sediment. Tissue sample results were JN qualified because of analytical interference, but only 1% of the samples had detectable concentrations.	Baseline risk is within EPA target risk range.
Metals	Tributyltin (TBT)	3 (HQ)[c]	Risk estimate is driven primarily by concentrations in clams. Several clam sampling locations will be remediated as part of early actions, which may reduce TBT concentrations in clams.	Legacy compound expected to be managed by natural recovery.
	Vanadium	2 (HQ)[c]	Exposure concentration in LDW surface sediment (average of 58 mg/kg dw) was less than PSAMP rural Puget Sound concentration (64 mg/kg dw [90th percentile]).	Baseline concentrations are below background.
Organochlorine Pesticides	Aldrin	5×10^{-5}	Rarely detected (2%) at very low concentrations (2 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	alpha-BHC	2×10^{-5}	Rarely detected (2%) at very low concentrations (2 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	beta- BHC	6×10^{-6}	Rarely detected (2%) at concentrations that were likely biased high because of interference from PCBs. The highest concentration in surface sediment was detected at the head of Slip 4, which is an EAA.	Baseline risk is within EPA target risk range.
	Total chlordane	6×10^{-6}	Detected concentrations in surface sediment were likely biased high because of interference from PCBs. The two highest concentrations in surface sediment were at the head of Slip 4, which is an EAA.	Baseline risk is within EPA target risk range.

Table 9-26 Remaining Human Health Contaminants of Concern for Consideration in FS and Expected Risk Outcomes (continued)

Human Health Contaminant of Concern		Risk Estimate[a]	Additional Considerations[b]	Expected Outcome
Organochlorine Pesticides	Total DDTs	2×10^{-5}	Although DDT and its isomers were frequently detected in surface sediment and tissue samples, DDT concentrations may have been biased high because of PCB interference. Tissue data were JN-qualified.	Baseline risk is within EPA Target Risk Range.
	Dieldrin	1×10^{-4}	Rarely detected (4%) at concentrations that were likely biased high because of interference from PCBs. The highest concentration in surface sediment was detected at the head of Slip 4, which is an EAA.	Managed by Alternatives 1 and 2.
	gamma through BHC	6×10^{-6}	Rarely detected (6%) at low concentrations (7 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Heptachlor	1×10^{-5}	Rarely detected (3%) at very low concentrations (5 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Heptachlor-epoxide	3×10^{-5}	Rarely detected (3%) at very low concentrations (5 µg/kg or less) that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Hexachloro-benzene	1×10^{-5}	Rarely detected (6%) at concentrations that were likely biased high because of interference from PCBs.	Baseline risk is within EPA target risk range.
	Toxaphene	6×10^{-6}	Rarely detected (1%) in sediment.	Baseline risk is within EPA target risk range.

Notes:

a. Risk estimates are from the HHRA (Windward 2007b) and are for seafood consumption with one exception, toxaphene, which is for direct contact (tribal netfishing). The seafood consumption excess cancer risk estimates are for the Adult Tribal RME seafood consumption scenario (using Tulalip data). Adult Tribal RME had the highest cancer risk estimates among the RME seafood consumption scenarios. The direct contact risk estimate presented for toxaphene is the highest risk estimate for any direct contact scenario for toxaphene reported in the RI (Windward 2010).

b. Detection frequency and concentrations in tissue are based on data in the RI baseline dataset.

c. HQs were below 1 for the Adult Tribal RME scenario based on Tulalip data. HQs listed in table are for the Child Tribal RME seafood consumption scenario based on Tulalip data.

BEHP = bis(2-ethylhexyl) phthalate; BHC = benzene hexachloride; DDT = dichlorodiphenyltrichloroethane; EAA = early action areas; EPA = U.S. Environmental Protection Agency; FS = feasibility study; HHRA = human health risk assessment; HQ = hazard quotient; JN = tentatively identified compound present; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; PCB = polychlorinated biphenyl; PSAMP = Puget Sound Ambient Monitoring Program; RI = remedial investigation; RL = reporting limit; RME = reasonable maximum exposure; SQS = sediment quality standard

Table 9-27 Remaining Ecological Contaminants of Concern for Consideration in FS and Expected Outcomes

Ecological Contaminant of Concern		Receptor of Concern	Maximum NOAEL-Based Hazard Quotient[a]	Maximum LOAEL-Based Hazard Quotient[a]	Additional Considerations[b]	Expected Outcome
Metals	Cadmium	juvenile chinook salmon, English sole, Pacific staghorn sculpin	6.1	1.2	The site-wide average concentration of cadmium will likely be reduced through remediation of EAAs to concentrations corresponding to a LOAEL-based HQ of less than 1.0.	Managed by Alternative 1
	Chromium	spotted sandpiper; Area 2[c]	8.8	1.8	The LOAEL-based HQ was greater than 1.0 in only one area (Area 2 of sandpiper habitat). The HQ would have been less than 1.0 if the single anomalously high benthic invertebrate tissue sample from RM 3.0 West was excluded. This sample was collected from the beach just south of Slip 4 on the western shoreline. Chromium concentrations in surface sediment were low in this area. This area is a candidate for verification monitoring during remedial design.	May require verification monitoring
	Copper	spotted sandpiper; Area 3[c]	1.5	1.1	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1). Also, the average concentration in surface sediment (57 mg/kg dw)[b] from Area 3 was similar to PSAMP rural Puget Sound concentrations (50 mg/kg dw [90th percentile]). Thus, Alternative 1 is considered sufficient for addressing protection of spotted sandpiper for exposure to copper.	Managed by Alternative 1
	Lead	spotted sandpiper; Area 2[c]	19	5.5	The LOAEL-based HQ was greater than 1.0 in only one area (Area 2 of sandpiper habitat). The HQ would have been less than 1.0 if the single anomalously high benthic invertebrate tissue sample from RM 3.0 West was excluded. This sample was collected from the beach just south of Slip 4 on the western shoreline. Lead concentrations in surface sediment were low in this area. This area is a candidate for verification monitoring during remedial design.	May require verification monitoring
		spotted sandpiper; Area 3[c]	5.0	1.5	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1).	Managed by Alternative 1

Table 9-27 Remaining Ecological Contaminants of Concern for Consideration in FS and Expected Outcomes (continued)

Ecological Contaminant of Concern		Receptor of Concern	Maximum NOAEL-Based Hazard Quotient[a]	Maximum LOAEL-Based Hazard Quotient[a]	Additional Considerations[b]	Expected Outcome
Metals (continued)	Mercury	spotted sandpiper; Area 3[d]	5.3	1.0	The LOAEL-based HQ was greater than 1.0 in only one area (Area 3 of sandpiper habitat). The HQ will likely be reduced to less than 1.0 following remediation of EAAs (Alternative 1).	Managed by Alternative 1
	Vanadium	English sole, Pacific staghorn sculpin	5.9	1.2	Average concentrations in LDW surface sediment (58 mg/kg dw)[b] were less than the PSAMP rural Puget Sound concentration (64 mg/kg dw [90th percentile]).	Levels were within PSAMP background range
		spotted sandpiper – all exposure areas	2.0 – 2.7	1.0 – 1.4	Mean surface sediment concentrations in sandpiper exposure areas ranged from 49 to 57 mg/kg dw[b] and were lower than the PSAMP rural Puget Sound background concentration of 64 mg/kg dw (90th percentile).	Levels were within PSAMP background range
	Nickel	benthic invertebrates	6.6	2.5	The LOAEL-based HQ was exceeded at four locations in the LDW;[b] all were located within EAAs.	Managed by Alternative 1
Pesticides	Total DDTs	benthic invertebrates	5.1	2.7	The LOAEL-based HQ was exceeded at one location,[b] which was located within an EAA.	Managed by Alternative 1
	Total chlordane	benthic invertebrates	82	48	The LOAEL-based HQ was exceeded at 12 locations in LDW;[b] all but three of these locations were within EAAs.	Managed by Alternative 1

Notes:

1. PCBs were designated as a risk driver for river otter. LOAEL-based HQs were also greater than or equal to 1.0 for crabs (1.0), English sole (0.98 – 5.0), Pacific staghorn sculpin (0.3 – 3.8), and spotted sandpiper (0.18 – 1.5, on a TEQ basis).
2. HQs for fish are the highest HQs in cases where more than one approach was used.

[a] HQs were calculated in the ERA using the baseline surface sediment dataset available at that time. The RI baseline surface sediment dataset included additional samples collected in 2006 during Round 3 of the RI sediment sampling.

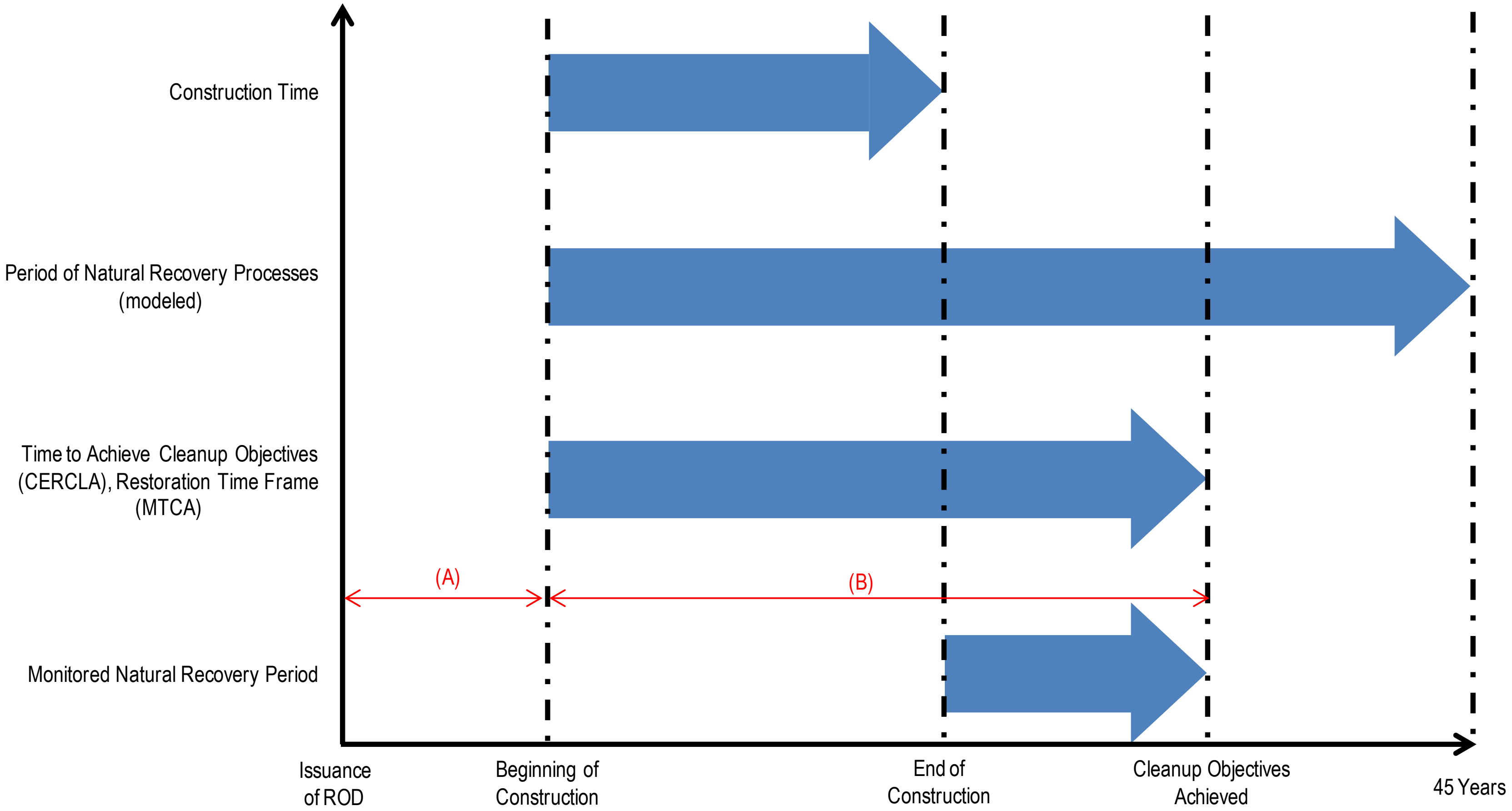
[b] Concentrations in surface sediment are based on the RI baseline dataset. Comments regarding the HQs are based on the ERA baseline dataset; these comments would not change if the RI baseline dataset had been used.

[c] Both high and poor quality foraging habitat.

[d] Only high quality foraging habitat.

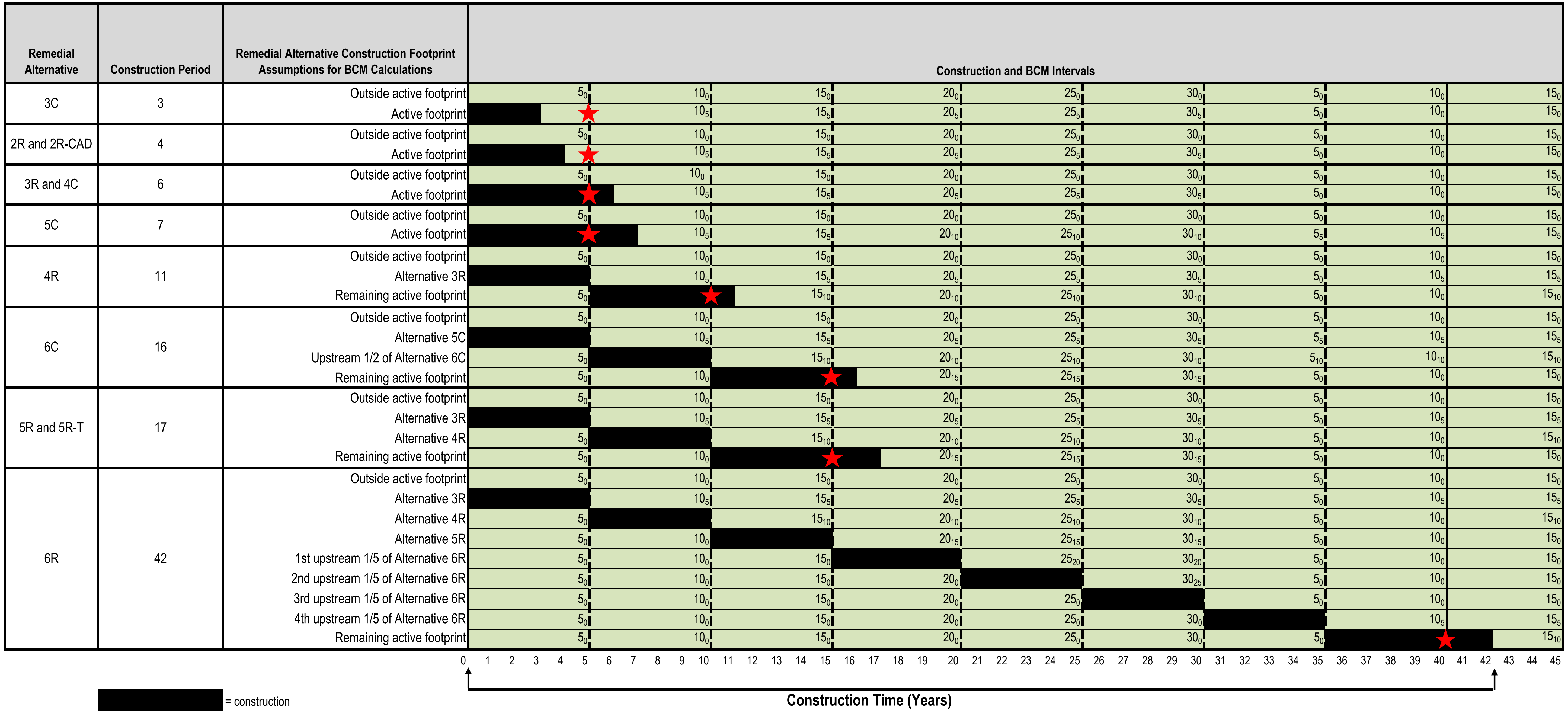
DDT = dichlorodiphenyltrichloroethane; dw = dry weight; EAA = early action area; ERA = Ecological Risk Assessment; FS = feasibility study; HQ = hazard quotient; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest-observed-adverse-effect level; µg = microgram; mg = milligram; NOAEL = no observed adverse effect level; PSAMP = Puget Sound Ambient Monitoring Program; RI = remedial investigation; RM = river mile; TEQ = toxic equivalent.

Figure 9-1 Conceptual Relationships among Time Periods Used in the Evaluation of the Remedial Alternatives



Notes:
(A): Period between issuance of ROD and the beginning of construction: EAAs are managed (Alt. 1), initial design period for other remedy components, priority source control, baseline monitoring, and verification monitoring.
(B): The BCM is used during this period to model future conditions before, during, and after construction for each of the remedial alternatives.
Alt. = alternative; BCM = bed composition model; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; EAA = early action area; MTCA = Model Toxics Control Act; ROD = Record of Decision.

Figure 9-2 Time Frame and Base-Case BCM Modeling Framework for the Remedial Alternatives



Remedial Alternative	Construction Period	Remedial Alternative Construction Footprint Assumptions for BCM Calculations	Construction and BCM Intervals								
3C	3	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Active footprint	★	10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{0}	15_{0}
2R and 2R-CAD	4	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Active footprint	★	10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{0}	15_{0}
3R and 4C	6	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Active footprint	★	10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{0}	15_{0}
5C	7	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Active footprint	★	10_{5}	15_{5}	20_{10}	25_{10}	30_{10}	5_{5}	10_{5}	15_{5}
4R	11	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Alternative 3R		10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{5}	15_{5}
		Remaining active footprint	5_{0}	★	15_{10}	20_{10}	25_{10}	30_{10}	5_{0}	10_{0}	15_{10}
6C	16	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Alternative 5C		10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{5}	10_{5}	15_{5}
		Upstream 1/2 of Alternative 6C	5_{0}		15_{10}	20_{10}	25_{10}	30_{10}	5_{10}	10_{10}	15_{10}
		Remaining active footprint	5_{0}	10_{0}	★	20_{15}	25_{15}	30_{15}	5_{0}	10_{0}	15_{0}
5R and 5R-T	17	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Alternative 3R		10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{5}	15_{5}
		Alternative 4R	5_{0}		15_{10}	20_{10}	25_{10}	30_{10}	5_{0}	10_{0}	15_{10}
		Remaining active footprint	5_{0}	10_{0}	★	20_{15}	25_{15}	30_{15}	5_{0}	10_{0}	15_{0}
6R	42	Outside active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	10_{0}	15_{0}
		Alternative 3R		10_{5}	15_{5}	20_{5}	25_{5}	30_{5}	5_{0}	10_{5}	15_{5}
		Alternative 4R	5_{0}		15_{10}	20_{10}	25_{10}	30_{10}	5_{0}	10_{0}	15_{10}
		Alternative 5R	5_{0}	10_{0}		20_{15}	25_{15}	30_{15}	5_{0}	10_{0}	15_{0}
		1st upstream 1/5 of Alternative 6R	5_{0}	10_{0}	15_{0}		25_{20}	30_{20}	5_{0}	10_{0}	15_{0}
		2nd upstream 1/5 of Alternative 6R	5_{0}	10_{0}	15_{0}	20_{0}		30_{25}	5_{0}	10_{0}	15_{0}
		3rd upstream 1/5 of Alternative 6R	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}		5_{0}	10_{0}	15_{0}
		4th upstream 1/5 of Alternative 6R	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}		10_{5}	15_{5}
		Remaining active footprint	5_{0}	10_{0}	15_{0}	20_{0}	25_{0}	30_{0}	5_{0}	★	15_{10}

(Dashed vertical lines indicate BCM output by year produced for SWAC calculations)

Notes:

1. Estimated construction times listed for the alternatives (first column) are represented on the chart as horizontal black bars.
2. Estimated construction times are based on the time required for open water dredging (see dredge production rate assumptions; Appendix I).
3. Construction times are not multiples of 5. Reconciliation of construction periods and the 5-year model intervals is accomplished by applying the nearest 5-year BCM output to the end of construction for each alternative. This is symbolized with a ★. For example, output from model-year 5 is used at the end of construction for Alternatives 2, 3C, and 4C, which have construction times of 4, 3, and 6 years, respectively.
4. The alternatives progressively build or integrate their respective footprints in 5-year intervals (i.e., 3R to 6R in succession) lending spatial consistency to the BCM calculations.
5. BCM calculations for fractional "remaining active footprints" assume construction begins at the head of the waterway (Reach 3) and works toward the mouth of the waterway (Reach 1).
6. BCM calculations use STM base case run with distributed lateral loads.
7. Example table notation: 15_{5} means BCM output for Year 15 excluding Years 0 to 5 of the hydrograph.
8. The temporal bias refers to the difference between the end of the estimated construction time and when the post-remedy bed sediment replacement value is assigned to coincide with a 5-year model interval. Construction and restoration time frames adjust for this bias.

BCM = bed composition model; C = combined-technology alternative; CAD = contained aquatic disposal; R = removal-emphasis alternative; STM = sediment transport model; SWAC = spatially-weighted average concentration; T = treatment

Notes:
1. Construction time frames rounded to nearest 5-year interval.
2. Sequencing prioritized with higher concentrations first (previous alternatives remediated first), then upstream to downstream.
3. Remaining EAAs are assumed to be completed in the first 5 years after the issuance of the ROD.
4. Five-year intervals are indexed to the start of construction.
5. Areas upstream of RM 4.75 are not sequenced in the BCM because they are outside of the STM domain.
6. BCM = bed composition model, EAA = early action area, RM = River Mile, ROD = Record of Decision, STM = sediment transport model.

Legend

Designations of Areas Assumed to be Actively Remediated during Indicated Time Period

▨ Completed EAAs
▩ Remaining EAAs
▩ 0 to 5 Years (Alternatives 3, 4, and 5 combined)
▩ 5 to 10 Years (Upstream Portion of Alternative 6 combined)
🟩 10 to 15 Years (Downstream Portion of Alternative 6 combined)
☐ Institutional Controls and Site-wide Monitoring with Natural Recovery
-·-·- Navigation Channel
— River Mile Marker

Feet
0 200 400 800

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Lower Duwamish Waterway
Final Feasibility Study
60150279-14.42

Temporal Sequencing of Actively Remediated Areas for BCM Calculations: Alternative 6 Combined

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 1

FIGURE 9-3

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Legend

Designations of Areas Assumed to be Actively Remediated during Indicated Time Period

▨ Completed EAAs

Remaining EAAs

🟩 0 to 15 Years (Alternative 5 Removal)

🟨 15 to 20 Years

🟧 20 to 25 Years

25 to 30 Years

🟥 30 to 35 Years

🟪 35 to 40 Years

☐ Institutional Controls and Site-wide Monitoring with Natural Recovery

Navigation Channel

River Mile Marker

Notes:

1. Construction time frames rounded to nearest 5-year interval.
2. Sequencing prioritized with higher concentrations first (previous alternatives remediated first), then upstream to downstream.
3. Remaining EAAs are assumed to be completed in the first 5 years after the issuance of the ROD.
4. Five-year intervals are indexed to the start of construction.
5. Areas upstream of RM 4.75 are not sequenced in the BCM because they are outside of the STM domain.
6. BCM = bed composition model, EAA = early action area, RM = River Mile, ROD = Record of Decision, STM = sediment transport model.

Feet
0 200 400 800

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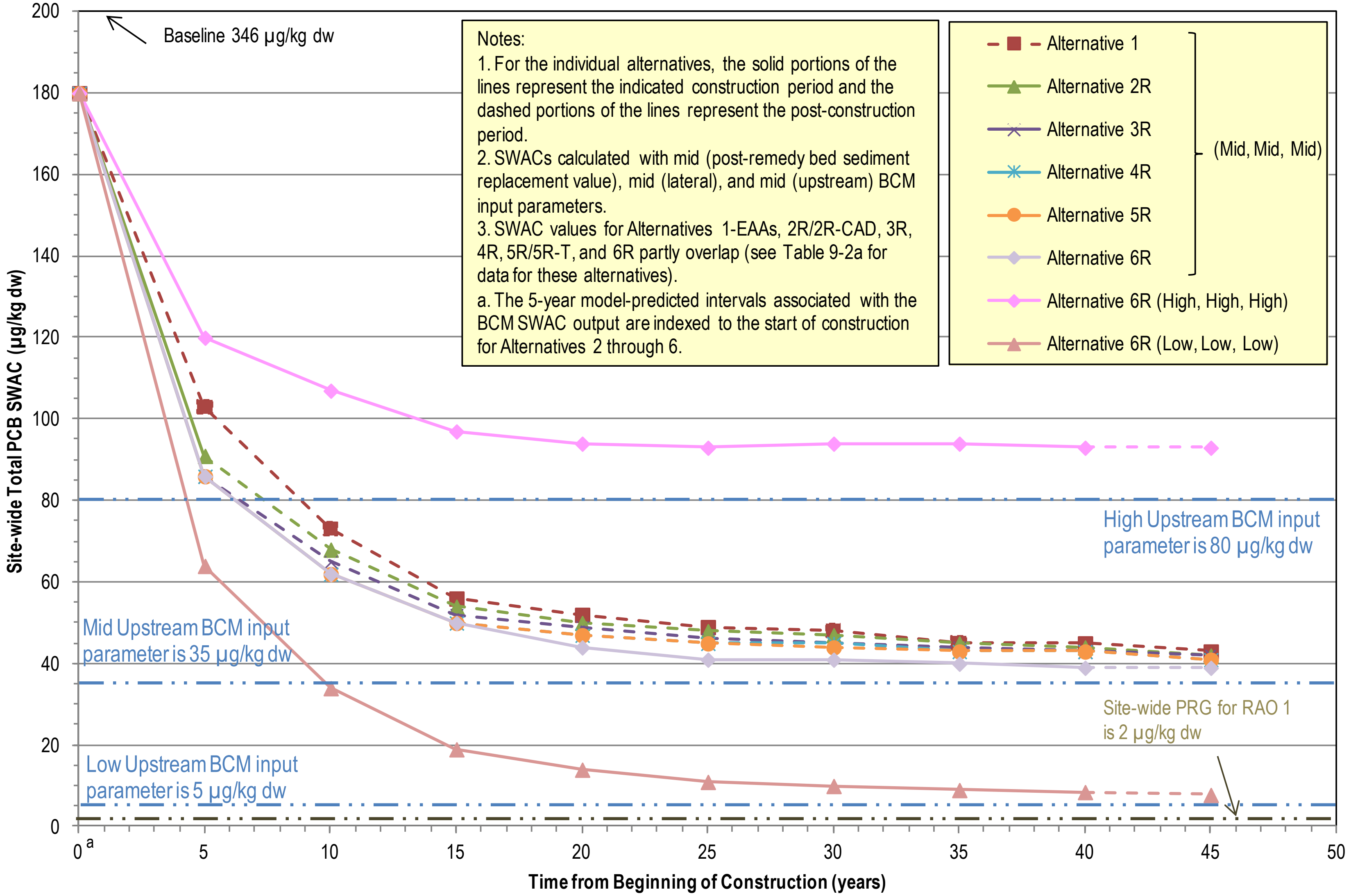
Lower Duwamish Waterway
Final Feasibility Study
60150279-14.42

Temporal Sequencing of Actively Remediated Areas for BCM Calculations: Alternative 6 Removal

DATE: 10/31/12 | DWRN:MVI/sea | Revision: 1

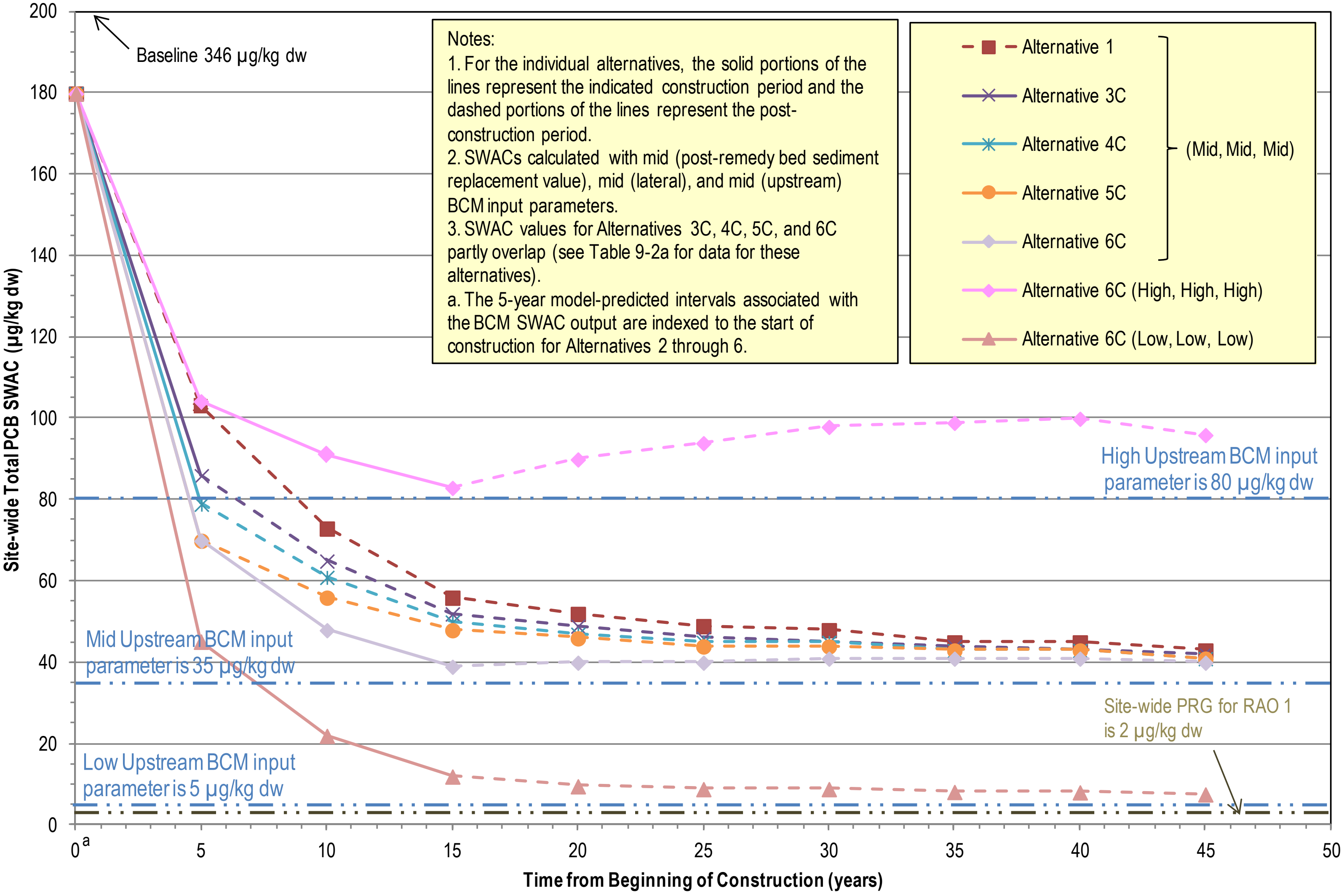
FIGURE 9-4

Figure 9-5a Site-wide Total PCB SWAC Versus Time – Removal Alternatives



Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 2R/2R-CAD, 3R, 4R, 5R/5R-T, and 6R partly overlap (see Table 9-2a for data for these alternatives).
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5b Site-wide Total PCB SWAC Versus Time – Combined Alternatives

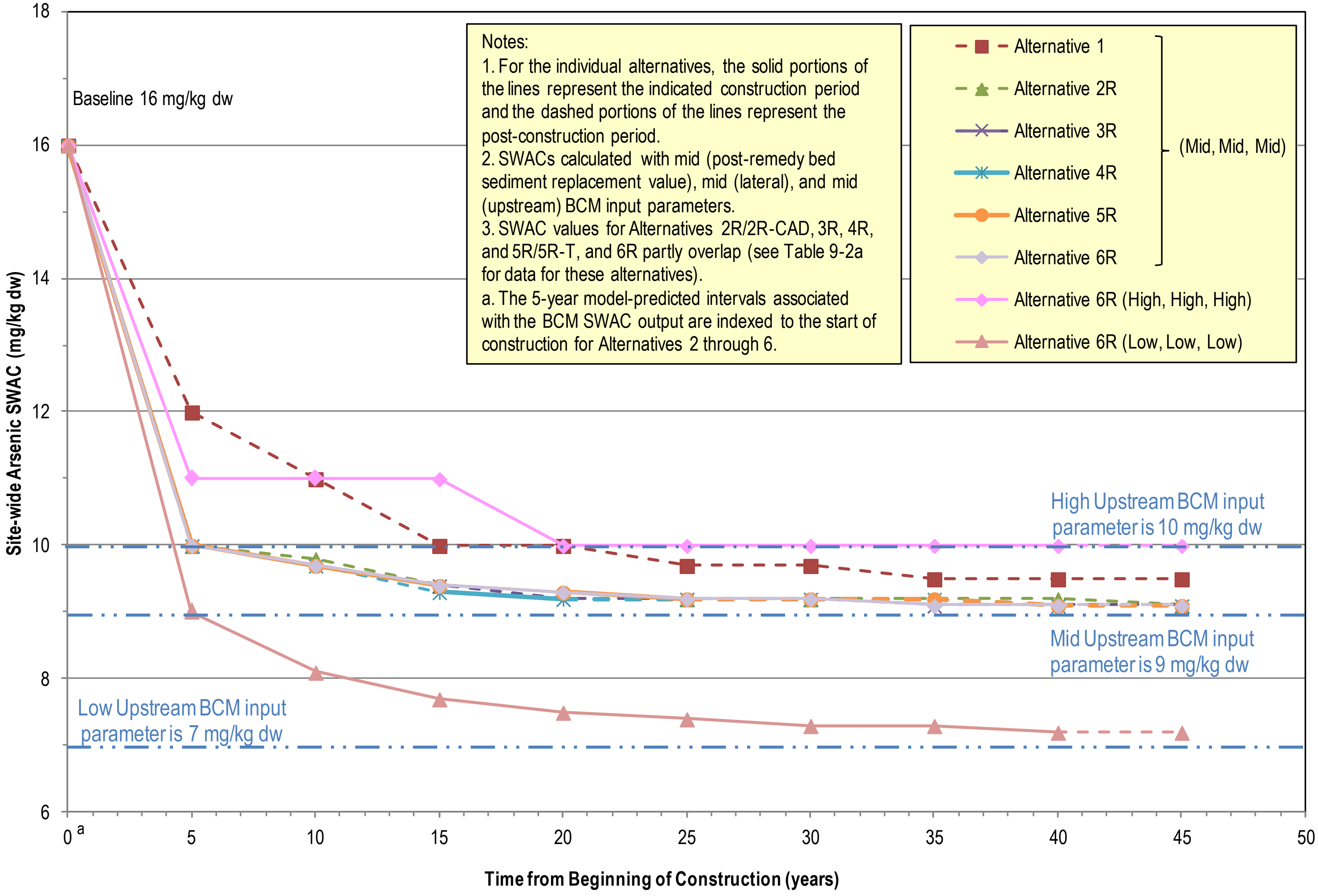


Notes:

1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 3C, 4C, 5C, and 6C partly overlap (see Table 9-2a for data for these alternatives).

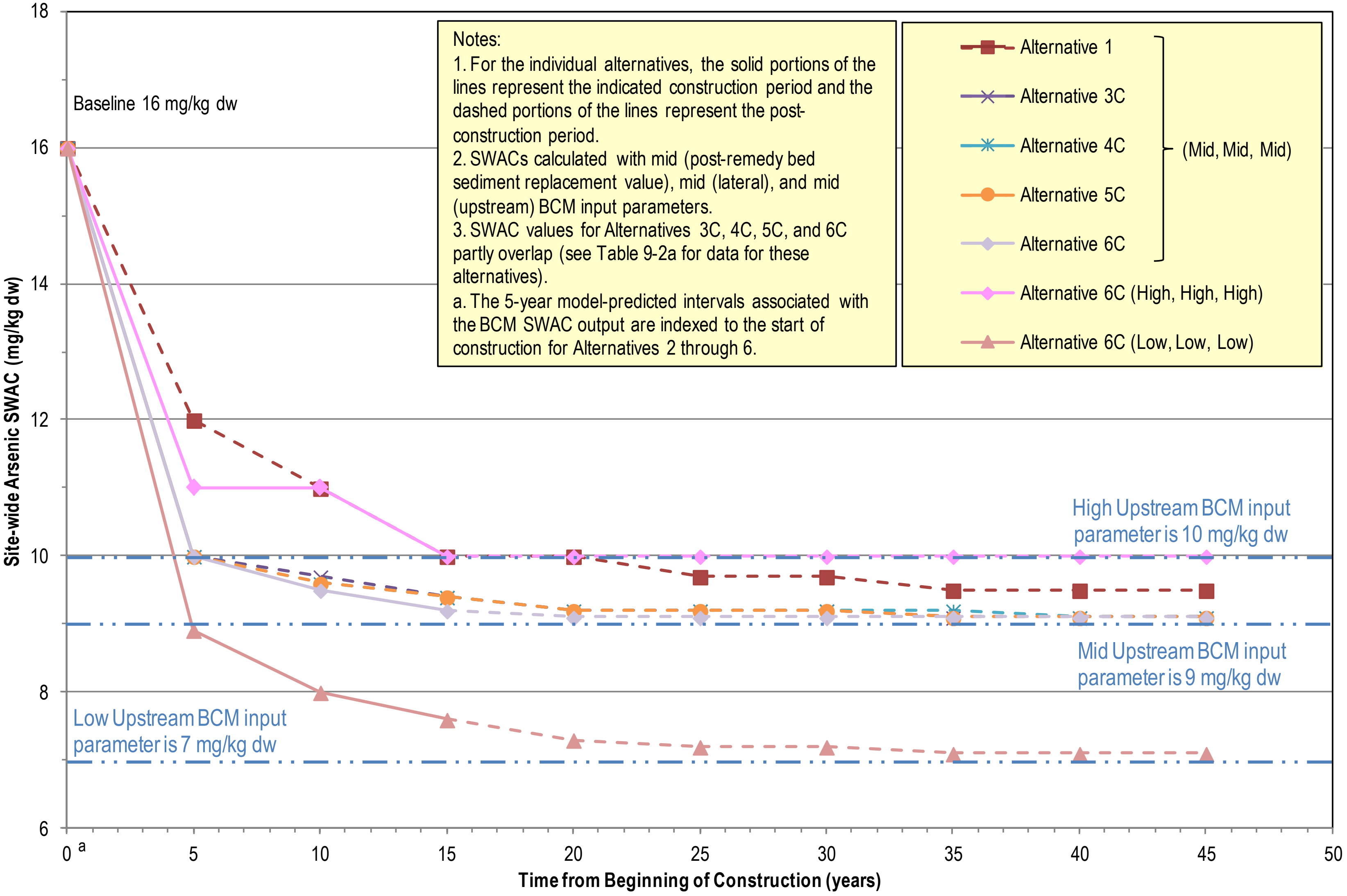
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5c Site-wide Arsenic SWAC Versus Time – Removal Alternatives



Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 2R/2R-CAD, 3R, 4R, and 5R/5R-T, and 6R partly overlap (see Table 9-2a for data for these alternatives).
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5d Site-wide Arsenic SWAC Versus Time – Combined Alternatives

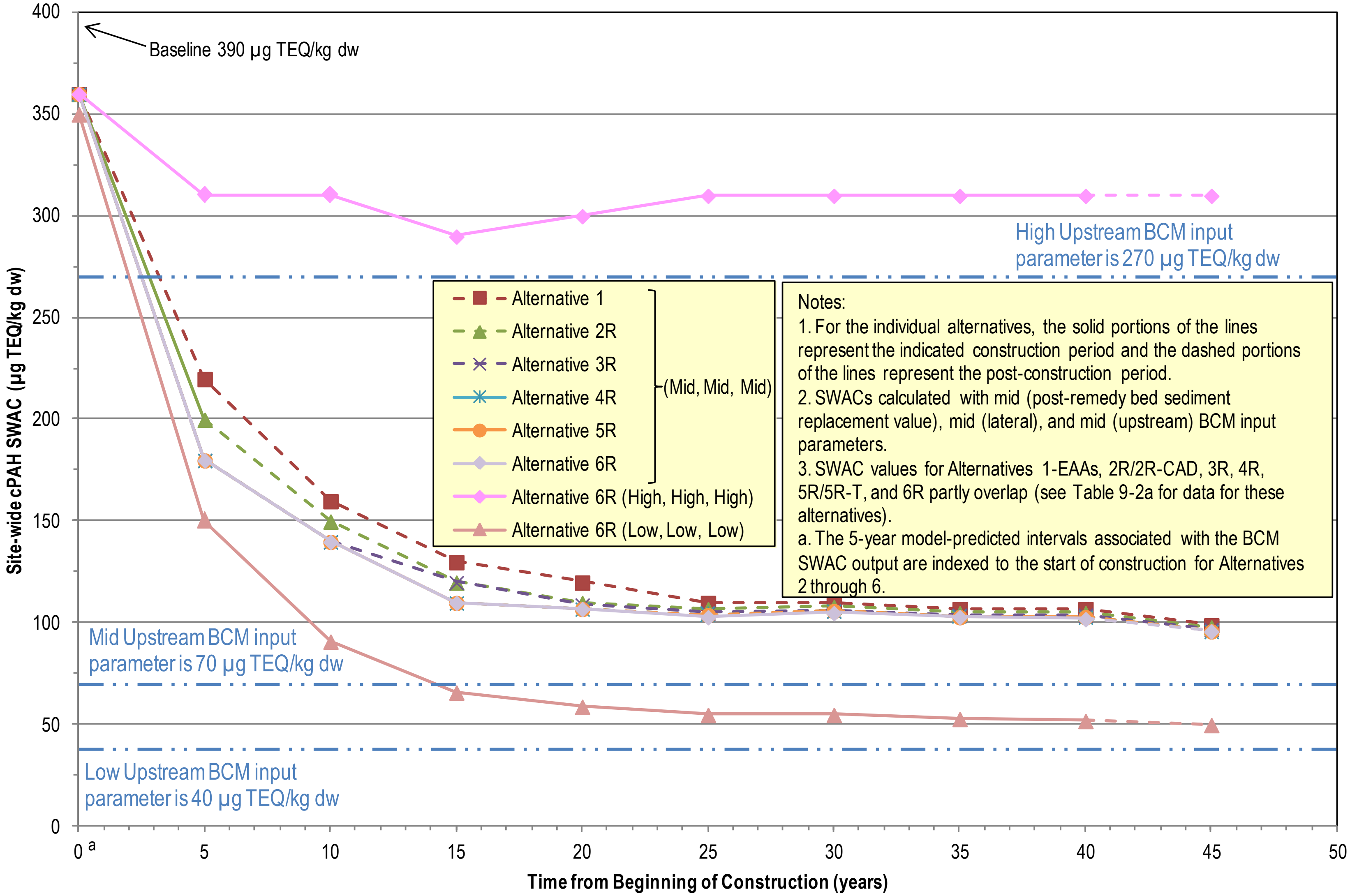


Notes:

1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 3C, 4C, 5C, and 6C partly overlap (see Table 9-2a for data for these alternatives).

a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5e Site-wide cPAH SWAC Versus Time – Removal Alternatives

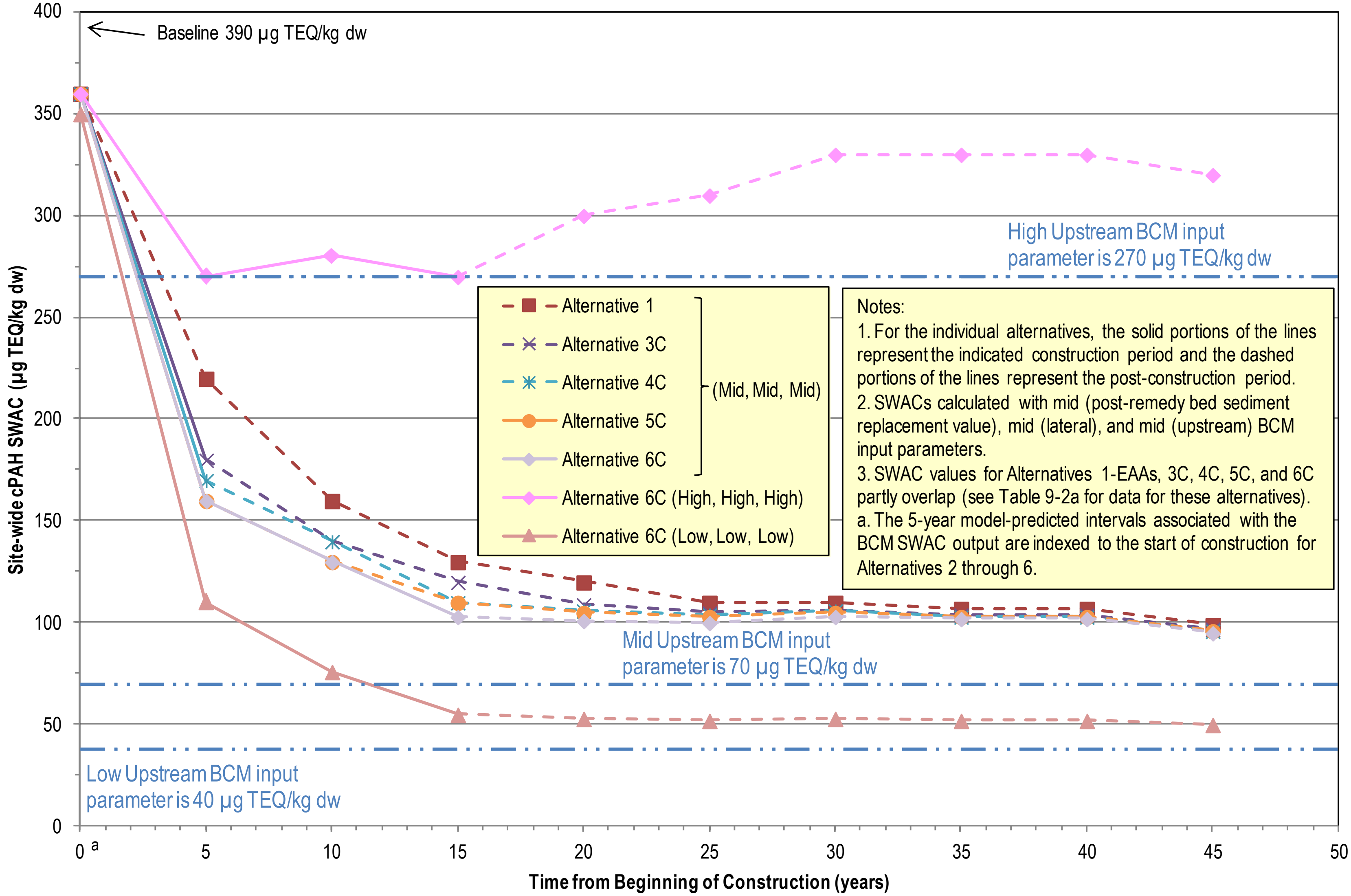


Notes:

1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 2R/2R-CAD, 3R, 4R, 5R/5R-T, and 6R partly overlap (see Table 9-2a for data for these alternatives).

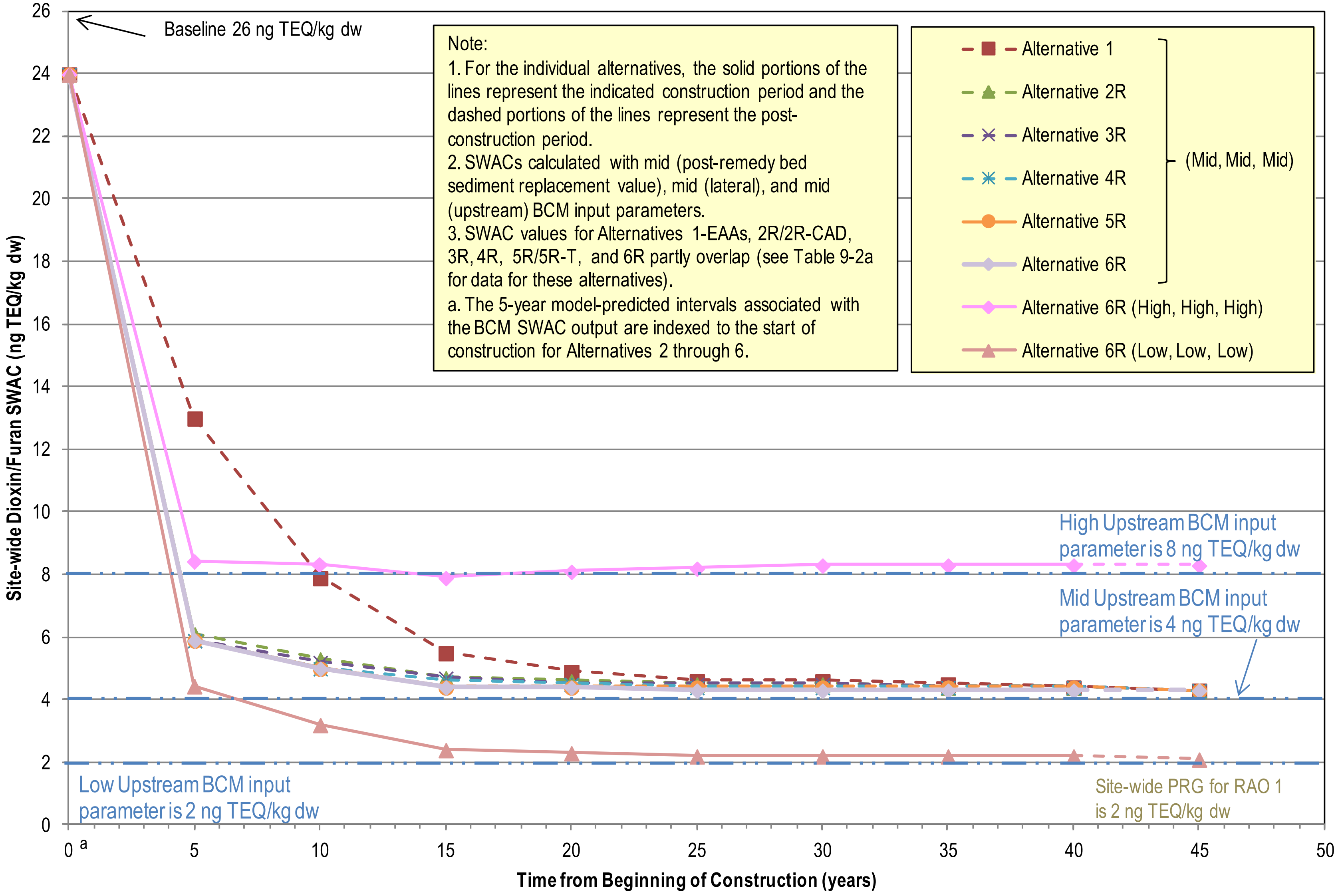
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5f Site-wide cPAH SWAC Versus Time – Combined Alternatives



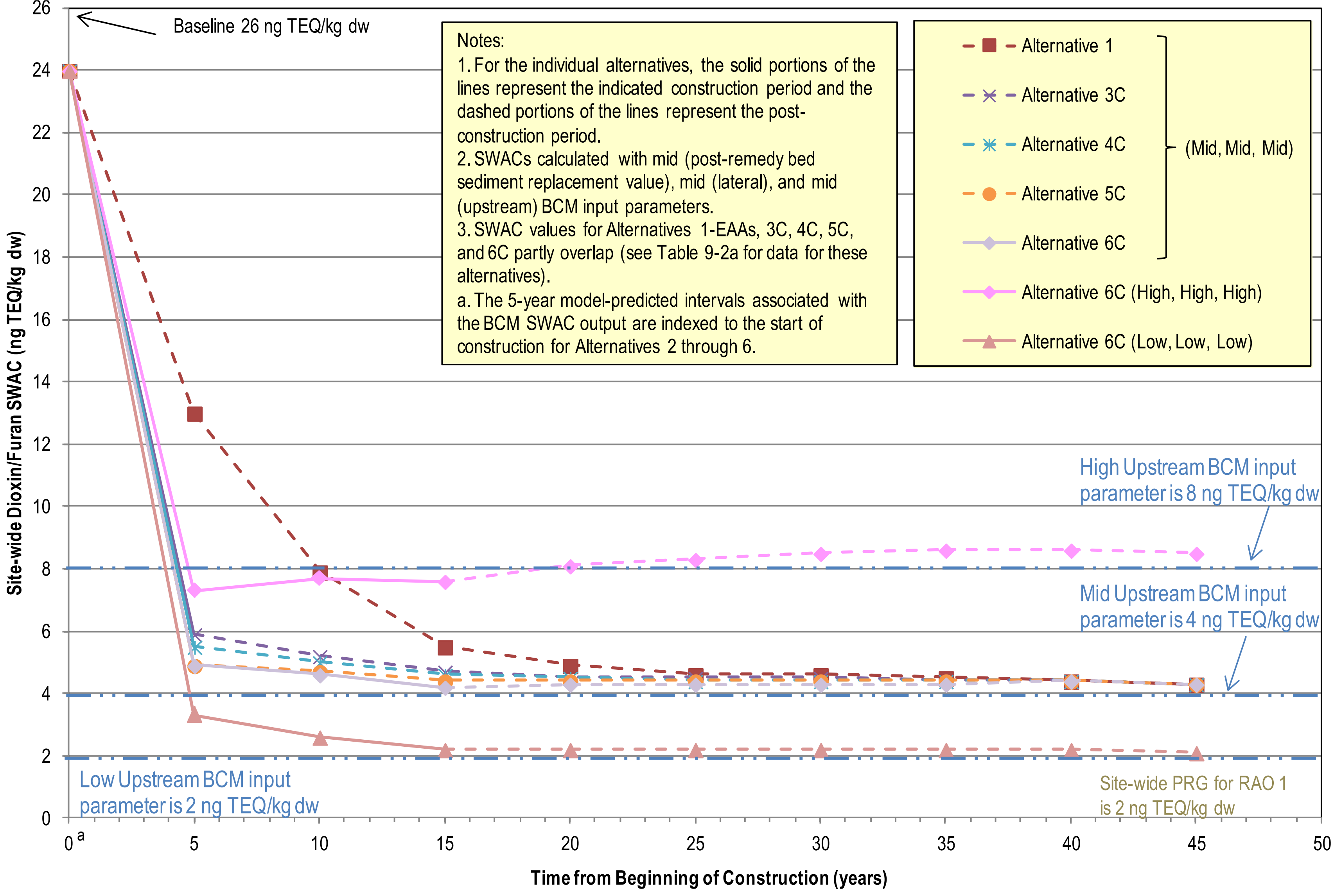
Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 3C, 4C, 5C, and 6C partly overlap (see Table 9-2a for data for these alternatives).
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5g Site-wide Dioxin/Furan SWAC Versus Time – Removal Alternatives



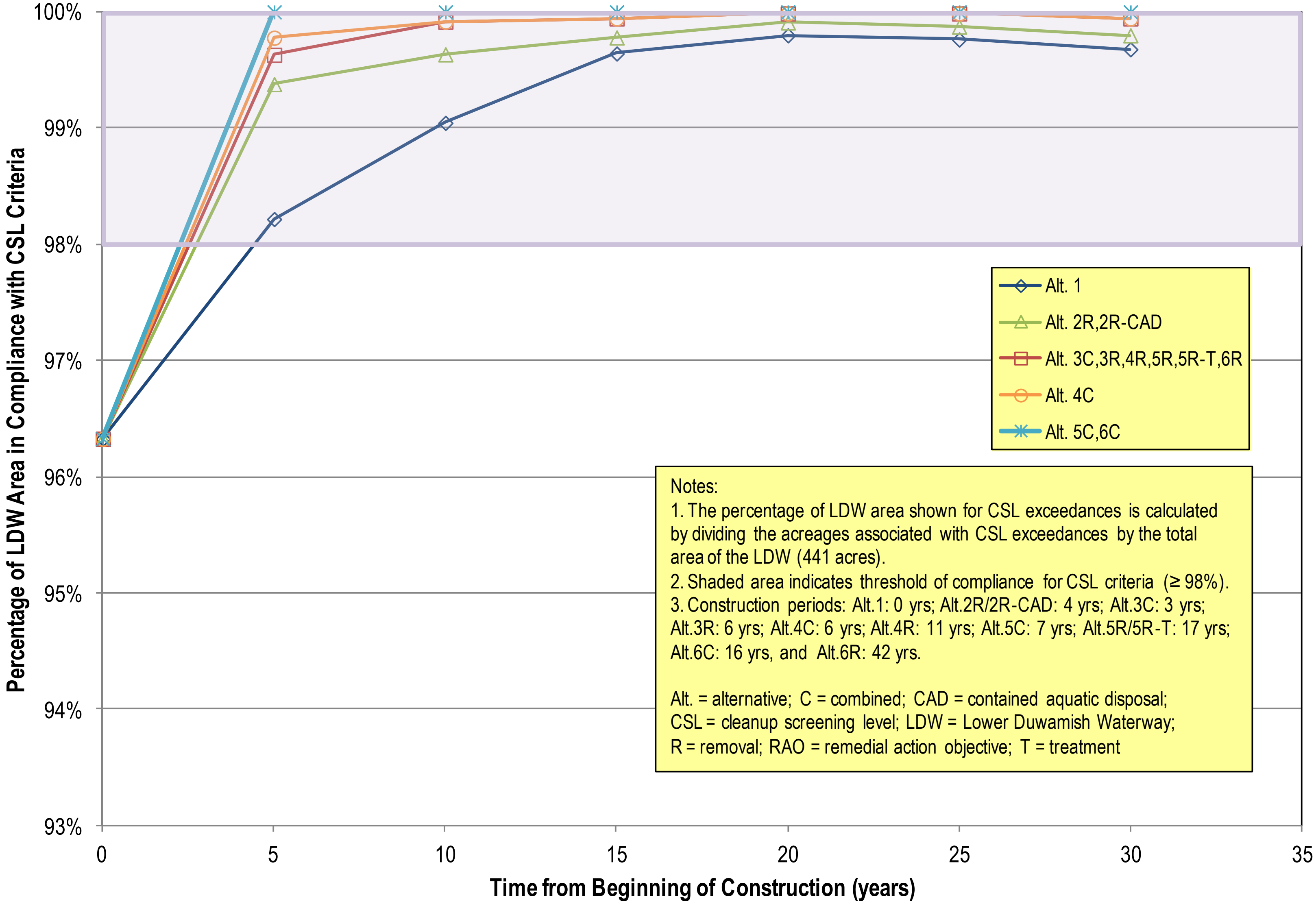
Note:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 2R/2R-CAD, 3R, 4R, 5R/5R-T, and 6R partly overlap (see Table 9-2a for data for these alternatives).
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-5h Site-wide Dioxin/Furan SWAC Versus Time – Combined Alternatives



Notes:
1. For the individual alternatives, the solid portions of the lines represent the indicated construction period and the dashed portions of the lines represent the post-construction period.
2. SWACs calculated with mid (post-remedy bed sediment replacement value), mid (lateral), and mid (upstream) BCM input parameters.
3. SWAC values for Alternatives 1-EAAs, 3C, 4C, 5C, and 6C partly overlap (see Table 9-2a for data for these alternatives).
a. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for Alternatives 2 through 6.

Figure 9-6a **Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of Baseline Stations in Compliance with CSL Concentrations after Remediation**

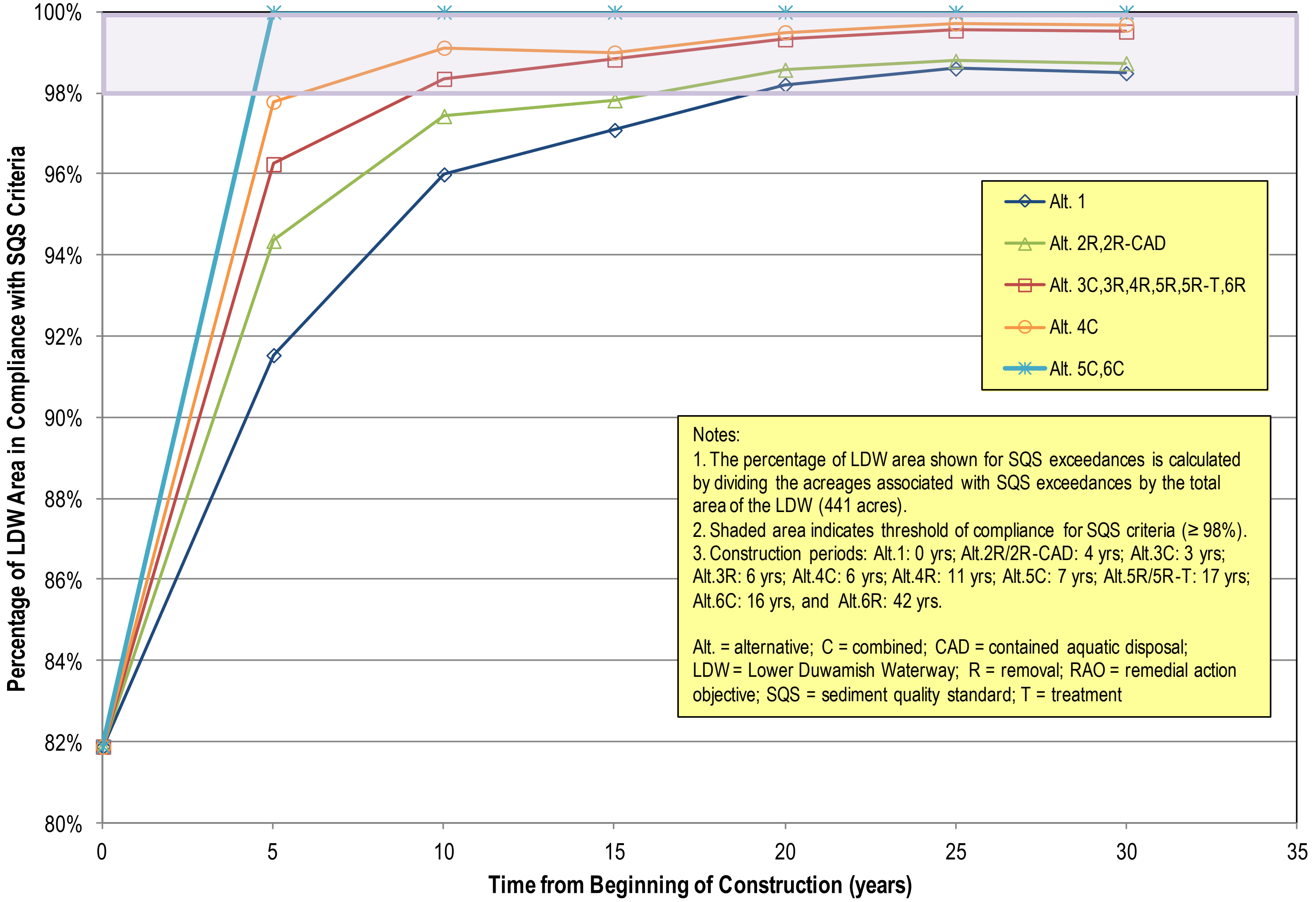


Notes:

1. The percentage of LDW area shown for CSL exceedances is calculated by dividing the acreages associated with CSL exceedances by the total area of the LDW (441 acres).
2. Shaded area indicates threshold of compliance for CSL criteria (≥ 98%).
3. Construction periods: Alt.1: 0 yrs; Alt.2R/2R-CAD: 4 yrs; Alt.3C: 3 yrs; Alt.3R: 6 yrs; Alt.4C: 6 yrs; Alt.4R: 11 yrs; Alt.5C: 7 yrs; Alt.5R/5R-T: 17 yrs; Alt.6C: 16 yrs, and Alt.6R: 42 yrs.

Alt. = alternative; C = combined; CAD = contained aquatic disposal; CSL = cleanup screening level; LDW = Lower Duwamish Waterway; R = removal; RAO = remedial action objective; T = treatment

Figure 9-6b Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of LDW Area in Compliance with SQS after Remediation

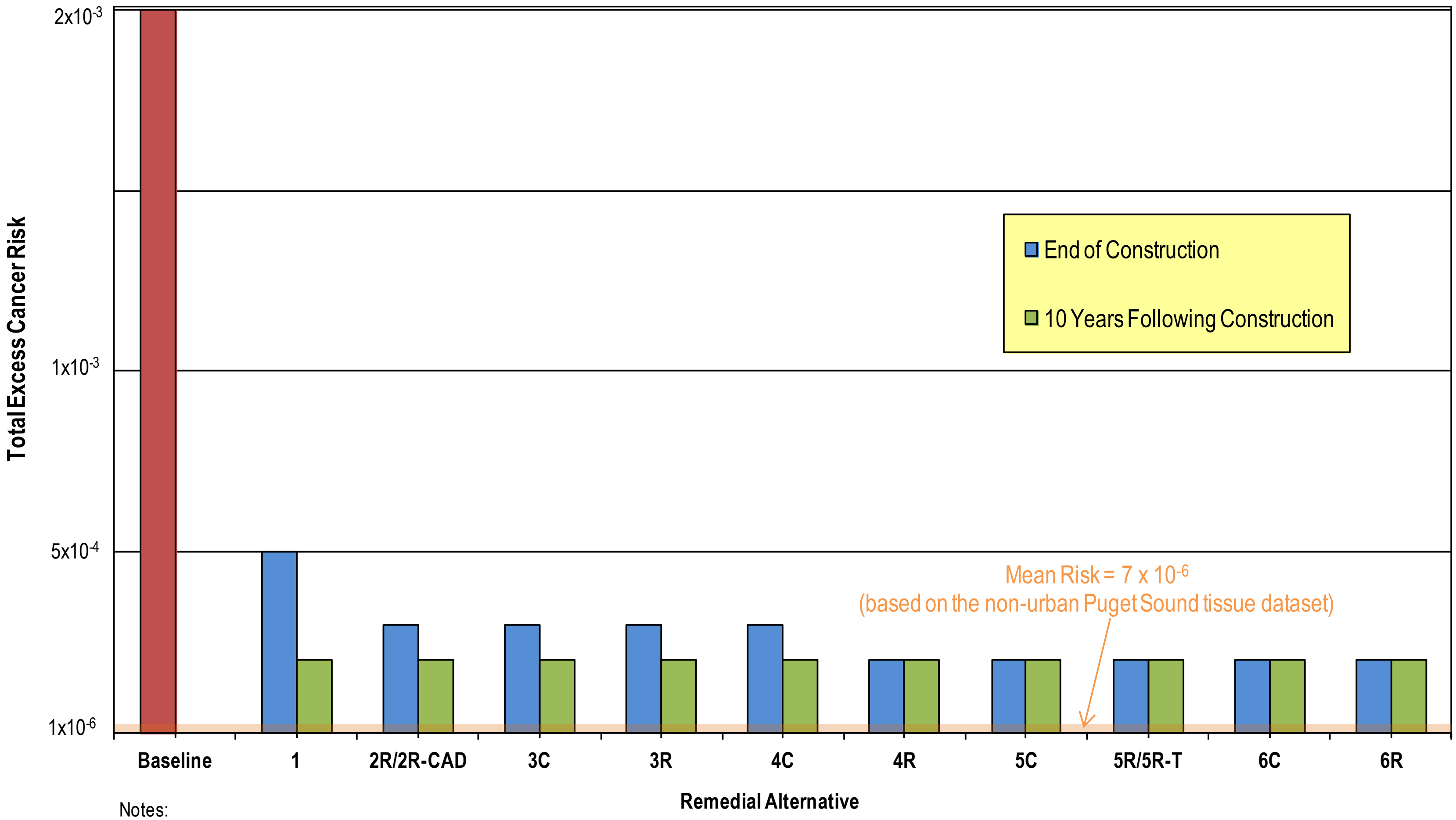


Notes:

1. The percentage of LDW area shown for SQS exceedances is calculated by dividing the acreages associated with SQS exceedances by the total area of the LDW (441 acres).
2. Shaded area indicates threshold of compliance for SQS criteria (≥ 98%).
3. Construction periods: Alt.1: 0 yrs; Alt.2R/2R-CAD: 4 yrs; Alt.3C: 3 yrs; Alt.3R: 6 yrs; Alt.4C: 6 yrs; Alt.4R: 11 yrs; Alt.5C: 7 yrs; Alt.5R/5R-T: 17 yrs; Alt.6C: 16 yrs, and Alt.6R: 42 yrs.

Alt. = alternative; C = combined; CAD = contained aquatic disposal; LDW = Lower Duwamish Waterway; R = removal; RAO = remedial action objective; SQS = sediment quality standard; T = treatment

Figure 9-7a Residual Adult Tribal Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs after Remediation

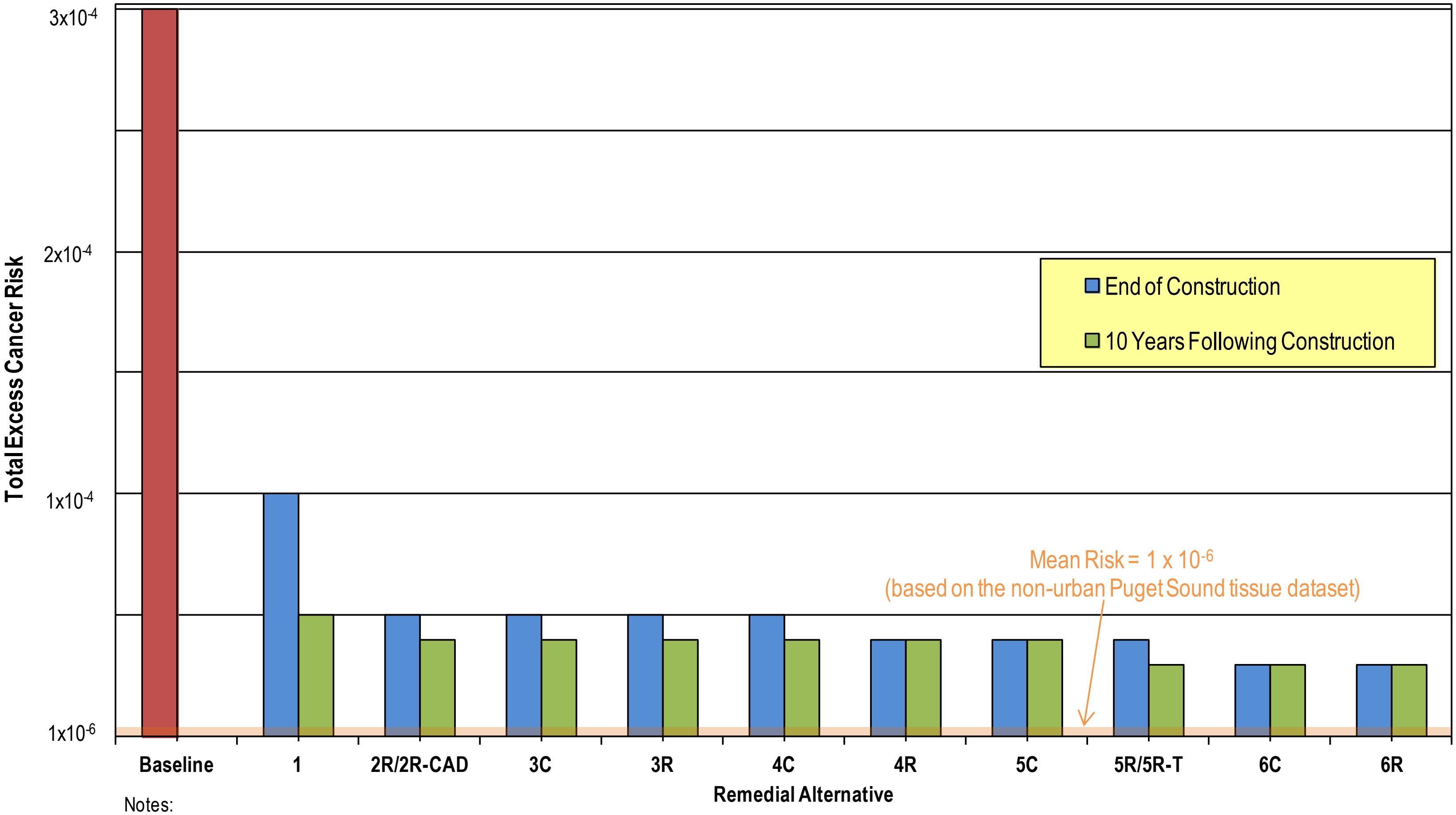


Notes:

1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Adult Tribal RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).

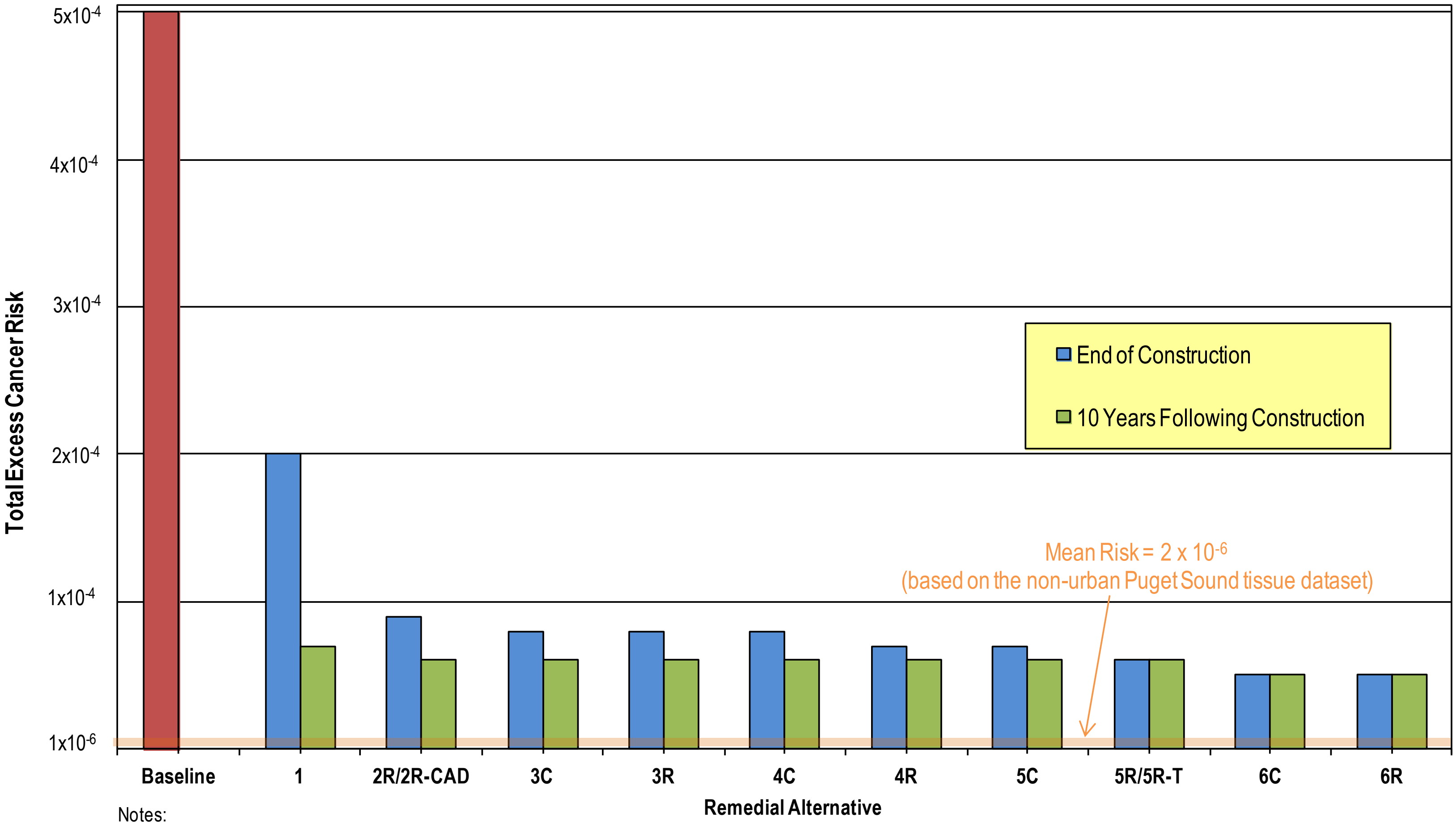
C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

Figure 9-7b Residual Child Tribal Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs after Remediation



Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Child Tribal RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).
C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

Figure 9-7c Residual Adult Asian Pacific Islander Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs after Remediation

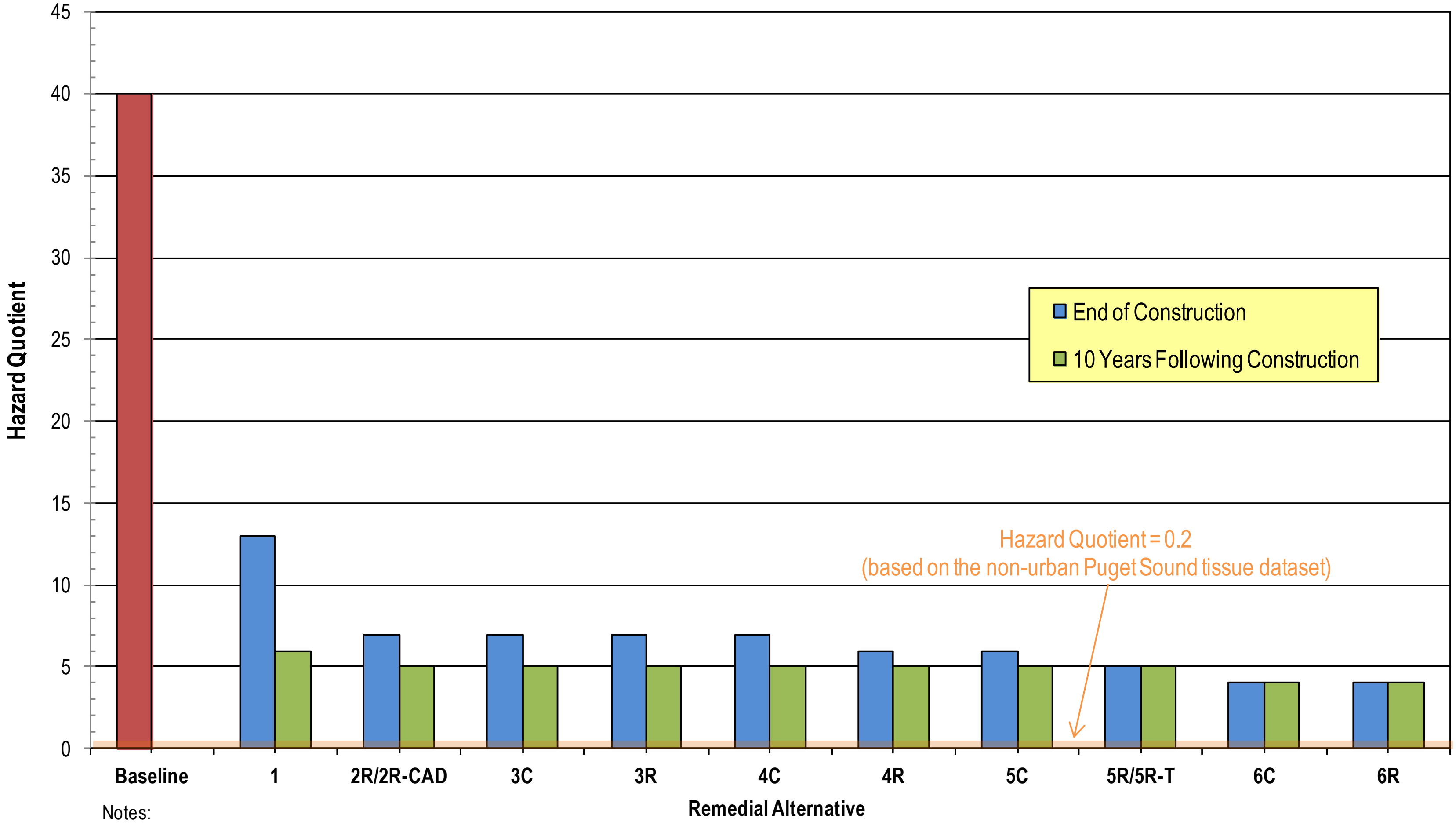


Notes:

1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Adult API RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).

API = asian pacific islander; C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

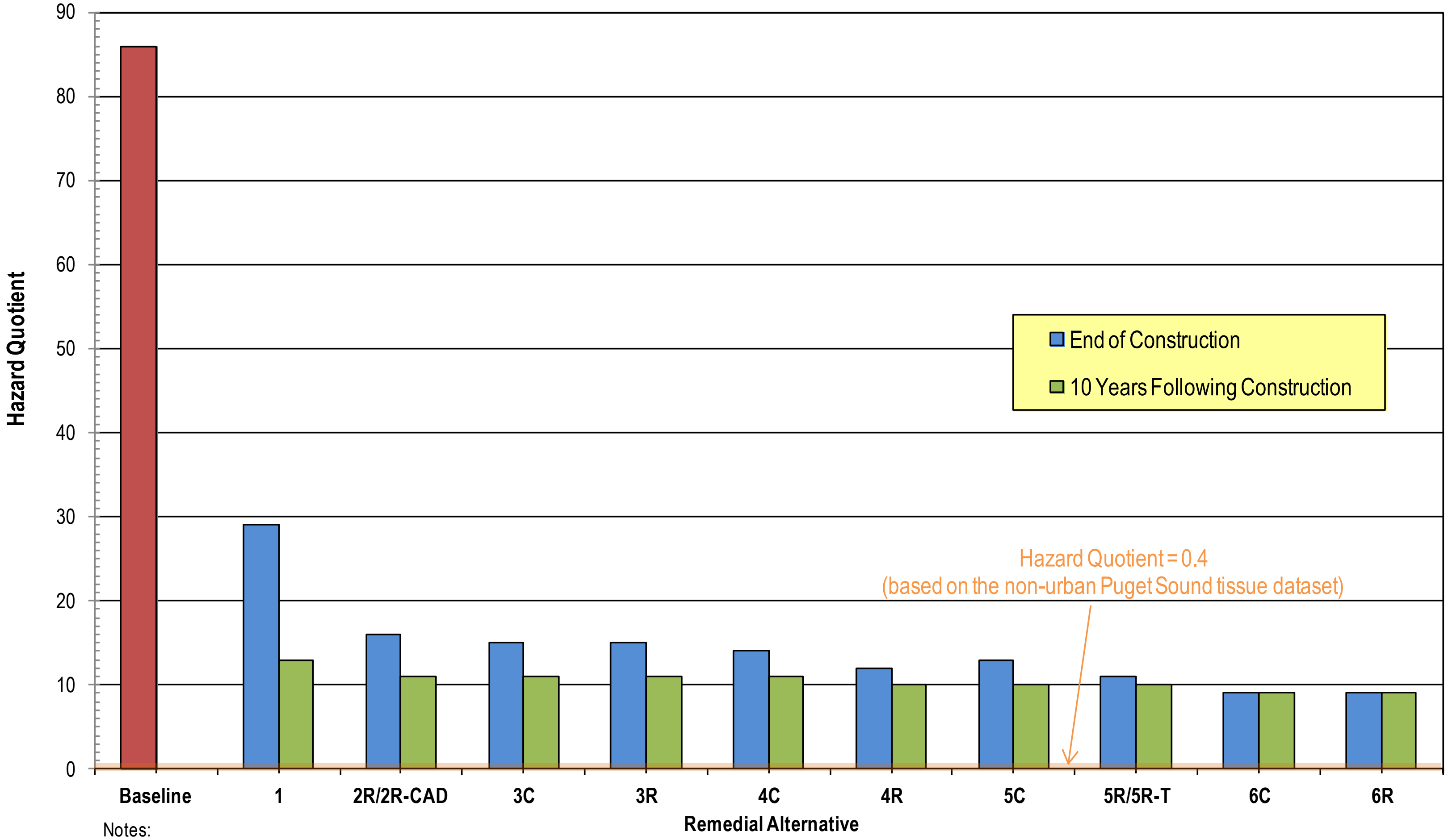
Figure 9-8a Residual Adult Tribal Reasonable Maximum Exposure Seafood Consumption Non-cancer Hazard Quotient (RAO 1) for Total PCBs after Remediation



Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate for the Adult Tribal RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).

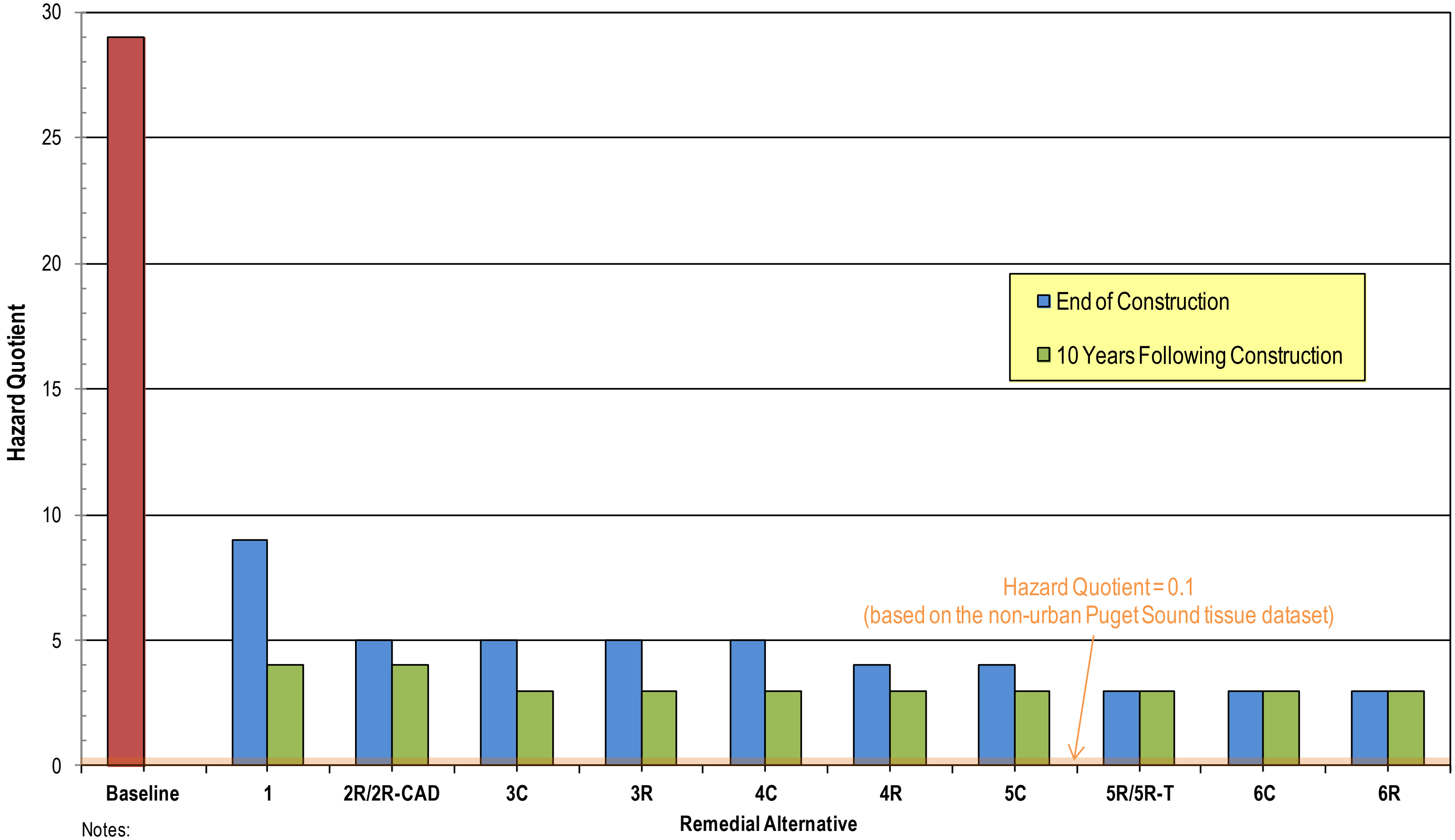
C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

Figure 9-8b Residual Child Tribal Reasonable Maximum Exposure Seafood Consumption Non-cancer Hazard Quotient (RAO 1) for Total PCBs after Remediation



Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate for the Child Tribal RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).
C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

Figure 9-8c Residual Adult Asian and Pacific Islander Reasonable Maximum Exposure Seafood Consumption Non-cancer Hazard Quotient (RAO 1) for Total PCBs after Remediation

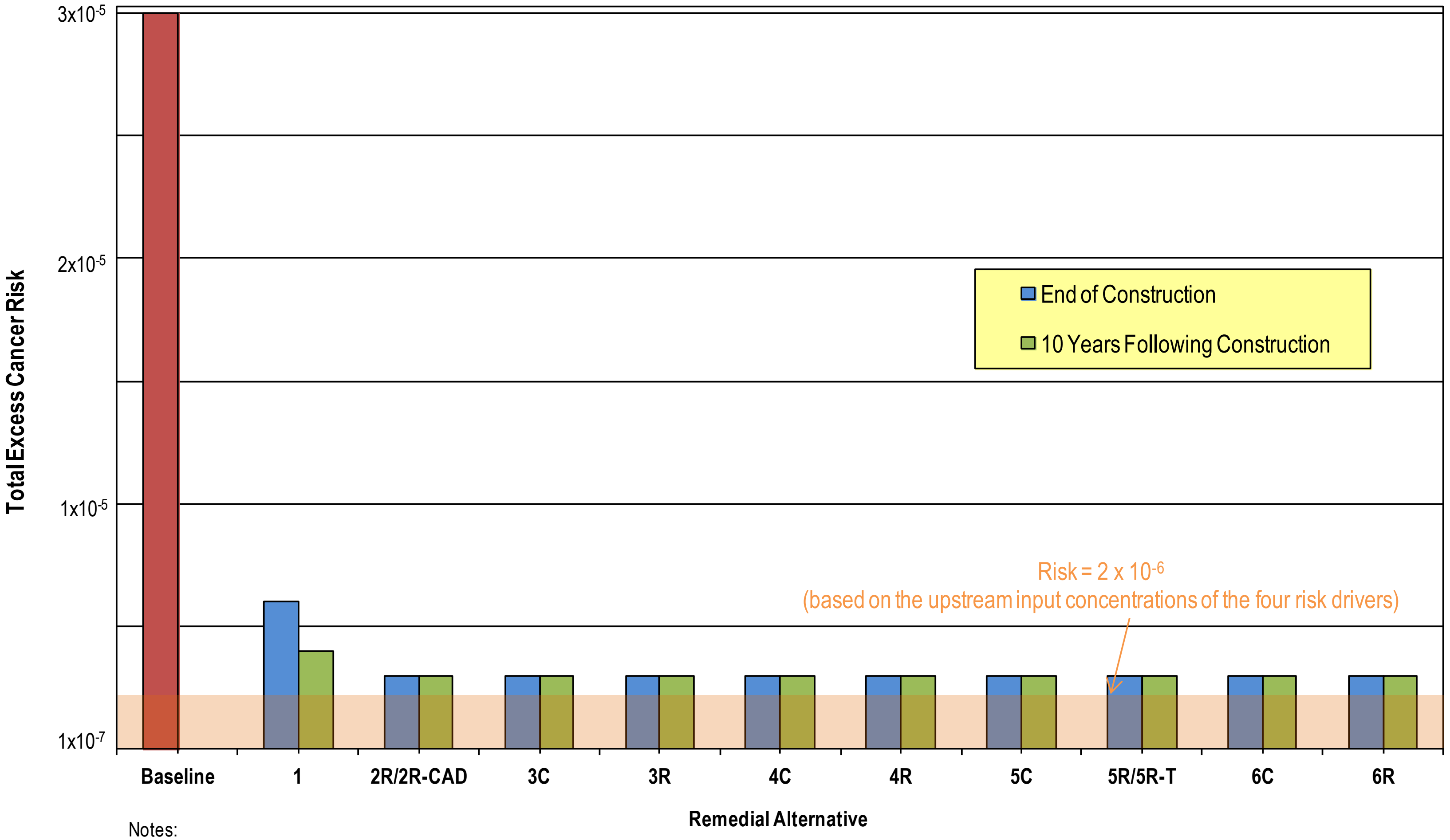


Notes:

1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate for the Adult Tribal RME seafood consumption scenario using the non-urban Puget Sound tissue dataset (see Appendix B for details).

API = Asian Pacific Islander; C = combined; CAD = contained aquatic disposal; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; RME = reasonable maximum exposure; T = treatment

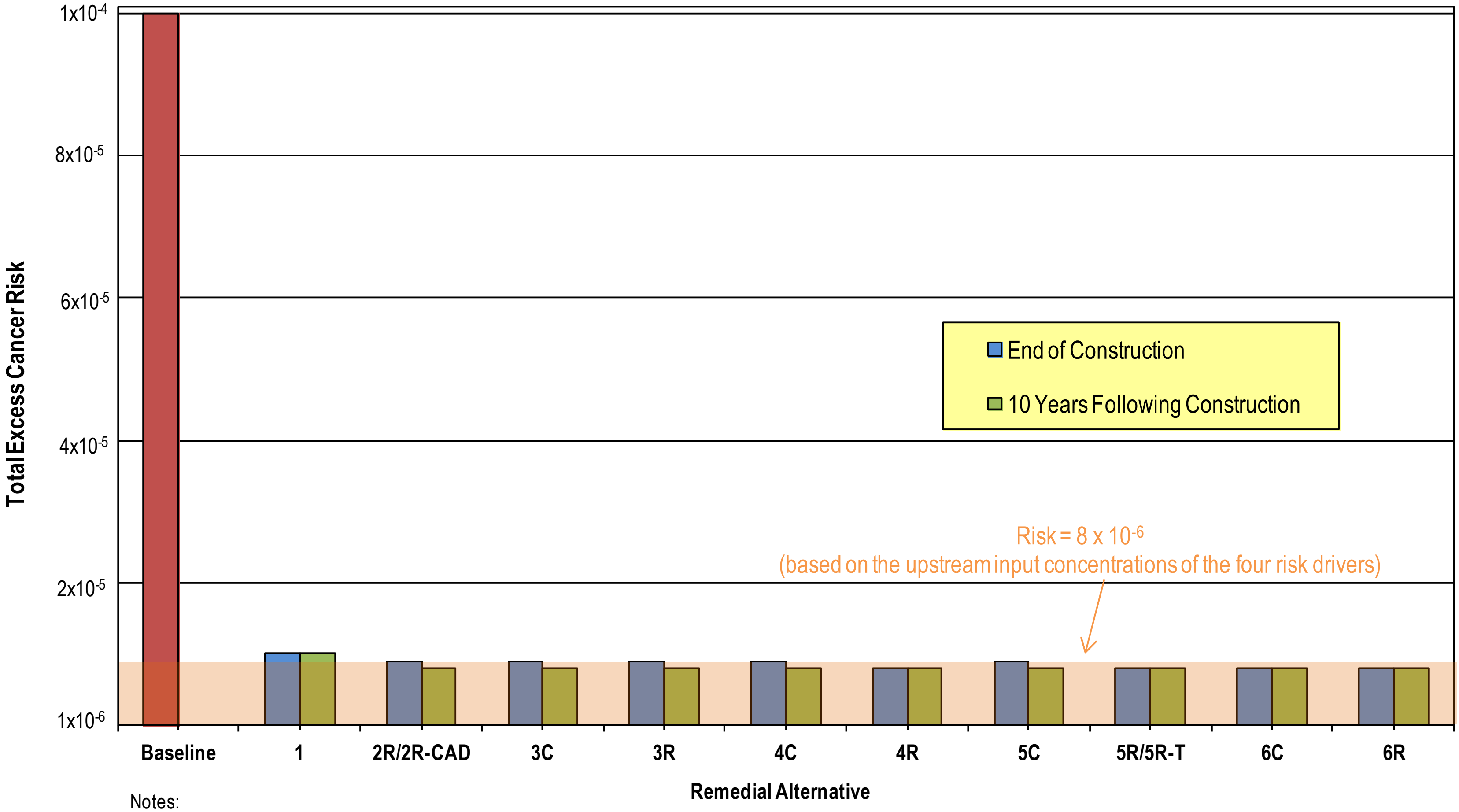
Figure 9-9a Site-wide (Netfishing) Total Direct Contact Risk (RAO 2) after Remediation



Notes:
1. Total risks include only the risk drivers (total PCBs, arsenic, cPAHs, and dioxins/furans).
2. Risk values shown for the alternatives are also presented in Table 9-8.
3. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
4. Shaded area in orange represents the upstream risk estimate for the netfishing total direct contact scenario based on the mid BCM upstream input parameters.

BCM = bed composition model; C = combined; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic aromatic hydrocarbon; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; T = treatment

Figure 9-9b Clamming Total Direct Contact Risk (RAO 2) after Remediation



Notes:
1. Total risks include only the risk drivers (total PCBs, arsenic, cPAHs, and dioxins/furans).
2. Risk values shown for the alternatives are also presented in Table 9-8.
3. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
4. Shaded area in orange represents the upstream risk estimate for the tribal clamming total direct contact scenario based on the mid BCM upstream input parameters.
BCM = bed composition model; C = combined; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic aromatic hydrocarbon; EAA = early action area; HHRA = human health risk assessment; PCB = polychlorinated biphenyl; R = removal; RAO = remedial action objective; T = treatment

10 CERCLA Comparative Analysis

This section compares the Lower Duwamish Waterway (LDW) remedial alternatives that were developed in Section 8 and evaluated individually in Section 9. This comparative analysis of alternatives uses the same set of nine Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) criteria that were used to evaluate each alternative in Section 9. Table 10-1 summarizes the information discussed herein. The alternatives are first evaluated to assess whether they achieve or do not achieve the two threshold criteria. Then all remaining alternatives undergo detailed comparison using the five balancing criteria. The two modifying criteria will be evaluated later by the U.S. Environmental Protection Agency (EPA) following public comment on its Proposed Plan. For the CERCLA balancing criteria, the table ranks the alternatives using a 5-star relative ranking scale: one star (★) is the lowest relative rank and five stars (★★★★★) is the highest relative rank. Because the remedial investigation/feasibility study (RI/FS) was performed under an Administrative Order on Consent issued by EPA and the Washington State Department of Ecology (Ecology) under both federal and state law, a comparative evaluation of alternatives under the Washington State Model Toxics Control Act (MTCA) is provided in Section 11. EPA will use the CERCLA nine-criteria analysis when selecting a remedy for the LDW.

10.1 Threshold Criteria

The two threshold criteria are:

1) Overall protection of human health and the environment, and
2) Compliance with applicable or relevant and appropriate requirements (ARARs).

10.1.1 Overall Protection of Human Health and Environment

Dredging, landfill disposal, capping, enhanced natural recovery and *in situ* treatment (ENR/*in situ*), and monitored natural recovery (MNR[1]) form the primary suite of remedial technologies around which Alternatives 2 through 6 are developed. Alternative 1 involves no active remediation (it assumes cleanup of the early action areas [EAAs] is complete). It does include LDW-wide long-term monitoring. Alternative 2R-contained aquatic disposal (2R-CAD) substitutes on-site CAD for upland landfill disposal. Alternative 5R-Treatment uses soil washing to treat a portion of the dredged material.

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[1] Although it is anticipated that some natural recovery will occur with all alternatives in this FS, the term "MNR" is used only when the alternative includes monitoring to track changes in contaminant concentrations over time and provides for contingency actions if monitoring data indicates inadequate performance.

Differences in overall protectiveness among Alternatives 1 through 6 are discussed below in the context of long-term effectiveness and permanence (magnitude and type of residual risk and adequacy and reliability of controls) and short-term effectiveness (predicted time to achieve risk reduction, time to complete the remedy, and risks during construction).

10.1.1.1 Overall Protection – Long-term Effectiveness and Permanence

Magnitude and Type of Residual Risks

Residual risks to humans, wildlife, and the benthic community were estimated from surface sediment concentrations remaining within the LDW after achieving cleanup objectives, as described in Section 9 and summarized in the first several rows of Table 10-1. Cleanup objective in this FS is used to mean the preliminary remediation goal (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 the natural background based PRGs.[2]

All alternatives are predicted to achieve an excess cancer risk for total polychlorinated biphenyls (PCBs)[3] of 2×10^{-4} and 3×10^{-5} for the Adult Tribal and Child Tribal seafood consumption reasonable maximum exposure (RME) scenarios, respectively. Non-cancer hazard quotients of 4 to 5 for the Adult Tribal seafood consumption RME and 9 to 10 for the Child Tribal seafood consumption RME are also predicted to be achieved for all alternatives. For the Asian and Pacific Islander seafood consumption RME scenario, total PCB excess cancer risks are predicted to be 5×10^{-5} and the non-cancer hazard quotient is predicted to be 3.

Alternatives 2 through 6 are predicted to achieve the following for direct contact RME scenarios (netfishing, clamming, and beach play): 1) a total excess cancer risk of less than 1×10^{-5}; 2) excess cancer risks for total PCBs, carcinogenic polycyclic aromatic hydrocarbons (cPAHs),[4] and dioxins/furans, considered individually, of less than or

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[2] A metric based on an excess cancer risk of 1×10^{-6} is used, instead of the long-term model-predicted concentration, to estimate the time to achieve the direct contact cleanup objective for carcinogenic polycyclic aromatic hydrocarbons (cPAHs) in the beach play scenario. As a result of rounding, predicted cPAH concentrations of up to 134 µg TEQ/kg result in an excess cancer risk estimate of 1×10^{-6}.

[3] Of the four risk drivers for the seafood consumption pathway (PCBs, arsenic, cPAHs, and dioxins/furans), only PCBs were modeled using a food web bioaccumulation model. Most of the risk from arsenic and cPAHs was related to consumption of clams. However, RI data showed little correlation between arsenic and cPAH concentrations in clams and sediment, leaving no basis on which to derive predictive regression models. Dioxins and furans were not modeled because tissue data were not collected; risks from dioxins/furans associated with seafood consumption were assumed to be unacceptable and thus remedial efforts for dioxins/furans will be based on background and other feasibility considerations. Additional efforts will be undertaken to examine the relationships between concentrations of arsenic and cPAHs in clam tissue and sediment.

[4] One beach play area is not predicted to achieve 1×10^{-6} excess cancer risk for cPAHs.

equal to 1 × 10^{-6}, and excess cancer risks between 1 × 10^{-5} and 1 × 10^{-6} for arsenic, and 3) non-cancer hazard quotients of less than or equal to 1.0. However, Alternative 2 does not actively remediate all areas of concern for clamming and beach play scenarios. Alternative 1 is no remedial action following cleanup of the five EAAs. In both cases, Alternatives 1 and 2 require more natural recovery to achieve remedial action objective (RAO) 2 cleanup objectives than Alternatives 3 through 6, and therefore have greater uncertainty.

All alternatives are predicted to achieve the sediment quality standards (SQS) of the Washington Sediment Management Standards (SMS). Alternatives 1 through 4 rely on natural recovery to varying degrees and thus have greater uncertainty than Alternatives 5 and 6. All alternatives are predicted to achieve a hazard quotient of less than 1.0 for wildlife (based on river otters), with Alternatives 1 through 3 requiring some natural recovery and thus having somewhat higher uncertainty.

The alternatives vary in the technologies used to reduce risk, the rate at which contaminant concentrations are reduced, and the uncertainty associated with model predictions. Section 10.2.1 provides a detailed discussion of long-term residual risk predictions. Model uncertainties related to these predictions are discussed in Sections 9.1.2.1 and 9.3.5, and below in Sections 10.2.1.2 and 10.2.1.3.

Adequacy and Reliability of Controls

Alternatives 2 through 6 differ in the degree to which they rely on engineering controls (i.e., active remediation) and natural recovery to reduce surface sediment concentrations and associated risks. Alternative 1 does not provide engineering controls and therefore relies on natural recovery alone to achieve reductions after completion of the EAAs. As the remedial action levels (RALs) decrease from Alternative 2 through Alternative 6, the alternatives rely more on engineering controls, and less on natural recovery to reduce risks. Table 10-2, Figures 10-1a through 10-1d, and Figure 10-2 illustrate the relative contributions from active remediation and natural recovery in reducing the LDW-wide spatially-weighted average concentrations (SWACs) for the four human health risk drivers in surface sediments. Incremental contributions to SWAC reduction are shown for cleanup of the EAAs, active remediation alone, natural recovery during the construction period, and lastly, natural recovery from the end of construction through the end of the model period (45 years). The SWAC estimates for construction only (i.e., ignoring any contribution from natural recovery) were calculated by assigning post-remedy bed sediment replacement values to the active construction footprint and preserving the original FS dataset interpolated concentrations outside of the active footprint.[5] The information provided in Table 10-2 and the trends illustrated

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[5] The construction-only results are influenced by the post-remedy bed sediment replacement values (especially as the active footprint increases) that were developed in Section 5. The post-remedy bed-sediment replacement values are independent of natural recovery and represent an assumed amount of recontamination following active cleanup.

in Figures 10-1a through 10-1d and Figure 10-2 suggest that active remediation alone provides significant risk reductions for Alternatives 2 through 6, even for the alternatives with relatively high RALs. The key outcomes reflected in this analysis are as follows and are organized by RAO:

- **RAO 1:** None of the alternatives are predicted to achieve the RAO 1 PRGs for total PCBs and dioxins/furans. Alternative 1 relies on natural recovery to reach long-term model-predicted surface sediment concentration ranges for total PCBs and dioxins/furans. Alternatives 2 through 5 require varying degrees of natural recovery both during and after construction to reach long-term model-predicted surface sediment concentration ranges for total PCBs and dioxins/furans (Figures 10-1a through 10-1d). Alternative 6 is predicted to achieve these ranges by active remediation alone.
- **RAO 2:** None of the alternatives are predicted to reduce arsenic concentrations to the PRG for all three direct contact exposure scenarios (Table 10-2 and Table 9-2a). Active remediation alone is predicted to be sufficient for all alternatives to achieve the total PCB, cPAH, and dioxin/furan PRGs for netfishing (Table 10-2), and the total PCB and dioxin/furan PRGs for tribal clamming and beach play. With the exception of Alternatives 1 and 2, the alternatives depend little on natural recovery to reduce cPAHs below or close to the PRG for exposure scenarios. This is because all of the remaining alternatives actively remediate these areas using the same cPAH RAL. The post-construction concentration estimates are strongly influenced by the post-remedy bed sediment replacement value for cPAHs. These differences are discussed in more detail in Section 10.2.1.1.
- **RAO 3:** All alternatives are predicted to achieve the RAO 3 PRGs (i.e., the SQS) over varying time periods, and with varying degrees of uncertainty, because they rely on natural recovery to varying degrees. Alternatives 5C, 5R, 5R-Treatment, 6C, and 6R are predicted to achieve the SQS by active remediation alone (Figure 10-2). Alternatives 1, 2R, 2R-CAD, 3C, 3R, 4C, and 4R, in sequence, are predicted to need progressively less natural recovery to achieve the SQS following active remediation.
- **RAO 4:** All alternatives are predicted to achieve the RAO 4 PRG for total PCBs (Figure 10-1a). Active remediation alone is predicted to be sufficient for Alternatives 4 through 6. Alternatives 1, 2, and 3 require a small amount of natural recovery either during or following construction.

Alternatives that apply engineering controls such as dredging and capping to larger areas reduce the potential of exposure associated with contaminated subsurface sediment left in place after active remediation is complete (Figure 10-3). Exposure of contaminated subsurface sediment by various disturbance mechanisms[6] has the potential to increase surface sediment contaminant concentrations, if not detected and adaptively managed as part of ongoing monitoring and maintenance programs. This is not accounted for in the bed composition model (BCM) used to predict future contaminant concentrations in surface sediment and the associated risks. Estimating increases in surface sediment contaminant concentrations from these disturbance mechanisms is a difficult undertaking because the magnitude and frequency of future disturbances are uncertain. The ability to detect these changes in the future in order to accomplish adaptive management is also uncertain. Therefore, alternatives that remove more subsurface contamination have more certainty in terms of long-term controls and their ability to address future contamination through adaptive management. Table 10-1 summarizes the degree to which the different engineering controls are applied by the remedial alternatives.

Alternative 1 leaves the most contaminated sediment in place, because it does not extend engineering controls beyond the EAAs. Alternatives 2 through 6 leave progressively less contaminated sediment in place as larger areas are dredged or capped within areas of potential concern (AOPCs) 1 and 2 (Figure 10-3). Also, the removal-emphasis alternatives remediate more area by dredging, leave less contaminated sediment in place, and therefore have lower risk of disturbances exposing subsurface contamination than their combined-technology counterparts.

Institutional controls, monitoring, and maintenance are additional controls employed by the alternatives to varying degrees, as shown in Table 10-1. All of the remedial alternatives are predicted to leave sediment in the LDW with concentrations above the natural background-based PRGs for resident seafood consumption for total PCBs and dioxins/furans. As a result, Alternatives 2 through 6 include institutional controls in the form of seafood consumption advisories and public education and outreach programs to reduce human exposure to these contaminants in resident LDW seafood. Alternative 1 has no institutional controls for managing residual risks outside of the EAAs beyond the existing Washington State Department of Health (WDOH) seafood consumption advisory. All alternatives include additional site-wide monitoring. The amount of additional monitoring specific to MNR areas varies by alternative. Alternatives 2R, 3C, and 3R employ MNR over the largest areas to achieve the SQS (RAO 3) while Alternative 4 employs MNR over a smaller area. Alternatives 5 and 6 do not employ MNR. However, Alternatives 1 through 5 rely on natural recovery processes to achieve the long-term model-predicted concentrations for total PCBs, dioxins/furans, and arsenic. Alternatives that remediate sediments by ENR/*in situ* (i.e., Alternatives 3 through 6C) and those that utilize MNR (i.e., Alternatives 2 through 4C) to reduce contaminant concentrations also include an adaptive management assumption that

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[6] Mechanisms for deep disturbance of subsurface sediment include vessels maneuvering under emergency and high-power operations, ship groundings, earthquakes, or operations such as dock construction/maintenance and vessel maintenance activities.

portions of the LDW designated for these technologies may require additional active remediation (dredging or capping) based on data collected during remedial design or as a result of future monitoring. Contingency actions could extend the overall period of construction, and potentially prolong the time to reach cleanup objectives.

10.1.1.2 Overall Protection – Short-term Effectiveness

Differences in overall protectiveness of the alternatives can also be discerned in the context of short-term effectiveness, which includes impacts during the construction phase, the time required to implement the remedy, and the time to achieve cleanup objectives. Alternatives with shorter construction periods translate into lower impacts to workers, the community, and the environment during implementation. Predicted impacts from construction include traffic, noise, emissions, resource depletion, physical disruption of aquatic habitat, and elevated fish and shellfish tissue contaminant concentrations (see Section 10.2.3).

Alternative 1 has no active remediation (it assumes that EAA cleanup is complete) and therefore has no short-term impacts from construction activities. Alternatives 2, 3, 4C, and 5C have construction periods ranging from 3 to 7 years and generally have lower short-term impacts. Alternatives 4R, 5R, 5R-Treatment, and 6C have construction periods ranging from 11 to 17 years, and thus, have greater short-term impacts. Alternative 6R is anticipated to require 42 years to construct, and thus, has the greatest short-term impacts.

Figure 10-4 illustrates the predicted periods required to achieve cleanup objectives. This information was presented previously in Table 9-25. In summary, Alternatives 1, 2, and 6R take the longest time to achieve cleanup objectives, because of the time required for natural recovery (Alternatives 1 and 2R/2R-CAD) and construction (Alternative 6R). Alternatives 4C and 5C, with construction periods of 6 to 7 years, are predicted to reach all of the cleanup objectives the fastest.

10.1.1.3 Overall Protection Summary

Alternative 1 provides the least protection of human health and the environment. While it is predicted to achieve PRGs or risk goals for RAOs 2 (except arsenic), 3, and 4 with natural recovery (PRGs for RAOs 2 and 3 require a lengthy period of time), it does not provide for institutional controls, other than the existing WDOH seafood consumption advisory. Further, Alternative 1 does not apply contingency actions if PRGs for RAOs 2, 3, and 4 are not achieved as predicted by the BCM. Because all of the remaining alternatives (2 through 6) do not achieve the very low PRGs for RAO 1, they require institutional controls to manage residual seafood consumption risks to satisfy the threshold criterion for overall protection. However, the extent to which human exposure to contaminants in resident fish and shellfish can be reduced through seafood consumption advisories is unknown. Eventually, residual risks from exposure to surface sediments are predicted to approach similar values for these alternatives (Table

10-1) because of the large influence that Green/Duwamish River upstream inputs to the LDW have on long-term BCM predictions.

As discussed previously, the predicted time to reach cleanup objectives differs among the alternatives. The predicted time to reach long-term model-predicted concentrations and the concentrations ultimately achieved are more uncertain for alternatives that rely more on natural recovery. This is because of model prediction uncertainties and the risk of exposure from remaining subsurface contamination, as discussed in Sections 10.2.1.1 and 10.2.1.2.

In summary, Alternatives 2 through 6 are each predicted to achieve the threshold criterion of Overall Protection of Human Health and the Environment through varying combinations of engineering controls, natural recovery, and institutional controls. Alternatives 2 through 6 require institutional controls to provide additional protectiveness for people who consume resident seafood, although the effectiveness of these controls is unknown. Alternative 1 does not satisfy this threshold criterion because it does not include institutional controls that are necessary for managing residual risks, beyond those required under enforcement agreements governing the EAA work and the existing WDOH seafood consumption advisory.

10.1.2 Compliance with ARARs

The two most important ARARs in terms of evaluating the remedial alternatives are: MTCA (statute and regulations) and federal and state surface water quality standards.[7] Under CERCLA, state legal requirements must be met whenever they are more stringent than federal requirements. Thus, MTCA is an ARAR whenever it would require a more stringent outcome than CERCLA requires, and applicable state surface water quality standards must be met whenever they are more stringent than relevant and appropriate federal water quality criteria. This FS was performed under a joint CERCLA-MTCA Order; however, EPA and Ecology have determined that the LDW cleanup decision will be a CERCLA Record of Decision (ROD). MTCA would therefore be an ARAR. Other ARARs listed in Table 4-1 (Section 4) were not discussed as explicitly as part of the detailed evaluation of remedial alternatives in Section 9. As described below, it is unlikely that any of the remedial alternatives would fully comply with all MTCA requirements or with surface water quality requirements for some contaminants that are based on human consumption of seafood.

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[7] The Washington SMS (WAC 173-204) are used to establish cleanup levels for sediment under MTCA. The SMS are ARARs under CERCLA and include promulgated numerical standards under MTCA for the protection of benthic invertebrates (RAO 3 in this FS). The SMS have a narrative standard requiring the protection of human health (RAOs 1 and 2 in this FS), which is essentially the same as CERCLA and MTCA's first threshold requirement that remedies protect human health along with the environment. The SMS are also promulgated state water quality standards, but will be discussed in the sections that address MTCA criteria.

MTCA Cleanup Levels

Because risk-based threshold concentrations (RBTCs) for some contaminants of concern (COCs) and pathways are below natural background, MTCA requires that final cleanup actions achieve natural background concentrations for those COCs. The promulgated MTCA natural background requirement for final cleanup actions where RBTCs are below background is an ARAR. This applies to PRGs for PCBs and dioxins/furans (for RAO 1) and for arsenic (for RAO 2). For this FS, EPA and Ecology established natural background concentrations for these risk drivers based on the 95% upper confidence limit on the mean (UCL95) using the 2008 EPA Ocean Survey Vessel (OSV) *Bold* survey dataset from Puget Sound (EPA 2008b). However, based on current information about sediment inputs to the LDW, and regardless of the effectiveness of source control, achieving these PRGs is considered unlikely. Although Alternatives 2 through 6 are not predicted to achieve MTCA-based PRGs, they all reduce risks through a combination of: 1) reduction of contaminant concentrations through active and passive remediation, 2) monitoring and potential contingency actions, and 3) application of institutional controls designed to reduce exposure, especially from consumption of resident LDW seafood.

For direct contact scenarios (RAO 2), Alternatives 2 through 6 are predicted to achieve MTCA's more stringent total excess cancer risk requirements (at or below 1×10^{-5}), a non-cancer hazard index of 1, and excess cancer risk requirements for individual carcinogens (at or below 1×10^{-6}) for the protection of human health in the following cases:

- Total PCBs and dioxins/furans under all direct contact exposure scenarios.
- cPAHs under the netfishing and tribal clamming direct contact exposure scenarios.

None of the alternatives are predicted to reduce arsenic concentrations to the PRG (based on natural background) for the three direct contact exposure scenarios. In the case of cPAHs, the long-term model-predicted concentrations at some beaches may slightly exceed the PRG regardless of the alternative (although the risk threshold of 1×10^{-6} is predicted to be achieved at all but one beach play area[8]). ARAR waivers could be issued by EPA in the future for those COCs and exposure scenarios that do not meet natural background PRGs or MTCA risk thresholds.

Alternative 1 may not comply with the MTCA direct contact risk requirements even though model predictions of surface sediment concentrations suggest that it may. This is because no active remediation takes place (outside of EAAs), model predictions are

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[8] As a result of rounding, predicted cPAH concentrations of up to 134 µg TEQ/kg result in an excess cancer risk estimate of 1×10^{-6}.

highly uncertain, and unremediated subsurface sediment contamination could cause exceedances of these risk thresholds, as discussed above.

The SMS (WAC 173-204) are rules promulgated under MTCA for establishing sediment cleanup standards. The SMS provide numerical criteria for the protection of marine benthic invertebrates (RAO 3 in this FS) and a narrative standard for the protection of human health and other biological resources. The SMS numerical sediment criteria do not address the effects of bioaccumulative contaminants on higher trophic level organisms, including humans. The SMS allow sediment cleanup standards to be set on a site-specific basis within an allowable range of concentrations. The upper end is the minimum cleanup level (MCUL), also called the cleanup screening level (CSL), not to be exceeded 10 years after completion of the active cleanup actions. The lower end is defined by the SMS as the cleanup objective, also called the SQS. Site-specific cleanup standards are to be as close as practicable to the cleanup objective or SQS. Factors considered for the site-specific sediment cleanup standards include environmental effects, technical feasibility, and cost. Longer time frames for achieving RAO 3 may be authorized when cleanup standards cannot be practicably achieved within 10 years after construction of the remedial alternative (WAC 173-204-580(3)(b).

Over time, all of the alternatives are predicted to comply with the SMS, but Alternative 1 and possibly Alternative 2 are not predicted to do so within 10 years following active remediation. Section 4 of this FS identifies the SQS as the PRG for sediments only for RAO 3. Cleanup standards will be established in the ROD consistent with the SMS.

Water Quality Standards Compliance

All of the remedial alternatives must comply substantively with relevant and appropriate federal surface water quality criteria and any more stringent state water quality standards upon completion of remedial action, except to the extent that they may be formally waived by EPA. Dredging and capping projects previously implemented in the LDW have complied with project-specific water-quality certification requirements. Compliance with these or similar certification requirements can be expected regardless of the remedial alternative selected, provided that dredging methods include best management practices (BMPs) to ensure that dissolved and/or suspended releases (e.g., of total suspended solids [TSS] and COCs) do not result in exceedances of water quality standards (EPA 2005b, NRC 2007, USACE 2008a). Implementing multiple remedial actions simultaneously and in relative proximity to one another could increase the risk of violating short-term water quality requirements, a consideration that should be factored into project sequencing and production rate decisions. Careful planning, production rate controls, and the use of BMPs are warranted in all cases to reduce short-term water quality impacts.

Cleanup of sediments, along with source control actions, are expected to reduce concentrations of COCs in the water column following cleanup actions, an important consideration toward achieving RAO 1 cleanup objectives to the maximum practicable extent. Other factors not related to releases from the site (e.g., inflow of river water from upstream of the LDW, aerial deposition of COCs from distant sources) also contribute to COC concentrations in water. For FS purposes, none of the alternatives are anticipated to comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of seafood containing bioaccumulative contaminants (e.g., PCBs) that magnify through the food chain. Monitoring will assess the extent to which water quality ARARs can be attained in the long term and should inform EPA decision-making with respect to issuance of any future ARAR waivers. To the extent that surface water quality criteria are not met, further action may be required under CERCLA, MTCA, the Clean Water Act (CWA), the Clean Air Act (CAA), and potentially other authorities.

Compliance with Other ARARs

The construction elements for the remedial alternatives are similar in nature and scope to sediment remediation projects previously implemented in the Puget Sound region. It is therefore anticipated that all of the remedial alternatives can be designed and implemented to comply with ARARs pertaining to:

- **Management and disposal of generated materials (e.g., contaminated sediment, wastewater, and solid waste).** These ARARs primarily concern the handling and disposal of materials. They may complicate implementation and add costs but should not influence whether a remedial alternative is fundamentally viable.
- **Resource protection requirements (e.g., habitat preservation, mitigation).** These do not pose a fundamental obstacle to the design and implementation of the remedial alternatives. In the short term, the benthic community within the intertidal and shallow subtidal habitat areas above -10 feet (ft) mean lower low water (MLLW) would be impacted during dredging and capping activities. However, each alternative can be designed to result in no net loss of aquatic habitat area over time.

CWA 404 dredge and fill requirements can be met for all remedial alternatives. As with previous regional CERCLA sediment remediation projects, EPA would evaluate the selected alternative for substantive compliance with CWA 404(b)(1) and Rivers and Harbors Act Section 10 requirements. Specific design elements would ensure these requirements are satisfied.

Alternative 5R-Treatment may include construction and operation of a treatment facility located outside of the LDW Superfund Site, in which case, all permits related to the facility would need to be obtained. This is, however, unlikely given the CERCLA "on-site" definition in Section 300.5 of the National Contingency Plan (NCP), embracing "the areal extent of contamination" as well as "suitable areas in very close proximity" for such a facility. Off-site placement of any treated sand under Alternative 5R-

Treatment, if determined to be legally and commercially viable, would also need to obtain regulatory approvals.

Alternative 2R-CAD includes off-site open water disposal of clean sediments excavated from CAD pits. This disposal would be subject to full administrative compliance (including permitting) under the Dredged Material Management Program (DMMP) process. Such compliance may be feasible. If dredged materials do not meet DMMP requirements for open water disposal, they will likely be disposed of at a commercial landfill.

Summary of Compliance with ARARs

Natural background PRGs for PCBs and dioxins/furans (for RAO 1) in sediment are minimum cleanup levels under MTCA for protection of human health via the seafood consumption pathway. None of the alternatives are predicted to achieve concentrations at or below these PRGs. Therefore, an institutional controls program designed to reduce exposures from LDW resident seafood consumption would be required for each alternative during and after remedy implementation. An institutional controls program is included in Alternatives 2 through 6. Alternative 1 includes only the existing WDOH seafood consumption advisory as an LDW-wide institutional control.

As described above, it is unlikely that any of the remedial alternatives would fully comply with MTCA and water quality ARARs. CERCLA requires that all ARARs be met or waived on any one or more of six bases upon completion of remedial actions. By far, the most common waiver has historically been for technical impracticability. The goal in all instances where predictions are that ARARs may not be achieved is to get as close as technically practicable to the ARAR, and apply a waiver only to the extent necessary. Because future conditions are difficult to predict, actual data available upon completion of the remedial action will underlie the basis for any such waivers, which are formally documented and issued by EPA. For this reason, more definitive statements on whether, and perhaps more significantly to what extent, ARARs (such as those used to set sediment PRGs for PCBs, dioxins/furans, and arsenic, or certain water quality criteria based on bioaccumulation of contaminants through the food chain) will be achieved or potentially waived cannot be made at this time, but must be made at the completion of cleanup and source control work at the site.

10.2 Balancing Criteria

The alternatives were compared using the five balancing criteria designated by CERCLA. The subsections below present the comparison.

10.2.1 Long-term Effectiveness and Permanence

This balancing criterion compares the relative magnitude and type of residual risk that would remain in the LDW after implementation of each alternative (i.e., active remediation plus a period of natural recovery if needed to achieve cleanup objectives).

It also assesses the extent and effectiveness of the controls that may be required to manage the risks posed by residual contamination.

10.2.1.1 Magnitude of and Type of Residual Risks

The remedial alternatives were evaluated for two types of residual risks. One type is the risk predicted to remain on-site from exposure to surface sediment containing residual concentrations of risk drivers. The other form of residual risk is from sediments remaining in the subsurface that contain COCs above levels needed to achieve the cleanup objectives and that may be disturbed and thereby exposed in the future.

Residual risks to humans, wildlife, and the benthic community from surface sediment concentrations after remediation were estimated as described in Section 9 and are summarized in Section 10.1.1.1 and in the first four rows of Table 10-1. All of the alternatives are predicted to achieve similar residual surface sediment COC concentrations and risk levels in the long term, with varying degrees of uncertainty, as described in Sections 10.2.1.2 and 10.2.1.3.

Evaluation of residual risks also considered the potential for exposure of subsurface contamination left in place following remediation. The LDW is a working industrial waterway in which scour from vessel operations is one mechanism that can expose subsurface sediment on a recurring basis. Earthquakes have the potential to cause instability and movement of sediment that episodically could expose contaminated subsurface sediment. In general, remedial alternatives that emphasize removal and upland disposal of contaminated sediments outside of the LDW have a lower potential for subsurface sediment to be exposed than alternatives emphasizing capping, ENR/*in situ*, and MNR. Table 10-1 contains the following metrics, developed and presented in Section 9, that were used to compare the magnitude of subsurface contamination remaining in place and the potential for it to be exposed for each alternative:

- **Total area dredged**: Areas dredged range from a low of 29 acres (Alternative 2R) to a high of 274 acres (Alternative 6R). Removal-emphasis alternatives dredge more contaminated sediment than the combined-technology alternatives with the same active footprint or RALs, and higher numbered removal or combined alternatives dredge more contaminated sediment than lower numbered removal or combined alternatives, respectively.

- **Total area capped, including partial dredge and cap**: The risk of exposing contaminated subsurface sediment is relatively low in capped areas because the caps are engineered to remain structurally stable under location-specific conditions. Areas capped range from a low of 3 acres (Alternative 2R) to a high of 143 acres (Alternative 6C). Combined-technology alternatives cap more sediments than the removal-emphasis alternatives with the same active footprint or RALs, and higher numbered combined alternatives cap more sediment than lower numbered combined alternatives.

- **ENR/*in situ* area grouped by recovery categories:**[9] Areas remediated by ENR/*in situ* have a higher potential for exposure of contaminated subsurface sediment than capped areas because, unlike caps, these technologies are not engineered to completely isolate subsurface contaminated sediments. However, specification and use of aggregate mixes can reduce impacts from the types of scour associated with routine and emergency vessel operations. Also, limiting ENR/*in situ* to areas in Recovery Categories 2 and 3, which have a higher potential for recovery, should reduce the occurrence of subsurface contaminated sediment exposure.

- **Remaining area (in acres) not actively remediated:** AOPCs 1 and 2 define areas of the LDW where the majority of sediment contamination resides and thus where exposure of subsurface sediment has the potential to increase SWACs. In sequence, the alternatives have progressively smaller areas that are not actively remediated in this portion of the LDW.

- **Number of core stations outside of the dredge prism and cap footprint:** The combined-technology alternatives have progressively more core locations with contaminant concentrations exceeding the CSL that are contained under caps and progressively fewer core locations with such exceedances remaining in the subsurface outside of the dredge and cap areas. The removal-emphasis alternatives leave fewer cores with subsurface contamination in place that are above the CSL outside of the dredge prism and cap footprint.

- **Total PCB concentrations remaining in the subsurface:** As described in Section 9.1.2.1 and Appendix M, Part 1 (Tables M-9a and M-9b), the means of the vertically averaged total PCB concentrations in the core stations remaining in the subsurface outside of the dredge prism and cap footprint (Alternatives 2 through 6C) range from approximately 250 to 400 micrograms per kilogram dry weight (µg/kg dw) and the UCL95 values range from approximately 500 to 600 µg/kg dw (see Figure 10-5). The range of total PCB concentrations is small, with the exception of a few cores (i.e., those above the 75th percentile; Figure 10-5). However, the PCB concentrations in the subsurface should be considered in relation to the amount of surface area where subsurface contamination remains outside of dredged and capped areas (see Figure 10-5).

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[9] As defined in Section 6, Recovery Category 1 has a high potential for scour, and, consequently, exposure; therefore, recovery is presumed to be limited. Recovery Categories 2 and 3 are either stable or expected to recover over time and thus have a lower exposure potential than Recovery Category 1 areas.

Alternatives 4C, 4R, 5C, and 6C do not use ENR/*in situ* or MNR to remediate any Recovery Category 1 areas with surface sediment COC concentrations above the RALs. Therefore, these alternatives have a lower potential for exposure of subsurface contaminated sediment than Alternatives 1, 2, and 3. The remaining FS dataset cores with sediment concentrations above the CSL are either capped or are located in the less energetic or more depositional areas found in Recovery Categories 2 or 3. Alternatives 5R and 6R have the lowest potential for exposure because they rely exclusively on dredging and capping technologies.

Alternatives 1 and 2R have the highest likelihood of increases in surface sediment SWACs over long-term model-predicted values from disturbances of contaminated subsurface sediments (see Appendix M Part 5, Figure 2). Alternatives 3R, 3C, and 4C have a lesser (or moderate) likelihood of increased surface sediment SWACs, and surface sediment SWACs for Alternatives 4R, 5C, 5R, 6C, and 6R are least likely to be affected by exposure of subsurface contamination.

The CAD component of Alternative 2R-CAD has a higher exposure potential for LDW receptors because contaminated sediments would remain in the LDW rather than being disposed of in an upland landfill. However, the risk of exposure of contaminated sediments placed in the CAD is relatively low because the CAD cell and engineered sediment cap would be designed, monitored, and maintained for long-term stability. The CAD is similar to other caps with respect to exposure potential.

In the long term, exposure of subsurface contamination by mechanical disturbances (e.g., propeller scour) is likely to occur as a series of localized events. Localized risks to benthic organisms could occur in these instances both from the physical disturbance and the exposed subsurface contamination. The overall impact of multiple events on residual risks that are based on SWACs (i.e., direct contact and seafood consumption risks) is difficult to predict but could result in differences among the alternatives that are not made evident by the BCM, which predicts similar long-term outcomes for all alternatives (see additional discussion in Section 9.1.2.1).

The possibility exists that a major earthquake in the Puget Sound region could occur, and that contaminant concentrations in LDW surface sediments could increase as a result. Subsurface contamination could be exposed by a variety of earthquake induced ground disturbances (e.g., slope failure, liquefaction). Other factors such as damage in the uplands could produce lateral, upstream, and even downstream (e.g., from a tsunami) inputs of contaminants not originating in the LDW. It is difficult to accurately predict how such factors could affect post-earthquake conditions in the LDW, if not detected and addressed as part of the long-term monitoring program. The potential for earthquakes to disturb subsurface contaminated sediments is a factor in the evaluation of residual risks, as discussed in Section 10.2.1.3.

10.2.1.2 Adequacy and Reliability of Controls

This factor assesses the adequacy and reliability of controls used to manage residual risks from contaminated sediment that remains on site following remediation. Residual risks for each alternative were discussed above in Section 10.2.1.1. The alternatives include varying amounts of monitoring, maintenance, and institutional controls to manage residual risks and the potential for recontamination.

The relative magnitude and importance of the post-remediation control components for the alternatives differ, primarily in relation to the potential for exposure of subsurface contaminated sediment under caps and in areas managed for natural recovery (MNR and ENR/*in situ*) and the size of the disturbance event. Information gathered during routine monitoring or in response to a large-scale disturbance (e.g., an earthquake) will be used to assess the need to replace technical components of the alternative (e.g., a cap) should the remedial action need replacement or repair. Section 10.1.1.1 discusses differences among the alternatives with respect to the potential for disturbances to increase surface sediment contaminant concentrations.

Control of Dredge Residuals

All dredging projects leave behind some level of residual contamination immediately after completion of in-water work (USACE 2008a). Dredge residuals are produced by the resettling of sediments suspended during dredging, subsequent disturbance and transport of the material as fluidized mud layers along the bottom, or material left behind (not removed from) in the dredge prism (USACE 2008a). Surface sediments in the LDW will be affected to some degree by dredge residuals following remediation. The inevitability of dredge residuals was acknowledged in the development of remedial alternatives (Section 8) with a specific assumption that dredging is followed by a thin-layer application of sand as an engineering control for dredge residuals.[10] Placement of contaminated dredged materials into an underwater CAD (Alternative 2R-CAD) would release contaminants into the water column and generate settled residuals outside of the engineered cap footprint. Residuals outside of the CAD footprint could be managed by applying a thin layer of sand.

Source Control

For FS purposes, upland source control sufficient to minimize recontamination from ongoing upland sources is assumed to occur in advance of remedy implementation. Uncontrolled sources contribute to and influence post-remediation surface sediment contaminant concentrations. In general, areas near stormwater and combined sewer overflow (CSO) outfalls have a higher potential for being recontaminated than areas that are distant from such outfalls.[11] The same can be said of areas adjacent to

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[10] Also, the post-remedy bed sediment replacement values assigned to remediated surfaces following construction were developed, in part, to account for the effects of dredge residuals.

[11] Monitoring at the Duwamish/Diagonal EAA and the Norfolk area show decreasing overall trends,

contaminated and erodible bank soils and areas near the discharge zones of contaminated groundwater. Control of upland sources of contamination to the LDW is therefore an important factor for limiting sediment recontamination. A more intractable problem to quantify and control is the immediate urban, broader regional, and even global contaminant sources and transport mechanisms (e.g., for PCBs, dioxins/furans).

Legacy compounds such as PCBs can be expected to diminish over time as a result of source control and because these contaminants are no longer being manufactured and used within the United States, although their persistence since they were banned in 1979, particularly in urban waterways, suggests that this will be a long-term process. Global use and transport of PCBs through atmospheric deposition is likely to continue to influence long-term concentrations (see Appendix J). In addition, PCBs are likely to continue to enter runoff from pre-ban construction materials like paints and caulks that remain where they were applied prior to the ban and continue to be released as they age. Other contaminants (e.g., cPAHs and phthalates) continue to be generated and released into the environment. Empirical data trends for PCBs and other contaminants in Puget Sound (Appendix J) show that recontamination is expected in urban environments. Zero discharge of any of these contaminants is neither a practicable nor achievable goal.

Technological advances or societal changes (e.g., energy use, transportation, infrastructure investment [particularly in source control], waste generation, handling and recycling) and many other possible factors will affect ongoing inputs to the LDW. Collectively, the pace and efficacy of these factors make predictions for the LDW uncertain. Monitoring programs would be used to evaluate the impact empirically. This FS anticipates that each remedial design effort will specifically address the adequacy of completed source control activities or the need for additional control of near-field sources that could impact the cleanup.

Monitoring

Long-term monitoring of sediment, fish and shellfish tissue, and surface water quality will be required regardless of the remedial alternative selected for cleanup of the LDW. Monitoring methods are considered reliable for tracking remedy performance, achievement, and maintenance of cleanup objectives. Monitoring data will also be used to assess whether and to what extent sediment recontamination is occurring, as well as where it might be coming from. In the short term, monitoring data would be used to identify the need for managing dredge residuals. Depending on the risks posed by the residuals, accumulations of residual contaminated material could trigger a need for additional actions if COC concentrations exceed RALs, as described in Section 8.2.5. This latter point is discussed further as part of the implementability criterion (Section 10.2.4).

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but continue to produce occasional exceedances of the SQS for a few contaminants.

Differences in the adequacy and reliability of long-term post-cleanup monitoring are minor among the alternatives. However, the scope and duration of monitoring differ among the alternatives. For example, the MNR and ENR/*in situ* components of the combined-technology alternatives require the collection of more project-specific operation and maintenance (O&M) monitoring data than do the removal-emphasis alternatives to achieve equivalent data quality objectives.

The entire LDW will require monitoring under all remedial alternatives. The major difference among the alternatives is whether they have large, moderate, or small surface areas that require technology-specific monitoring (i.e., cap, ENR/*in situ*, and MNR) during the O&M period (Table 10-1). For Alternative 1, technology-specific monitoring is confined to the EAAs. Alternatives 2R, 3C, 3R, 4C, 5C, and 6C have comparatively large areas to monitor, with Alternatives 2R, 3C, and 3R having the largest areas to monitor. Alternative 2R-CAD has the additional requirement to monitor the CAD within the LDW. The monitoring requirement for Alternative 4R is moderate. Alternatives 5R and 6R have lower monitoring requirements because they have the least area remediated by capping, and neither ENR/*in situ* nor MNR is used for these two alternatives.

Maintenance

After construction, the primary form of maintenance, when needed, consists of placing additional granular material (of varying types and quantities) to repair caps and ENR areas. Localized removal and disposal may also be necessary in some cases. Long-term monitoring, repair, and adaptive management responses (including contingency actions where appropriate, such as spot removals) would decrease the residual risk of post-remediation exposure to subsurface contaminated sediment.

Maintenance technologies are drawn from the same set of technologies used to develop the remedial alternatives. The primary maintenance technologies are dredging or application of granular material (e.g., to repair a cap or ENR area).[12] These activities are performed using the same marine construction technologies employed during remedy construction. These technologies are as reliable for maintenance as they are for constructing the alternatives themselves, assuming that the engineering, planning, and execution of the repairs are done with a similar level of proficiency. A review of maintenance records for completed capping projects that have been in place for more than 15 years (e.g., a number of estuarine caps constructed throughout the Puget Sound region) shows that the caps have largely been successful in containing the contaminated sediments and are performing as designed (see Sections 7.1.3.4 and 7.1.4).

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[12] In developing the remedial alternatives, a specific assumption was made that 15% of designated ENR/*in situ*, MNR, and verification monitoring areas of any given remedial alternative will require dredging as a contingency action based on remedial design sampling or subsequent monitoring data.

Alternatives emphasizing removal have a reduced level of effort for maintenance compared to alternatives emphasizing containment and natural recovery. ENR/*in situ* and MNR areas are assumed to have a higher maintenance requirement (i.e., per unit area) compared to capping. The maintenance evaluation factor is qualitatively assessed in terms of whether the remedial alternatives have large, moderate, or small surface areas to maintain (Table 10-1). Therefore, the comparison of alternatives with regard to maintenance requirements is the same as previously discussed for monitoring.

Institutional Controls

None of the alternatives are predicted to achieve natural background-based PRGs for total PCBs or dioxins/furans. Thus, remaining risks to the community from consuming resident fish and shellfish must be managed by institutional controls designed to reduce such consumption. These institutional controls are primarily seafood consumption advisories and public education and outreach programs. Alternatives 2 through 6 would require similar advisories and programs. Alternative 1 assumes continuation of the existing WDOH seafood consumption advisory but no public education and outreach programs. Dependence on these programs to reduce exposures may be more critical in the short term for alternatives with longer construction periods, because tissue concentrations and risks are expected to be elevated during construction.

The WDOH issues seafood consumption advisories, although they are not necessarily the exclusive issuing authority. EPA or Ecology may select, design, and require implementation of seafood consumption advisories like any other institutional control to help reduce exposures to hazardous substances. Advisories, in any case, are informational devices, are not enforceable against potential consumers of LDW fish and shellfish, and are generally understood to have poor compliance. Thus, enhanced public education and outreach efforts are crucial to reduce exposures through changes in behavior (e.g., encouraging consumption of migratory fish, such as salmon, which are less contaminated than resident seafood in the LDW). Part of this effort could involve conducting periodic seafood consumption surveys to identify, by population group, which seafood species are consumed and in what quantities. This information would be used to update an Institutional Controls Implementation Plan and to improve seafood consumption advisories and the associated public outreach and education programs. These education programs could be developed and administered by responsible parties with EPA or Ecology oversight and participation from local governments, Tribes, and other community stakeholders. Alternatives 2 through 6 assume the same type of advisories and programs in the long term.[13]

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[13] During construction, resident seafood tissue concentrations are expected to remain elevated. Thus, alternatives that have longer construction periods will depend to a greater degree on advisories to reduce exposures during construction than following construction when tissue concentrations and risks should be reduced.

Another important informational device is monitoring and notification of waterway users. All alternatives that leave subsurface contamination in place (particularly lower numbered and combined alternatives) require waterway users' notifications and institutional controls. The essential components of these, as developed in Section 7.2, could include:

- Reviewing U.S. Army Corps of Engineers (USACE) dredging plans and other Joint Aquatic Resource Permit Application construction permitting activities to identify any projects with the potential to compromise containment remedies (cap or CAD). EPA and Ecology would be notified during the permitting phase of any project that could affect containment remedies.[14]
- Using signs and other forms of public notice to notify waterway users of use restrictions in areas where contamination remains above levels needed to achieve cleanup objectives.
- Establishing an LDW cleanup hotline for private citizens to call or e-mail information on potential violations. EPA and Ecology would be notified of any issues, as appropriate. The agencies have the authority to require performing parties and/or violating parties to assess or correct any damage to the remedy based on this information.
- Conducting periodic vessel-based surveys, in which the vessel operator would educate potential violators about the LDW use or activity restrictions. Potential violations of use restrictions would be reported to appropriate law enforcement authorities, as well as to Ecology and EPA, if such acts are or may be criminal. Responsible parties with rights to enforce use restrictions should be obligated to enforce them, as set forth in the legal instrument that created them (e.g., Uniform Environmental Covenant Act [UECA] restrictions).

Environmental covenants would be applied to properties within the LDW by their owners where needed. Alternative 1 does not include any such covenants outside the EAAs. Alternatives that leave more contaminated sediment in place will rely more on covenants to protect against exposing subsurface contaminants (i.e., to address larger areas). Owners of LDW properties that have contamination remaining above levels needed to achieve cleanup objectives following remediation (e.g., in the subsurface) would create an environmental (generally UECA) covenant for their property. This FS assumes that a standardized UECA covenant could be developed and used for this purpose. Portions of the LDW owned by public entities, such as the Port of Seattle and

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[14] This function is currently in place in the form of a Standard Operating Procedure agreed upon between EPA and USACE, and the existing mechanism could either be funded or assumed by the responsible parties.

State of Washington, may present more complex enforcement issues for environmental covenants. In any case, alternatives with smaller active footprints and those that rely less on removal would leave more subsurface contamination and would have more area affected by covenants. Therefore, the magnitude and duration of this institutional control, and its overall importance to managing residual risk, would be greater for alternatives that emphasize capping, ENR/*in situ*, and MNR, because subsurface contamination that exceeds levels needed to achieve cleanup objectives could be exposed by mechanical disturbances caused primarily by human activity.

10.2.1.3 Uncertainty Related to Long-term Effectiveness and Permanence

There are several sources of uncertainty in the estimation of future surface sediment concentrations and risks, the most important of which were discussed in Sections 9.1.2.1 and 9.3.5. These can be grouped into those associated with predictions of surface sediment concentrations using the sediment transport model (STM) in combination with the BCM, the potential for exposure of contaminated subsurface sediment and its influence on surface sediment conditions, and estimation of risk from exposure to surface sediment concentrations (if undetected during monitoring).

Figure 10-6 summarizes results of several parameter sensitivity evaluations that were discussed earlier in the FS. The figure illustrates the potential contributions of each to the long-term model-predicted concentrations of total PCBs as compared to the base case (i.e., using mid-BCM input values). The most pronounced change from the base case result of approximately 40 µg/kg results from assuming all low or all high values for the BCM contaminant input parameters. Long-term surface sediment SWACs predicted by the BCM for all alternatives trend toward the same values, which will be influenced mostly by incoming solids from the Green/ Duwamish River. Source control is clearly an important factor in reducing long-term contaminant concentrations to the maximum extent practicable.

The BCM does not consider disturbance of subsurface contamination, however. Uncertainty is also associated with mechanisms that can disturb sediment, such as vessel scour under high power operations (see Section 10.2.1.1 and Appendix C, Part 5) and earthquakes. These processes have the potential to expose contaminated subsurface sediment that remains following remedial action.

As discussed in Section 9.3.5, predictions of future tissue contaminant concentrations and associated human health risks calculated from the SWAC estimates also have uncertainties associated with both the food web model predictions and those inherent to the human health risk estimates. For the most part, these uncertainties are consistent across alternatives. Exposure of subsurface sediment could increase contaminant concentrations in the water column and surface sediments. The degree to which such increases could increase fish and shellfish tissue PCB concentrations is difficult to predict. This uncertainty diminishes with alternatives that progressively remove or cap more sediment. While the absolute risk outcome is uncertain, the risk predictions are sufficient for comparing alternatives.

10.2.1.4 Summary of Long-term Effectiveness and Permanence

Post-remediation residual risks from surface sediment are predicted to be similar among the alternatives based on long-term model-predicted outcomes (Table 10-1), although the alternatives are predicted to take differing time periods to reach this outcome and have differing degrees of uncertainty. Active remediation alone (i.e., ignoring any contribution from natural recovery) is responsible for the majority of progress toward achieving the residual risk levels for Alternatives 2 through 6, although in different degrees. Alternatives 1, 2, 3, and 4 rely more on natural recovery (both monitored and not monitored) and thus have more uncertainty associated with: 1) the rate and effectiveness of natural recovery and 2) the potential for exposure of subsurface contamination. The uncertainty progressively diminishes in importance from lower to higher number alternatives and for those that rely more on removal than ENR/*in situ* and MNR. Alternative 5 does not rely on MNR, although it is anticipated that surface sediment contaminant concentrations will continue to decline after active remediation through natural recovery processes. Alternative 6 relies solely on active remedial technologies rather than natural recovery to further reduce surface sediment contaminant concentrations and achieve cleanup objectives.

Ultimately, with the caveats noted above, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River, resulting in similar levels of risk over time for all remedial alternatives. In the long term, the effectiveness of source control for the LDW, inputs from the Green/Duwamish River, and residual contamination remaining in the LDW after cleanup are likely to be the primary factors governing surface sediment concentrations. Alternatives 2 through 6 require monitoring, maintenance, and institutional controls, with contingency actions as necessary and periodic reviews (e.g., every 5 years) to ensure achievement of cleanup objectives. Among these alternatives, post-remediation differences in the level of effort and reliability of these control mechanisms (i.e., ability to identify and respond to events that cause recontamination) are related primarily to the magnitude of subsurface contamination remaining.

Higher numbered alternatives and removal-emphasis alternatives, in particular, remove more subsurface contaminated sediments from the LDW and thus have a lower exposure potential than alternatives emphasizing capping, ENR/*in situ*, and MNR. The risk of exposure is minimized in capped areas because caps are engineered to remain structurally stable under location-specific conditions, although it is unlikely that caps can be engineered to preclude the possibility of disruption or displacement in a major earthquake. In comparison to capped areas, residual subsurface contamination in ENR/*in situ* and MNR areas has greater potential for exposure because these technologies are not engineered to completely isolate subsurface contaminated sediments. Also, alternatives that rely on MNR to passively remediate larger areas (e.g., Alternatives 1 and 2) are the most dependent on model-predicted outcomes and generally take a longer time to reduce risks. They also would potentially require more maintenance or contingency actions.

As shown in Table 10-1, Alternatives 1 and 2R-CAD have the lowest relative rank (★) for long-term effectiveness and permanence. Alternative 1 does not provide reliable controls and leaves the largest amount of subsurface contamination in place. Alternative 2R-CAD requires long-term maintenance of a CAD located within the LDW and leaves the next largest amount of subsurface contamination in place. The removal-emphasis alternatives, 2R through 6R, have progressively increasing relative ranks (★★ to ★★★★★) because they progressively leave less subsurface contamination in place that could be exposed by vessel scour or earthquakes, have fewer restrictive controls, and require less maintenance. Alternatives 5R/5R-Treatment and 6R rank the highest (★★★★★) because they leave the least amount of subsurface contamination in the LDW that could be exposed and they also require the least amount of monitoring and maintenance. Alternatives 4R, 4C, 5C, and 6C (★★★★) rank below Alternatives 5R and 6R, because they leave an incrementally larger area managed by ENR/*in situ* and MNR (and thus more subsurface contamination), and have greater monitoring and maintenance requirements. Alternatives 2R (★★), 3C, and 3R (★★★) rank low to moderate because they have even larger areas managed by ENR/*in situ* and MNR. Monitoring and maintenance requirements are greater in general for the combined-technology alternatives than for the corresponding removal-emphasis alternatives throughout the construction and post-construction phases.

10.2.2 Reduction in Toxicity, Mobility, or Volume through Treatment

This criterion assesses the degree to which site media are treated to reduce permanently and significantly the toxicity, mobility, or volume of site contaminants. The NCP specifically applies this criterion to cleanups involving principal threat wastes. Most of the contaminated sediments within the LDW are likely low-level threat wastes (Section 9.1.2.2).

Alternative 5R-Treatment is the only alternative that includes an *ex situ* treatment technology (soil washing) that can be employed in the uplands to treat dredged sediment. Soil washing decreases the volume of dredged sediment containing contaminants, but does not decrease the actual mass of contaminants. The residuals from soil washing are distributed into the separated fine-grained material containing the majority of the contaminants; the treated sand fraction contains low residual contaminant concentrations; and a large amount of wastewater contains low particulate and dissolved contaminant concentrations. The treated sand fraction would require testing to quantify residual contaminant concentrations and to assess its suitability for potential beneficial reuse. The process wastewater would require treatment to reduce residual contaminant concentrations prior to discharge back into the LDW. Depending on how these materials are handled, residual contaminants may pose a different exposure potential to human health and the environment.

For FS purposes, 50% of the total ENR area for the combined-technology alternatives is assumed to undergo some form of *in situ* treatment. *In situ* treatment, using activated carbon or other sequestering agents, lowers contaminant mobility and hence contaminant toxicity and availability to biological receptors (i.e., bioavailability). The alternatives with the greatest ENR area that could include *in situ* treatment are Alternatives 5C and 6C. Similar agents could also be incorporated into caps to reduce contaminant bioavailability. For comparison, the reduction of mobility achieved by *in situ* treatment is assumed to be proportional to the area that undergoes treatment.

Based on these considerations, the removal-emphasis alternatives, except for Alternative 5R-Treatment, have low ranks (★) because they don't treat contaminated sediment. Alternative 5R-Treatment ranks highest (★★★★) because it is the only alternative that removes and treats sediment (via soil washing). However, while potentially reducing the volume of sediment that must otherwise be disposed of in a landfill, the treatment does not reduce either the contaminant mass or toxicity. The combined alternatives receive intermediate ranks (either ★★ or ★★★) due to the relative contribution (area) of *in situ* treatment.

10.2.3 Short-term Effectiveness

This evaluation criterion addresses the effects of the alternatives during construction and any additional period of natural recovery until cleanup objectives are achieved. Under this criterion, alternatives are evaluated with respect to their effects on human health and the environment during construction of the remedial action, including impacts on the community, workers, and the environment. This criterion also considers the time predicted for each alternative to meet these objectives.

10.2.3.1 Protection of Workers and Community during Construction

This aspect of short-term effectiveness addresses risks from construction of the alternatives. Short-term impacts to both workers and the community are largely proportional to the length of the construction period (Table 10-1); thus, longer construction periods are associated with greater relative impacts.

For workers, activities on the construction job site (from operation of heavy equipment) pose the greatest risk of physical injury. Risk to workers from exposure to site-related contaminants is generally low and is managed through established health and safety requirements for hazardous materials site work. Nevertheless, in both cases, the potential for exposure and injury increases in proportion to the duration of construction. Diver-operated dredging, which may be used to address under-pier areas for the removal-emphasis alternatives, poses unique hazards to workers.

Similarly, impacts to the community increase with the amount and duration of construction. The potential for physical injury is primarily a function of accidents associated with transport of contaminated sediment and clean import material to and from the site. This potential is related to the anticipated amount of truck and train traffic. Table 10-3 summarizes estimates of truck and train miles under each alternative. Truck miles are estimated according to the amount of dredged material generated, recognizing that the configuration and location of potential transloading facilities will affect the truck miles. Train miles are estimated based on an assumed round trip of 568 miles to the landfill. Transportation-related impacts would be managed in part with traffic control plans developed during remedial design.

Other community impacts from transportation and heavy equipment operations are air emissions (e.g., PM_{10}, a respiratory irritant), noise, and nighttime illumination of operations. Also, consumption of resident seafood that occurs during construction, despite the current WDOH advisory against consuming any such seafood, presents short-term risks to the community because concentrations of COCs in resident seafood are likely to be higher during construction as a result of contaminated sediment resuspension and biological uptake.

Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 5C have relatively short construction periods (3 to 7 years) and therefore lower short-term risks to workers and the community. Alternative 4R has a significantly longer construction period (11 years) and therefore moderate impacts for this factor. Alternatives 5R/5R-Treatment, 6C, and 6R have the longest construction periods (17, 16, and 42 years respectively), the most dredging, and thus, particularly Alternative 6R, the highest short-term impacts to the community and workers.

10.2.3.2 Protection of the Environment during Construction

Cleaning up the LDW will have environmental impacts that can be grouped into the categories of atmospheric emissions, ecological impacts, and resource consumption. In general, longer duration alternatives and those that emphasize removal have greater short-term impacts in all of these categories than similarly scaled alternatives that emphasize containment (see Table 10-3).

Larger actively remediated footprints increase the areal extent of short-term disturbances to the existing benthic community and other resident aquatic life. During the construction phase of removal-emphasis alternatives, concentrations of bioaccumulative contaminants (e.g., total PCBs) are likely to increase in the tissues of aquatic organisms, as well as in the organisms that feed on them such as river otters. Finally, damage or destruction of the benthic community would reduce food sources for other organisms until the aquatic habitat areas are restored and their ecological functions reestablished.

Although BMPs (e.g., controls on dredge operations) will be used to minimize resuspension of contaminated sediment during dredging, some releases are an inevitable short-term impact. Resuspended material would resettle primarily on the dredged surface and in areas just outside of the dredge footprint (near-field). Fine-grained material that is slow to resettle could be transported well beyond the dredge operating area (far-field). Dredging also releases contaminants into the water column.

All of these impacts from resuspension increase relative to the amount of material dredged in each alternative. Adequate controls to manage dredge residuals that are deposited in the near-field (i.e., thin-layer sand placement) can be included in engineering design requirements and are an assumed element of the remedial alternatives developed in this FS. Removal-emphasis alternatives require more dredge residuals management actions than the combined technology alternatives. The estimated PCB exports from the LDW associated with dredging range from approximately 5 kg for Alternative 3C up to 17.5 kg for Alternative 6R (Appendix M, Part 2). These exports are up to several-fold greater than the PCB exports from the LDW associated with natural resuspension/erosion of bed-source sediments over the same period (approximately 3 kg or less). In contrast, the predicted PCB export from the LDW associated with solids incoming from the Green/Duwamish River that pass through the LDW without depositing over the course of the construction period exceeds the exports associated with dredging. For Alternative 3C, predicted PCB export from the Green/Duwamish River is 11 kg over a 6-year construction period, and for Alternative 6R, it is 155 kg over a 42-year construction period.

Longer construction time frames increase air emissions and noise. Air emissions include components with local environmental impacts (e.g., sulfur oxides, nitrogen oxides); those that can cause respiratory problems (PM_{10}); and those with global impacts (carbon dioxide and other greenhouse gases). The primary source of air emissions is fuel consumption during construction activities. Transportation accounts for the largest portion of the emissions. The FS assumes that rail and barge transport will be used to the maximum extent possible. This is the most efficient way to reduce air emissions and will significantly reduce project air emissions as compared to long-haul trucking. Additional incremental reductions in air emissions may be possible by using BMPs during construction. Examples of BMPs that can be used to reduce emissions (e.g., use of biodiesel or low-sulfur fuels, use of rail versus truck transport) are discussed in Appendix L.

The remedial alternatives consume quarry materials (sand, gravel) to satisfy the varying requirements for capping, backfilling (for habitat restoration), ENR/*in situ*, and management of dredge residuals (Table 10-3). Removal-emphasis alternatives consume similar amounts of material as their combined technology counterparts, because the backfill requirements following dredging (i.e., to restore the pre-existing grade in shallow subtidal and intertidal areas) are considerable. Alternative 2R-CAD has a relatively high material demand for construction of the CAD cap. Alternative 6R has by far the greatest material demand, primarily because the remediation footprint is expanded into AOPC 2.

All of the alternatives dredge some volume of material and therefore consume landfill space (Table 10-3). Alternatives 2R-CAD and 5R-Treatment reduce utilization of landfill capacity to the extent that:

- The CAD capacity reduces the volume of dredged material requiring landfill disposal.
- A beneficial use can be identified for the treated coarse-grained material resulting from the soil washing component of Alternative 5R-Treatment.

The removal-emphasis alternatives consume more landfill space than their combined technology counterparts and alternatives with larger active footprints place a higher demand on landfill space.

Alternatives 5R, 6C, and 6R take the longest to construct, consume the greatest amount of natural resources, generate the most transportation-related impacts, produce the most emissions, create the longest periods of elevated bioaccumulation and exposure in resident species, disturb the largest surface area of benthic community, and destroy areas of higher value habitat (i.e., shallower than -10 ft MLLW) that require restoration and time to regain ecological functions. These alternatives rank relatively low because the short-term community and environmental impacts last for a longer time period compared to the other alternatives. At the other end of the spectrum, Alternatives 1, 2R, 2R-CAD, and 3C rank relatively high because the community and environmental impacts last for a much shorter time. Between these are Alternatives 3R, 4R, 4C, and 5C, all of which have a moderate ranking for short-term community and environmental impacts.

10.2.3.3 Time to Achieve Cleanup Objectives

Table 10-1 and Figure 10-4 present the predicted times at which the alternatives achieve cleanup objectives based on the metrics defined previously (see Section 9.1.2.3).

Some comparative observations from Figure 10-4 are as follows:

- **RAO 1**: Because no alternative achieves the RAO 1 PRGs for total PCBs and dioxins/furans, Figure 10-4 charts instead the time to achieve two human health risk thresholds and the long-term model-predicted total PCB and dioxin/furan concentrations in surface sediments LDW-wide. These seafood consumption risk estimates do not reflect any of the incremental benefits of using *in situ* treatment to reduce contaminant bioavailability. Remedial construction for any cleanup in the LDW is expected to cause elevated contaminant concentrations in resident fish and shellfish tissue until after active remediation is complete. Estimated excess cancer risks associated with total PCBs in resident seafood were calculated only after construction is completed. Alternatives 1 through 5 require a period of natural recovery to reach the long-term model-predicted SWAC for total PCBs (about 40 to 50 µg/kg dw). (Note: A site-wide institutional controls program is included in Alternatives 2 through 6, but not in Alternative 1, to manage residual seafood consumption risks).

- **RAO 2**: Alternatives 3 through 6 achieve acceptable direct contact risks through engineering controls within 3 to 6 years. Alternatives 1 and 2 rely to varying degrees on natural recovery and are predicted to require 25 and 19 years, respectively, to reduce direct contact risks to acceptable levels (see Section 10.1.1.1 for discussion of which PRGs are achieved).

- **RAO 3**: Alternatives 2R/2R-CAD, 3C, and 3R are predicted to achieve the SQS in 14, 8, and 11 years respectively, and all within 10 years after construction through MNR. Alternatives 4 through 6 achieve the SQS during or at the end of construction (6 or 11 years after construction begins for the combined-technology and removal-emphasis alternatives). Alternative 1 is predicted to achieve the SQS through natural recovery processes about 20 years after construction of the EAAs. Alternatives 4C, 5C, and 6C are predicted to achieve the SQS in the shortest time.

- **RAO 4**: The RAO 4 PRG is predicted to be achieved by Alternatives 2 through 6 at the end of construction. Although surface sediment SWACs are predicted to be reduced below the PRG before the end of construction, resident fish and shellfish tissue contaminant concentrations are likely to remain elevated during construction. Therefore, alternatives with shorter construction periods are predicted to achieve RAO 4 faster. Alternative 1 is predicted to require another 5 years following completion of the EAAs to achieve cleanup objectives for RAO 4 through natural recovery.

The combined-technology alternatives have the shortest construction periods and achieve cleanup objectives for all RAOs in the shortest time frames (16 to 21 years). Alternatives 2R, 3R, 4R, and 5R take moderately longer to achieve cleanup objectives (21 to 24 years). Alternative 6R takes the longest time, 42 years, to achieve cleanup objectives for all RAOs.

10.2.3.4 Uncertainty Related to Short-term Effectiveness

Natural recovery predictions are a source of uncertainty influencing predictions of the time to achieve cleanup objectives (see Section 9.3.5). Therefore, uncertainty in the time to achieve cleanup objectives is higher for alternatives that rely more on natural recovery (including MNR), especially in Recovery Category 1 areas where scour is predicted (Alternatives 1 and 2). The actual contaminant concentrations in surface sediment that will be achieved and the time it will take to reach them are difficult to predict with a high degree of certainty.

The rates of construction and sequencing of remedial actions are other uncertainty factors that influence the time to achieve cleanup objectives, as discussed below. The basis for estimating the years of construction for each alternative was described in Section 8 and Appendix I. If the construction rate could be increased appreciably from that assumed for this FS, the effect on time to achieve all cleanup objectives would be most pronounced for alternatives that are designed to rely predominantly on active remediation alone (e.g., Alternatives 5R and 6R). Faster construction would have a negligible effect on the time to achieve all cleanup objectives for alternatives that require additional time beyond construction to reach long-term risk-driver concentrations via natural recovery (e.g., Alternatives 2, 3, and 4).

Another source of uncertainty stems from how the overall cleanup project is sequenced. Sequencing assumptions made for the BCM framework used in the FS may not be realized in practice given the numerous factors that will affect individual project time lines. To explore the effect of alternative sequencing on future contaminant concentrations and risk reduction, a simple upstream to downstream remediation sequence, which eliminates the hot-spot prioritization aspect inherent to the BCM framework, was evaluated using Alternative 6R. This evaluation extended the time to reach the long-term model-predicted range of surface sediment concentrations by approximately 5 years (see Table 10-4 and Figure 10-6) and produced a slightly higher site-wide total PCB SWAC at the end of construction. This suggests that the net effect would be slightly higher SWACs and a longer time to achieve cleanup objectives, if the sequencing of remedial actions is not optimized from highest to lowest concentrations. Also, if the worst areas are not prioritized first, then some recontamination associated with construction can be expected in areas that have already been remediated.

10.2.3.5 Summary of Short-term Effectiveness

Alternatives with longer construction times present proportionately larger risks to workers, the community, and the environment. Longer construction periods increase equipment and vehicle emissions, noise, and other resource use. Larger actively remediated footprints increase the short-term disturbance of the existing benthic community and other resident aquatic life and generate more releases of bioavailable contaminants over a longer period of time. However, risks associated with construction must be balanced against the time to achieve cleanup objectives for this criterion.

As shown in Tables 10-1 and 10-3, Alternative 1 has a low rank (⋆) because, although it has no impacts associated with construction, it has the longest predicted time frame (other than Alternative 6R) to reach cleanup objectives. Alternatives 2R and 2R-CAD rank low (⋆⋆) for short-term effectiveness, primarily because of their long times to achieve cleanup objectives attributable to their primary reliance on natural recovery. Alternatives 5R, 5R-Treatment, 6C, and 6R also rank low (⋆ or ⋆⋆) because of their high short-term impacts and relatively long times to achieve cleanup objectives that stem from the long construction periods and the persistence of elevated fish and shellfish tissue contaminant concentrations during construction. Alternatives 3C, 4C, and 5C are ranked relatively high (⋆⋆⋆⋆), because of their shorter construction periods, comparatively lower construction-related environmental impacts, and shorter times to achieve cleanup objectives. Alternatives 3R and 4R have a moderate ranking (⋆⋆⋆) that results from moderate construction periods and moderate short-term impacts from dredging.

10.2.4 Implementability

Technical feasibility, administrative feasibility, and availability of services and materials are factors considered under this criterion. This implementability evaluation focuses primarily on the first two factors because, with the exception of Alternative 5R-Treatment, the alternatives use the same types of technologies or the same types of equipment and methods, all of which are available and for which expertise exists in the Puget Sound region.

10.2.4.1 Technical and Administrative Implementability during Construction

In general, the potential for technical problems and schedule delays increases in direct proportion to the duration, complexity, and amount of active remediation. Alternatives with more stringent (i.e., lower) RALs require more active remediation and are therefore more complex, have longer construction periods, and require more administrative coordination than do alternatives that have less stringent or higher RALs, less active remediation, and shorter construction periods. Alternatives with shorter and less complex construction are easier to implement, both technically and administratively (e.g., coordination with agencies), and have less potential for technical problems leading to schedule delays. For this reason, alternatives with shorter construction periods are rated higher for implementability in Table 10-1. Similarly, the amount of dredge residuals increases as RALs decrease. This would require additional dredging passes or would expand the geographic extent of residuals management. In addition, alternatives with the lowest RALs (Alternatives 5C/5R and 6C/6R) have a greater potential for triggering additional actions if source control is inadequate and portions of the LDW are recontaminated to levels that exceed RALs.

The CAD component of Alternative 2R-CAD would be administratively challenging from the standpoint of locating, using, and maintaining one or more CAD facilities. Implementing CAD will involve obtaining permission from the landowner; sequencing remedial projects for effective CAD use; potential disruption of navigation and tribal fisheries throughout construction, filling, and closure; obtaining agreements among multiple parties for CAD use; costs; maintenance; and liability.

The soil washing component of Alternative 5R-Treatment also has technical and administrative challenges associated with locating and perhaps permitting an upland soil washing facility. Treatability studies would be required to verify the suitability of soil washing as a viable treatment technology. Further, the ability to reuse the treated cleaner sand fraction of the sediment is not assured.

10.2.4.2 Technical and Administrative Implementability after Construction

The technology reliability and relative ease of undertaking additional remedial actions after construction of the remedial alternatives are also important to consider in the comparative evaluation of alternatives. Alternatives that rely less on dredging and capping (i.e., more on ENR/*in situ* and MNR) to achieve cleanup objectives have a higher potential for requiring contingency actions in the future. This can result in an increased technical and administrative burden associated with: 1) evaluating monitoring data over time; 2) considering the need for contingency actions if cleanup levels are not achieved in the predicted time frame; and 3) implementing contingency actions. In this context, alternatives that rely to a greater extent on active construction to achieve cleanup objectives are more favorable.

The need for additional actions after construction could result from monitoring data that show inadequate cleanup performance, particularly in areas undergoing natural recovery, or as a result of contaminated subsurface sediment being exposed. Thus, alternatives with higher RALs and larger areas that undergo remediation by ENR/*in situ* or MNR have a higher potential for requiring additional actions. The degree to which the remedial alternatives rely on natural recovery can provide insight on the potential magnitude and difficulty associated with additional actions.[15] As discussed earlier for Adequacy and Reliability of Controls (Section 10.2.1.2), Table 10-2 and Figures 10-1a through 10-1d show predicted site-wide SWACs for the four human health risk drivers at the end of construction for Alternatives 2 through 6 and for the three risk exposure areas (site-wide [netfishing], clamming, and beach play areas), ignoring any contribution from natural recovery. Incremental contributions to SWAC reduction are shown for cleanup of the EAAs, active remediation alone, modeled natural recovery during the construction period, and lastly, recovery from the end of construction through the end of the model period (45 years). The trends illustrated in Figures 10-1a through 10-1d and 10-2 suggest that the potential for future remedial actions and associated difficulties of undertaking such actions may be relatively low and diminish progressively from the smaller active remedial footprints to the larger active remedial footprints.

10.2.4.3 Summary of Implementability

Alternatives 5R-Treatment and 6R receive the lowest rank (★) for implementability relative to the other alternatives. Alternative 5R-Treatment is ranked low relative to the other alternatives because of the administrative and technical difficulties associated with the soil washing technology as well as the long construction time and complex scope. Alternative 6R also is ranked low because it has the longest construction period and largest construction scope. The administrative issues of implementing a CAD are responsible for the low ranking of Alternative 2R-CAD (★★). Alternatives 5R and 6C also rank low (★★) because of longer construction periods, larger and more complex project scopes, and potential for low RALs triggering significant additional actions because of recontamination. Alternatives 2R, 3C, and 3R receive a moderate ranking (★★★) because they are technically reliable and administratively feasible; however, the relatively large MNR and ENR/*in situ* areas may require additional remedial actions based on performance results. Alternatives 4C, 4R, and 5C are highly implementable

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[15] A specific assumption was made in the development of remedial alternatives that 15% of designated ENR/*in situ*, MNR, and verification monitoring areas of any given remedial alternative will require dredging as a contingency action based on remedial design sampling or subsequent monitoring data.

(★★★★) because they are technically reliable and administratively feasible, and their large actively remediated surface areas equate to a low potential for triggering additional actions. Alternative 1 is given the highest implementability rank (★★★★) because it has no construction elements and no provisions to trigger contingency actions.

10.2.5 Costs

This assessment evaluates the capital and operation, maintenance, and monitoring costs of each alternative. Detailed cost estimates for each remedial alternative are presented in Appendix I, and summarized in Figure 10-7. These estimated costs include assumptions for long-term monitoring, institutional controls, and contingency actions. Contingency action costs and the separate 35% contingency factor applied to capital costs (see Appendix I) are assumed to cover a range of assessment and repair work that might be needed; however, the amount of repair needed following a major disruptive event such as an earthquake is unknown. The estimates do not include anticipated costs for upland remediation or source control efforts, nor do they include the estimated $95 million for in-water design and construction for the EAAs. The estimated cost for Alternative 1 is approximately $9 million for site-wide monitoring, agency oversight, and reporting. The EAA cleanup costs are not included in the estimated costs for Alternatives 2 through 6 because the EAA actions are not part of the alternatives being evaluated in this FS. Total project costs for the remedial alternatives are reported as net present values and are assumed to be accurate within the range of -30%/+50%.

As discussed in Appendix I, the costs are very sensitive to the estimated dredge removal volume. Modest changes in dredge design factors (e.g., dredge footprint, depth of contamination, depth required for navigation clearance, side-slope designs) can result in significant changes to dredge volumes, which would significantly impact costs. Other factors, such as fuel and labor, can also significantly impact costs. The FS cost estimates are best estimates expressed on a net present value basis that are based on present day costs projected into the future; however, future economic conditions are difficult to predict.

Another consideration is the degree to which natural recovery of sediments may occur prior to implementing the selected remedy. This may reduce the size of the remediation footprints and therefore costs relative to the acre and volume estimates presented in this FS. A cost sensitivity analysis (low and high estimates around the best estimate presented in the FS) is included in Appendix I and includes many of the uncertainty factors listed above.

Alternative 6R has the highest base case cost ($810 million) and therefore ranks lowest for this criterion (★). Alternatives 4R, 5R, 5R-Treatment, and 6C are assigned the next lowest rank (★★).[16] Base case costs for these alternatives range from approximately

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[16] Alternative 5R-Treatment has the additional cost uncertainty associated with whether a beneficial use can be identified for the treated material.

$360 to $530 million. Alternatives 3R, 4C, and 5C receive a three-star ranking with costs from approximately $260 to $290 million. Alternatives 2R, 2R-CAD, and 3C are next, with costs of approximately $200 million to $220 million (★★★★). Alternative 1 at $9 million (★★★★★) has the highest ranking for cost.

10.3 Modifying Criteria – State/Tribal and Community Acceptance

Ecology co-issued the RI/FS Order and has overseen its implementation with EPA. The FS anticipates that Ecology will work with EPA to select the preferred remedy in the Proposed Plan and will similarly work with EPA on the ROD. The community acceptance criterion refers to acceptance of EPA's preferred alternative in the Proposed Plan, rather than the FS. However, EPA and Ecology have engaged with the tribes and community to review and comment on the RI/FS documents. The framework for tribal and community involvement is described in a community involvement plan for the LDW.[17] A summary of the tribal and community involvement in the FS process and major comments received on the draft FS is provided in Section 9.1.3.

EPA will evaluate state, tribal, and community acceptance of the cleanup remedy in the ROD following the public comment period on EPA's Proposed Plan. In the interim, community and stakeholder groups will continue to be engaged by EPA and Ecology during quarterly stakeholder meetings and other forums. Therefore, Table 10-1 does not include relative alternative ranks for the State/Tribal and Community Acceptance criteria.

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[17] EPA and Ecology developed and published a community involvement plan in October 2002 for the Lower Duwamish Waterway Site.

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives[a]

				Remedial Alternative											
Evaluation Criteria				1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Overall Protection of Human Health and the Environment	Long-term Effectiveness and Permanence	Magnitude and Type of Residual Risk	RAO 1: Residual seafood consumption risk from total PCBs – Adult and Child Tribal RME[b,c]	All alternatives are predicted to achieve excess cancer risks of 2×10^{-4} and 3×10^{-5} for the Adult Tribal and Child Tribal RMEs, respectively. They are also predicted to achieve non-cancer risk of HQ = 4 to 5 and HQ = 9 to 10 for the Adult Tribal and Child Tribal RMEs, respectively. For the API RME scenario, total PCB risks are predicted to be 5×10^{-5} excess cancer risk and HQ = 3 for non-cancer risk. Times required to reach lowest predicted surface sediment concentrations vary, as does the degree of uncertainty inherent in these model predictions. Model uncertainty decreases as alternatives rely less on natural recovery. No alternative is predicted to achieve 1×10^{-5} total excess cancer risk, 1×10^{-6} individual carcinogen risk, or HI of 1 as required by MTCA.											
			RAO 2: Residual direct contact excess cancer risk[d]	May not achieve RAO 2 cleanup objectives because no active remediation in clamming and beach play areas	Following construction, Alternatives 2 through 6 are predicted to achieve: 1) a total excess cancer risk of $< 1 \times 10^{-5}$; 2) excess cancer risks for total PCBs, cPAHs, and dioxins/furans considered individually less than or equal to 1×10^{-6}, 3) arsenic reaches the long-term model-predicted concentration range (associated with an excess cancer risk range between 1×10^{-5} and 1×10^{-6}), and 4) non-cancer hazard quotients for each risk-driver are less than or equal to 1.0 in netfishing, clamming, and beach play areas.										
			RAO 3: Benthic invertebrate toxicity	All alternatives are predicted to achieve the SQS in varying time frames with varying degrees of certainty. Alternative 1 may require more than 10 years of natural recovery to achieve the SQS.											
			RAO 4: Risk from consumption of seafood by the river otter	Alternatives 2 through 6 are predicted to achieve HQ<1 following construction. Alternative 1 requires a period of natural recovery to achieve HQ<1.											
		Adequacy and Reliability of Controls	Achievement of cleanup objectives for all RAOs	May not achieve all cleanup objectives.	Alternatives 2 through 5 rely on varying combinations of natural recovery, engineering and institutional controls to achieve protectiveness. Alternative 6 relies on engineering and institutional controls only.										
			Types of engineering controls used to achieve cleanup objectives (numeric values are in units of acres)	Uses no engineering controls outside of EAAs.	Least use of dredging (29) and capping (3) and most MNR. No ENR/*in situ*.	Same as Alt 2R, but adds long-term management of in-waterway CAD.	Same use of dredging (29) and more capping (19) than Alt 2. Less MNR. 10 acres ENR/*in situ*.	More dredging (50) and less capping (8) than Alt 3C. Same MNR as Alt 3C. No ENR/*in situ*.	More dredging (50) and capping (41) than Alt 3C. Less MNR. 16 acres ENR/*in situ*.	More dredging (93) and less capping (14) than Alt 4C. Same MNR as Alt 4C. No ENR/*in situ*.	More dredging (57) and capping (47) than Alt 4C. No MNR. 53 acres ENR/*in situ.*	More dredging (143) and less capping (14) than Alt 5C. No ENR/*in situ* or MNR.	Same as Alt 5R. Adds *ex situ* treatment.	More dredging (108) and capping (93) than Alt 5C. No MNR.101 acres ENR/*in situ*.	Most dredging (274). 28 acres of capping. No ENR/*in situ* or MNR.
			Institutional Controls	No proprietary controls, education, outreach or waterway user notification programs	Seafood consumption advisories are required to manage residual seafood consumption risks. Proprietary controls (e.g., environmental covenants) are also needed to manage residual contamination left in place. The number and importance of these proprietary controls progressively diminishes as the amount of dredging increases because the amount of contamination left in place is correspondingly diminished.										
			Monitoring and maintenance (area in acres remediated by (capping) / (ENR/*in situ*)	Only EAAs monitored and maintained.	3/0	3/0	19/10	8/0	41/16	14/0	47/53	14/0	14/0	93/101	28/0
			Monitoring (area in acres remediated by MNR)		19 (MNR10) 106 (MNR20)	19 (MNR10) 106 (MNR20)	99 (MNR20)	99 (MNR20)	50 (MNR10)	50 (MNR10)	0	0	0	0	0
	Short-term Effectiveness			No short-term impacts because no construction. Longest time to achieve cleanup objectives. Highest natural recovery prediction uncertainty.	Low short-term impacts during construction. Long time to achieve cleanup objectives. High natural recovery prediction uncertainty.		Low short-term impacts during construction and moderate time to achieve cleanup objectives. Moderate natural recovery prediction uncertainty.		Moderate short-term impacts during construction and moderate time to achieve cleanup objectives. Low natural recovery prediction uncertainty.	High short-term impacts during construction and moderate time to achieve cleanup objectives. Low natural recovery prediction uncertainty.	Moderate short-term impacts during construction and moderate time to achieve cleanup objectives. Very low natural recovery prediction uncertainty.	High short-term impacts during construction and long time to achieve cleanup objectives. Very low natural recovery prediction uncertainty.		High short-term impacts during construction and long time to achieve cleanup objectives. Very low natural recovery prediction uncertainty.	
	Summary of Overall Protection of Human Health and the Environment			Does not provide adequate overall protection to human health and the environment.	All alternatives achieve overall protection of human health and the environment in varying time frames and degrees of certainty based on varying reliance on natural recovery. All require institutional controls to varying degrees to fully achieve protectiveness. Longer construction periods result in proportionately greater short-term impacts. Dredging or capping a larger surface area has a lower potential for subsurface contamination to be exposed by natural or mechanical disturbances (e.g., erosion, vessel scour, earthquakes). The potential for subsurface contaminated sediment to be exposed diminishes as more contaminated sediment is dredged. Exposure of subsurface contaminated sediment is less of a concern for maintaining PRGs based on SWACs than for maintaining PRGs that are based on point concentrations (e.g., the SMS COCs for RAO 3).										
Comply with ARARs	Compliance with ARARs	MTCA	Human Health Seafood Consumption	Not expected to comply.	EPA may choose to issue an ARAR waiver should the Agency determine that the final remedy does not meet the MTCA requirement to achieve natural background where RBTCs are more stringent than background.										
			Human Health Direct Contact	May not comply.	Alternatives 2 through 6 are predicted to achieve the total direct contact standard of 1×10^{-5} excess cancer risk and non-cancer HI of 1. They are predicted to achieve individual hazardous substance excess cancer risk thresholds of 1×10^{-6} for total PCBs and dioxins/furans. All exposure areas are predicted to be between 1×10^{-5} and 1×10^{-6} excess cancer risk for arsenic, and above the natural background-based PRG for arsenic. All exposure areas are predicted to be at or below the cPAH excess cancer risk of 1×10^{-6} except for Beach 3 where predictions are influenced by a lateral source.										

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives (continued)

Evaluation Criteria				Remedial Alternative											
				1	**2R**	**2R-CAD**	**3C**	**3R**	**4C**	**4R**	**5C**	**5R**	**5R-T**	**6C**	**6R**
Comply with ARARs *(continued)*	Compliance with ARARs		Sediment Management Standards (for RAO 3)	Alternative 1 is predicted to achieve the SQS 20 years after completion of EAAs.	Alternatives 2R and 2R-CAD are predicted (high model uncertainty) to achieve the SQS approximately 10 years after construction.		Alternatives 3C and 3R are predicted to achieve the SQS approximately 5 years after construction.		Alternatives 4 through 6 are predicted to achieve the SQS immediately following construction.						
			Water Quality Standards	No active remedial measures are feasible or anticipated expressly for the water column, although significant water quality improvements are anticipated from sediment remediation and source control. It is not anticipated that any alternative can comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain. ARAR waivers for some criteria and standards will be needed for a final remedy.											
	Summary of ARARs			Not expected to comply.	No alternatives are expected to comply with all surface water quality standards, or with all natural background sediment standards required under MTCA (for risk-based RBTCs below background). Surface water quality and MTCA ARAR waivers, the need for which varies among alternatives, will be required at or before completion of the remedial action.										
Achieve Threshold Requirements				No	Alternatives likely require one or more ARAR waivers to meet threshold criteria.										
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)		Total dredge area outside of EAAs (acres)	n/a	29	29	29	50	50	93	57	143	143	108	274
			Total cap, partial dredge/cap	n/a	3	3 (+ 23 acres of CAD)	19	8	41	14	47	14	14	93	28
			Total ENR/*in situ* area (in Category 1/ Categories 2 & 3 combined; acres) $^{e, f}$	n/a	0/0	0/0	0/10	0/0	0/16	0/0	0/53	0/0	0/0	0/101	0/0
			Total MNR, VM, and AOPC 2 area (in Category 1/Categories 2 & 3 combined; acres) $^{e, f}$	n/a	47/223	47/223	43/201	43/201	26/169	26/169	23/122	23/122	23/122	0/0	0/0
			Post-construction number of core stations remaining >CSL in the FS dataset (under caps / all other locations)^{g}	70 outside of EAAs (25 in Category 1)	0/37	0/37	15/32	1/24	18/26	1/14	20/22	1/5	1/5	27/8	1/0
			Potential for Exposing Remaining Subsurface Contamination	Largest amount of subsurface contamination and greatest potential for increases in long-term SWACs.	Moderate potential for exposure and high potential for increases in long-term SWACs.	Same as for Alt 2R plus: majority of contaminated sediment remains on site in CAD.	Moderate potential for exposure and moderate potential to affect long-term SWACs.	Same as for Alt 3C but lower amount of residual subsurface contamination than Alt 3C.	Lower potential for exposure than Alt 3C and 3R and moderate potential to affect long-term SWACs	Lower amount of residual subsurface contamination than Alt 4C and low potential to affect long-term SWACs.	Lower potential for exposure than Alt 4C or 4R, and low potential to affect long-term SWACs.	Lower amount of residual subsurface contamination than Alt 5C and low potential to affect long-term SWACs.	Same as for Alt 5R.	Low potential for exposure and low potential to affect long-term SWACs.	Least amount of residual subsurface contamination. Very low potential for exposure and very low potential to affect long-term SWACs.
	Adequacy and Reliability of Controls ^{h}		Relative amount of monitoring and maintenance required (based on total cap, ENR/*in situ* and MNR area).	Low – only EAAs monitored	Large area (128 acres)	Large area (128 + 23 acres of CAD)	Large area (128 acres)	Large area (107 acres)	Large area (107 acres)	Moderate area (64 acres)	Large area (100 acres)	Small area (14 acres)		Large area (194 acres)^{i}	Small area (28 acres)
		Magnitude and Duration of Institutional Controls	Monitoring and notification of waterway users (based on total cap, ENR, and MNR area; acres)	No institutional controls	Same relative rankings as for monitoring and maintenance (see above).										
			Seafood consumption advisories, public outreach, and education	No outreach or education	Similar seafood consumption advisories, public outreach, and education are required for all alternatives.										
			Summary	No institutional controls	The need for monitoring and maintenance is higher for combined alternatives and less for removal alternatives with the same RALs, and is greater for alternatives that rely more on natural recovery. Similar seafood consumption advisories and public outreach and education programs are required for all alternatives.										
	Summary			Low – only EAAs remediated. Not expected to achieve all RAOs.	Combined-technology alternatives as compared with removal-emphasis alternatives, and lower numbered alternatives leave a greater amount of contaminated subsurface sediment in place. They also have greater monitoring and maintenance requirements. Monitoring, maintenance, and ICs in varying degrees and/or durations are considered adequate and reliable for all alternatives.										
	Relative ranking (★= Lowest for long-term effectiveness and permanence)			★	★★	★	★★★	★★★	★★★★	★★★★	★★★★	★★★★★	★★★★★	★★★★	★★★★★

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives (continued)

Evaluation Criteria			Remedial Alternative											
			1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Reduction of Toxicity, Mobility, or Volume through Treatment	*Ex situ* treatment of dredged material		None	None	None	None	None	None	None	None	None	Treatment by soil washing to potentially reduce volume of waste requiring landfill disposal	None	None
	In situ treatment (area in acres potentially treated *in situ* is assumed to be 50% of total ENR and *in situ* treatment area)		0	0	0	5	0	8	0	26.5	0	0	50.5	0
	Relative ranking based on amount of material managed[i] (★ = Lowest for Reduction of Toxicity, Mobility or Volume)		★	★	★	★★	★	★★	★	★★★	★	★★★★	★★★	★
Short-term Effectiveness	Protection during Construction	Period of community exposure (including noise), worker exposure, ecological disturbance and resuspension of contaminated material from dredging (years of construction)[j]	0	4	4	3	6	6	11	7	17	17	16	42
		Dredge-cut prism volume/ Performance contingency (cy)	Not estimated	370,000/ 580,000	370,000/ 580,000	300,000/ 490,000	590,000/ 760,000	560,000/ 690,000	1,000,000/ 1,200,000	640,000/ 750,000	1,600,000/ 1,600,000	1,600,000/ 1,600,000	1,500,000/ 1,600,000	3,900,000/ 3,900,000
		Air quality impacts (CO_2/PM_{10}; metric tons)	Not estimated – Lowest impact	20,000/ 17	17,000/ 18	19,000/ 15	27,000/ 23	27,000/ 22	42,000/ 35	30,000/ 25	59,000/ 50	51,000/ 44	64,000/ 53	139,000/ 118
		Ecological – Habitat area shallower than -10 ft MLLW disturbed (dredging and capping)	Not estimated – Lowest impact	13	13	23	28	33	42	37	59	59	67	99
	Time to achieve RAOs or important risk reduction milestones (years)[k]	RAO 1: 10^{-4} magnitude PCB risk (Adult Tribal RME)[l]	5	4	4	3	6	6	11	7	17	17	16	42
		RAO 1: Predicted time for total PCBs and dioxins/furans to reach long-term model-predicted concentration range in surface sediment[l]	25	24	24	18	21	21	21	17	22	22	16	42
		RAO 2: Total risk $\leq 1 \times 10^{-5}$ (All exposure scenarios)[m]	5	4	4	3	4	3	4	3	4	4	3	4
		RAO 2: Individual risk from cPAHs $\leq 1 \times 10^{-6}$ in all areas except Beach 3	25	19	19	3	6	3	6	3	6	6	3	6
		RAO 3: Benthic invertebrates (SQS)[n]	20	14	14	8	11	6	11	6	11	11	6	11
		RAO 4: Ecological – river otters (HQ<1)[o]	< 5	4	4	3	6	6	11	7	17	17	16	42
	Summary of short-term effectiveness		No short-term impacts because no construction. Longest time to achieve cleanup objectives. Highest natural recovery prediction uncertainty.	Low impacts from construction. Moderate time to reduce contaminant concentrations. High uncertainty (125 acres MNR).	Slightly more impacts from construction than Alt 2R due to CAD. Similar time to reduce contaminant concentrations. High uncertainty (125 acres of MNR).	Similar impacts from construction, shorter time to reduce contaminant concentrations, and less uncertainty than Alt 2 (99 acres MNR).	Higher impacts from construction, longer time to reduce contaminant concentrations, and less uncertainty than Alt 3C (99 acres MNR).	Similar impacts from construction, similar time to reduce contaminant concentrations, and less uncertainty than Alt 3R (50 acres MNR).	Higher impacts from construction, similar time to reduce contaminant concentrations, and similar uncertainty to Alt 4C (50 acres MNR).	Impacts from construction similar to Alt 3R, and higher than Alt 4C. Shorter time to reduce contaminant concentrations. Very low uncertainty (no MNR).	More impacts from construction than Alt 4R and 5C. Longer time to reduce contaminant concentrations. Very low uncertainty (no MNR).		More impacts from construction, similar time to reduce contaminant concentrations, and lower uncertainty than Alt 5R (no MNR).	Highest impacts from construction and longest time to reduce contaminant concentrations with lowest uncertainty (no MNR).
	Relative Ranking (★ = Lowest for short-term effectiveness)		★	★★	★★	★★★★	★★★	★★★★	★★★	★★★★	★★	★★	★★	★

Table 10-1 Comparative Evaluation and Relative Ranking of Remedial Alternatives (continued)

Evaluation Criteria		Remedial Alternative											
		1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Implementability	Technical and administrative implementability during construction	No construction (other than EAAs)	Short construction period. Lowest potential for difficulties and delays.	Same as Alt 2R plus significant administrative issues with siting, maintenance, and liability of CAD.	Same construction period as Alt 2. Low potential for difficulties and delays.	Longer construction period than Alts 2 or 3C. Low potential for difficulties and delays.	Similar construction period to Alt 3R. Low potential for difficulties and delays.	Longer construction period than Alt 4C. Higher potential for difficulties and delays.	Construction period slightly longer than Alt 4C, and shorter than Alt 4R. Potential for difficulties and delays similar to Alt 4C.	Longer construction period than Alt 4R. Higher potential for difficulties and delays.	Same as Alt 5R plus significant issues with permitting facility and reusing treated material.	Construction period similar to Alt 5R. Similar potential for difficulties and delays.	Longest construction period. Highest potential for difficulties and delays.
	Technical and administrative implementability after construction	No contingency actions contemplated.	High potential for additional actions in MNR and ENR areas.	Same as Alt 2R.	Lower potential for additional actions in MNR and ENR areas than Alt 2.	Same as Alt 3C.	Lower potential for additional actions in MNR and ENR areas than Alt 3R.	Lower potential for additional actions in MNR areas than Alt 4C.	Additional actions may be needed after dredging to meet low RALs. Potential for additional actions in ENR areas similar to Alt 4R.	Same as Alt 5C.	Same as Alt 5R.	Additional actions likely needed after dredging to meet lower RALs. No MNR or ENR.	Same as Alt 6C.
	Summary of implementability	High	Moderate	Low	Moderate	Moderate	High	High	High	Low	Very Low	Low	Very Low
	Relative ranking (★= Lowest for implementability)	★★★★	★★★	★★	★★★	★★★	★★★★	★★★★	★★★★	★★	★	★★	★
Costs	Total (MM$)	9[p]	220	200	200	270	260	360	290	470	510	530	810
	Relative ranking (★= highest for cost)	★★★★★	★★★★	★★★★	★★★★	★★★	★★★	★★	★★★	★★	★★	★★	★

Notes:

a. Relative ranking compares alternatives to one another using a one star (★= low ranking) to five star (★★★★★= high ranking) system. See specific criteria for guide to interpreting star rankings.

b. Risk estimate is based on use of the total PCB SWAC (using base case [mid input values] BCM output) in the food web model. Total excess cancer risks (all carcinogens combined) are predicted to be similar to total PCB risks for the consumption of resident fish and crab. Risks due to clam consumption are largely due to arsenic and cPAHs in clam tissue, and were not calculated due to the poor relationship between sediment and tissue values in the RI dataset).

c. See Table 9-7a for other RME risk scenarios.

d. Base case (mid-range input values) BCM output used for estimation of direct contact risks.

e. The proportion of ENR or *in situ* treatment is assumed to be 50%/50% for the FS alternatives.

f. Recovery categories: Category 1 – presumed to be limited; Category 2 – less certain; Category 3 – predicted to recover. Best professional judgment was used during technology assignment work to consolidate small areas extending across two recovery categories into one category.

g. Remaining cores grouped by those located under caps and those located anywhere else within the LDW after construction.

h. This analysis evaluates the reliability of controls after cleanup objectives are achieved. The construction periods differ (see Short-term Effectiveness) and various controls will also be required during construction.

i. Alternative 6C extends project-specific O&M and monitoring into AOPC 2 (i.e., for capping and ENR/*in situ)* and is the only alternative to do so.

j. Construction period rounded to nearest year. Additional time beyond construction required for ecologically sensitive areas to recover. Also, fish and shellfish tissue contaminant concentrations may require additional time after construction to recover.

k. The predicted time to achieve cleanup objectives is keyed to the start of construction, except for Alternative 1 which is keyed to the completion of the EAAs.

l. No remedial alternative achieves RAO 1 PRGs. Alternatives 2 through 6 achieve protectiveness with some combination of active and passive remediation and ICs. Two time frames are provided for purposes of comparing the alternatives: 1) the point at which the alternatives reduce the Adult Tribal RME seafood consumption risk to 10^{-4}, and 2) the predicted time for risk-driver concentrations to achieve long-term model-predicted concentration ranges. The latter are based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw, and a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw. Fish and shellfish tissue concentrations are expected to remain elevated during construction as a result of resuspension and release of total PCBs into the water column.

m. Alternatives 3C and 3R specifically address direct contact risks and achieve the total and individual direct contact risk metrics defined in Section 9.1.2.3 at the end of construction for all exposure scenarios. The FS assumes that the Alternative 3 actions occur at the beginning of Alternatives 4, 5, and 6; these alternatives are assumed to have the same times to achieve the other RAO 2 metrics as described for Alternatives 3C and 3R. Alternative 2 does not actively remediate for all direct contact risks. However, surface sediments in clamming and beach play areas are ≤ 1×10^{-5} following construction of EAAs and are expected to continue recovering naturally over time. See Figure 10-4 for times for individual risk drivers to achieve cancer risk thresholds.

n. The FS assumes the time to achieve cleanup objectives for RAO 3 to be when at least 98% of FS surface sediment dataset stations are predicted to comply with the SMS and more than 98% of the LDW surface area is predicted to comply with the SMS. This is not intended as a compliance metric. EPA and Ecology will determine the appropriate metric for SMS compliance.

o. The time to achieve cleanup objectives for RAO 4 is when wildlife seafood consumption HQ <1 is achieved based on the site-wide total PCB SWAC at the end of construction.

p. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting. The cost for completing the cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided only for informational purposes, and are not included in the cost of the other alternatives or used in the comparison of alternatives.

AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined alternative; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; cPAH = carcinogenic polycyclic aromatic hydrocarbons; CSL = cleanup screening level; cy = cubic yards; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; HI = hazard index; HQ = hazard quotient; IC = institutional control; kg = kilograms; µg = micrograms; mg = milligrams; MLLW = mean lower low water; MM = million; n/a = not applicable; MNR = monitored natural recovery; ng = nanograms; O&M = operation and monitoring; PCB = polychlorinated biphenyls; R = removal alternative; RAL = remedial action level; RAO = remedial action objective; RME = reasonable maximum exposure; R-T = removal alternative with treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL95 = 95 percent upper confidence limit on the mean; VM = verification monitoring

Table 10-2 Predicted SWACs and SMS Exceedance Outcomes for Alternatives 2 through 6 by Only Active Remediation and Comparison to PRGs

		Site-wide SWAC				Clamming Area SWAC				Beach Play Area SWAC				SMS			
Alternative	Construction Time (years)	Arsenic (mg/kg dw)	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	Arsenic (mg/kg dw)	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	Arsenic (mg/kg dw)	Total PCBs (µg/kg dw)	cPAHs (µg TEQ/ kg dw)	Dioxins/ Furans (ng TEQ/ kg dw)	% of Stations <CSL	% of LDW Area <CSL	% of Stations <SQS	% of LDW Area <SQS
Predicted Outcomes without Natural Recovery																	
1	n/a	16	180	360	24	13	190	300	30	9.1	270	310	14	95	96	84	82
2R/2R-CAD	4	12	142	307	7.9	9.4	104	244	6.8	8.9	100	248	5.6	98	98	89	86
3R/3C	6 / 3	11	132	269	7.4	9.3	88	162	6.1	8.8	79	186	5.0	99	99	92	89
4R/4C	11 / 6	11	113	233	6.7	9.4	74	158	5.8	8.9	61	172	4.7	99	99	96	94
5R/5R-T/5C	17/ 17 / 7	11	95	207	5.6	9.4	69	153	5.2	9.1	58	157	4.5	100	100	100	99
6R/6C	42 / 16	9	45	135	4.3	9.1	48	137	4.3	8.9	43	148	4.0	100	100	100	99
Preliminary Remediation Goals for each Remedial Action Objective (shown for reference)																	
RAO 1 PRGs		n/a	2	n/a	2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
RAO 2 PRGs		7	1,300	380	37	7	500	150	13	7	1,700	90	28	n/a	n/a	n/a	n/a
RAO 3 PRGs		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	≤ 98% of LDW area SQS			
RAO 4 PRG		n/a	128-159	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Notes:

1. Results shown are predicted conditions immediately at the end of alternative construction using post-remedy bed sediment replacement values within the actively remediated footprint and the FS baseline dataset for all areas outside of the actively remediated footprint. This analysis assumes no natural recovery during construction.
2. Refer to Table 9-2a footnotes for additional information on post-remedy bed sediment replacement values and calculation methodologies.

C = combined technologies alternative; CAD = contained aquatic disposal; cPAH = carcinogenic polyaromatic hydrocarbons; CSL = cleanup screening level; dw = dry weight; FS = feasibility study; kg = kilograms; µg = micrograms; mg = milligrams; n/a = not applicable; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal-emphasis alternative; RAO = remedial action objective; R-T = removal-emphasis with treatment; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Table 10-3 Summary of Appendix L and Other Short-term Effectiveness Metrics for the Remedial Alternatives

Metric		Remedial Alternative											
		1	**2R**	**2R-CAD**	**3C**	**3R**	**4C**	**4R**	**5C**	**5R**	**5R-T**	**6C**	**6R**
Period of community exposure, worker exposure and ecological disturbance (years of construction)[a]		<5	4	4	3	6	6	11	7	17	17	16	42
Total PCB mass exported from site as a result of natural erosion; 45-yr model period (kg)		3.1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	2.8	2.9
Total PCB mass exported from site as a result of dredging (kg)		3.9	5.5	5.5[b]	5.1	6.1	6.0	7.6	6.3	10.0	10.0	9.0	17.5
Transportation (miles)[c]	Truck	n/c	380,000	180,000	320,000	490,000	440,000	740,000	480,000	1,100,000	800,000	1,100,000	2,500,000
	Train	n/c	100,000	47,000	84,000	130,000	120,000	200,000	130,000	280,000	210,000	280,000	670,000
Ecological – Habitat area above -10 ft MLLW disturbed (dredging/partial dredge and cap/capping)		n/c	13	13	23	28	33	42	37	59	59	67	99
Gas / Particulate Emissions	Greenhouse gas emissions (CO_2; metric tons)	n/c	20,000	17,000	19,000	27,000	27,000	42,000	30,000	59,000	51,000	64,000	139,000
	Other air pollutants (NO_x/SO_x; metric tons)	n/c	410 / 10	284 / 13	364 / 9	547 / 13	522 / 13	830 / 20	578 / 14	1,185 / 28	973 / 26	1,246 / 30	2,806 / 66
	Particulate matter emissions (PM_{10}; metric tons)	n/c	17	18	15	23	22	35	25	50	44	53	118
Energy Consumption (MJ)		n/c	2.8E+08	2.3E+08	2.6E+08	3.8E+08	3.79E+08	5.8E+08	4.2E+08	8.3E+08	7.1E+08	8.9E+08	1.9E+09
Landfill Capacity Consumed (1.2 × Dredge Volume)		n/c	700,000	330,000	590,000	920,000	830,000	1,400,000	900,000	2,000,000	1,500,000	2,000,000	4,700,000
Carbon Footprint (acre-years)[d]		n/c	4,775	4,029	4,384	6,468	6,358	9,831	7,094	14,015	12,128	15,190	33,008
Depleted natural resources (sand/gravel for in-water placement; cy)		n/c	120,000	200,000	270,000	260,000	470,000	430,000	580,000	590,000	590,000	1,100,000	1,200,000

Notes:

1. See Appendices L and M for details on basis and assumptions for short-term metric values.

a. Construction period rounded to nearest year. Additional time beyond construction required for ecologically sensitive areas to recover. Also, fish and shellfish tissue contaminant concentrations may require additional time (1 to 2 years) after construction to recover.

b. Additional mass of total PCBs will be exported from the site as a result of releases to the water column associated with depositing contaminated sediment into the CAD. This additional mass was not estimated.

c. Sediment is assumed to be disposed of by trucking from a transloading area to an intermodal station, where it is loaded onto train cars for transport to a landfill in Eastern Washington or Eastern Oregon. Trucking miles are estimated using an average 28 tons/truck and 12 miles to the intermodal station. Train miles are estimated assuming 568 miles (round trip) to the landfill and assuming that each train can carry 5,000 tons of dredged material.

d. One acre-year represents the amount of CO_2 sequestered by one acre of Douglas fir forest for one year. Carbon footprint in units of acre-years is an appropriate way to account for the differences in construction periods among the alternatives.

C = combined; CAD = contained aquatic disposal; CO_2 = carbon dioxide; cy = cubic yards; kg = kilograms; MJ = megajoule; MLLW = mean low lower water; n/c = not calculated; NO_x = nitrogen oxides; PM = particulate matter; R = removal; R-T = removal with treatment; SO_x = sulfur oxides

Table 10-4 Uncertainty in Site-wide SWACs and Time Frames Associated with Non-optimized Sequencing of Remedial Actions

Site-wide Total PCB SWAC (µg/kg dw)

Sequencing Assumption	Alternative	*Time From Start of Construction (years)*									Model Year When Total PCB SWAC is between 40 and 50 µg/kg dw	Difference in Years (between sequencing assumptions)
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*		
Upstream to Downstream	Alternative 6 Removal	180	101	70	54	50	48	47	46	45	25	5
	Alternative 6 Combined	180	91	64	47	44	43	43	42	42	15	5
Optimized as Worst First	Alternative 6 Removal	180	86	62	50	44	41	41	40	39	20	
	Alternative 6 Combined	180	70	48	39	40	40	41	41	41	10	

Site-wide Arsenic SWAC (mg/kg dw)

Sequencing Assumption	Alternative	*Time From Start of Construction (years)*									Model Year When Arsenic SWAC is between 9 and 11 mg/kg dw	Difference in Years (between sequencing assumptions)
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*		
Upstream to Downstream	Alternative 6 Removal	16.0	11.5	10.4	9.7	9.5	9.4	9.4	9.3	9.3	10	5
	Alternative 6 Combined	16.0	11.6	9.9	9.4	9.3	9.2	9.2	9.2	9.1	10	5
Optimized as Worst First	Alternative 6 Removal	16.0	10.0	9.7	9.4	9.3	9.2	9.2	9.1	9.1	5	
	Alternative 6 Combined	16.0	10.0	9.5	9.2	9.1	9.1	9.1	9.1	9.1	5	

Site-wide CPAH SWAC (µg TEQ/kg dw)

Sequencing Assumption	Alternative	*Time From Start of Construction (years)*									Model Year When cPAH SWAC is between 100 and 125 µg TEQ/kg dw	Difference in Years (between sequencing assumptions)
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*		
Upstream to Downstream	Alternative 6 Removal	360	219	162	125	115	111	113	110	108	20	5
	Alternative 6 Combined	360	216	153	110	106	103	106	103	103	15	0
Optimized as Worst First	Alternative 6 Removal	360	180	140	110	110	106	107	104	103	15	
	Alternative 6 Combined	360	160	130	103	101	100	103	102	102	15	

Site-wide Dioxin/Furan SWAC (ng TEQ/kg dw)

Sequencing Assumption	Alternative	*Time From Start of Construction(years)*									Model Year When Dioxin/Furan SWAC is between 4.3 and 5.4 ng TEQ/kg dw	Difference in Years (between sequencing assumptions)
		0	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*		
Upstream to Downstream	Alternative 6 Removal	24	12.7	7.8	5.3	4.6	4.4	4.4	4.3	4.3	15	5
	Alternative 6 Combined	24	12.4	5.0	4.2	4.3	4.3	4.3	4.3	4.3	10	5
Optimized as Worst First	Alternative 6 Removal	24	5.9	5.0	4.4	4.4	4.3	4.3	4.3	4.3	10	
	Alternative 6 Combined	24	4.9	4.6	4.2	4.3	4.3	4.3	4.3	4.4	5	

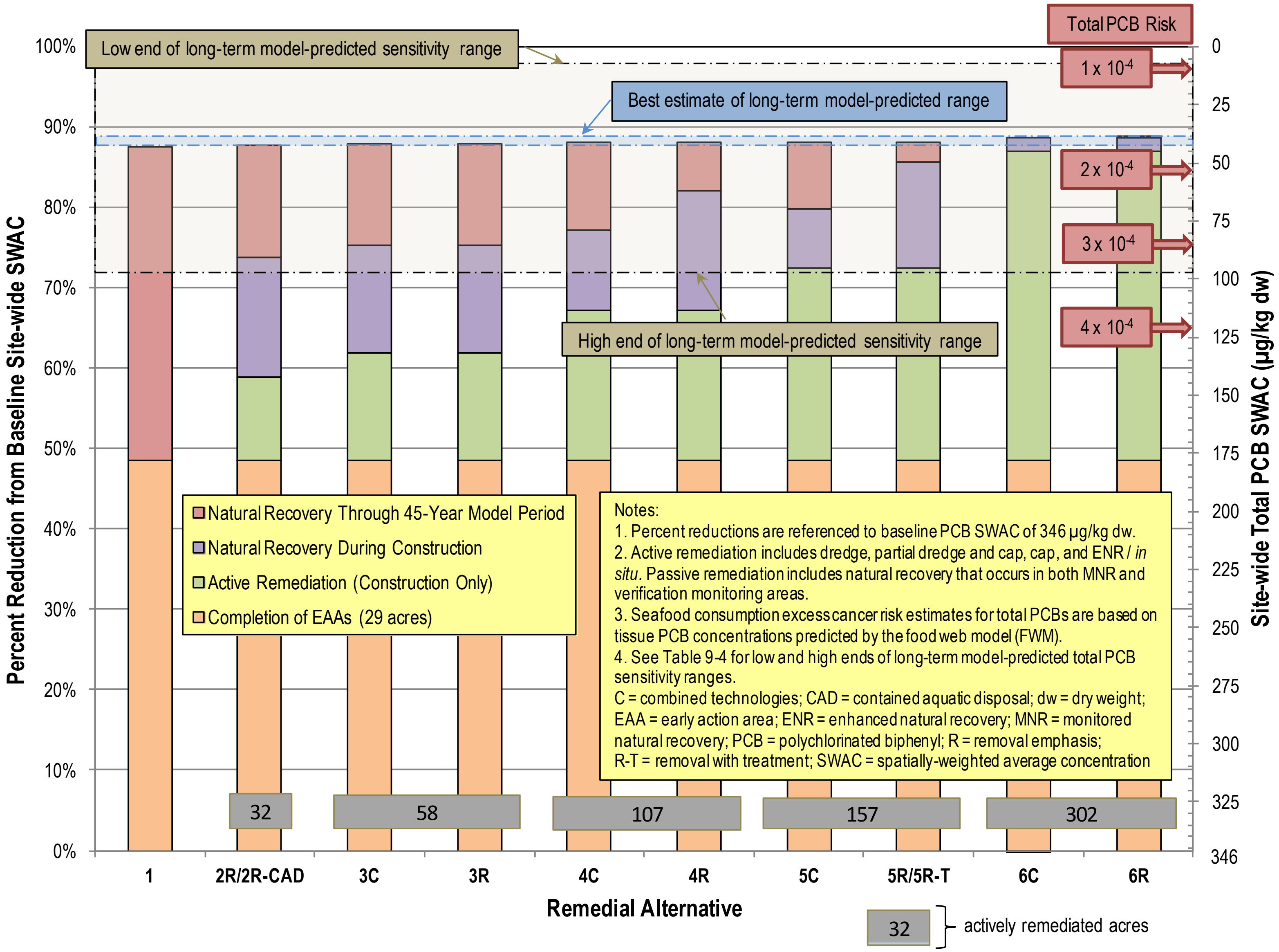
🟩 = Construction Time Frame

Notes:

1. The 5-year model-predicted intervals associated with the BCM SWAC output are indexed to the start of construction for all the alternatives.
2. Construction is assumed to begin at the upstream end of the BCM domain (RM 4.75) and sequentially work downstream toward the mouth (RM 0).
3. Construction is equally divided over 20 or 40 years for the combined and removal alternatives, respectively. The construction sequencing of "optimized as worst first" is used in the FS.
4. Model runs assume natural recovery during construction; larger differences are likely if no recovery is assumed during construction.
5. Remedial actions include dredging, capping, and ENR/*in situ* (the latter only for Alternative 6 Combined).

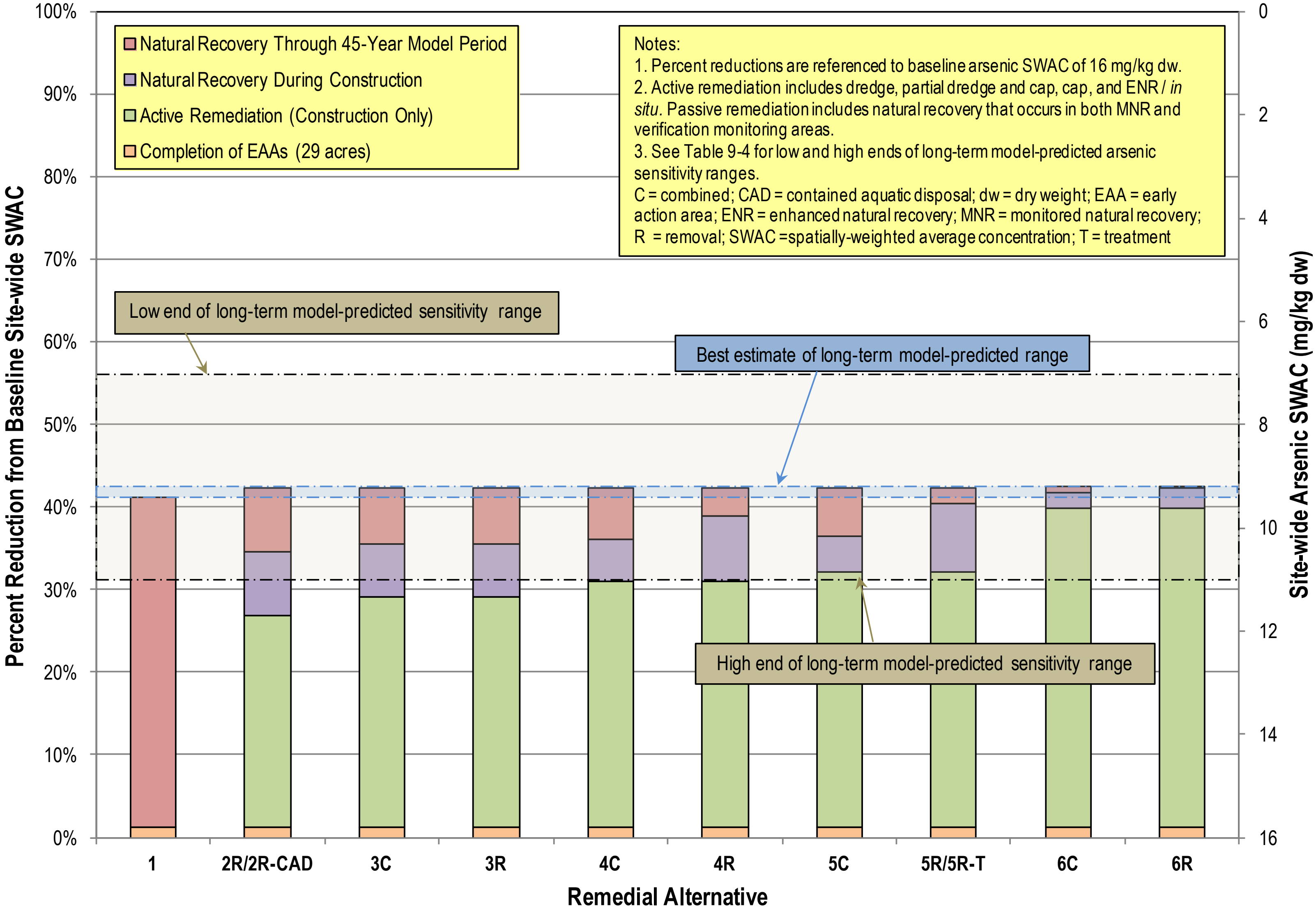
BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; ENR/*in situ* = enhanced natural recover/*in situ* treatment; FS = feasibility study; kg = kilograms; µg = micrograms; mg = milligrams; ng = nanograms; PCBs = polychlorinated biphenyls; RM = river mile; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent

Figure 10-1a Reduction of Total PCB SWAC by Active Remediation and Natural Recovery



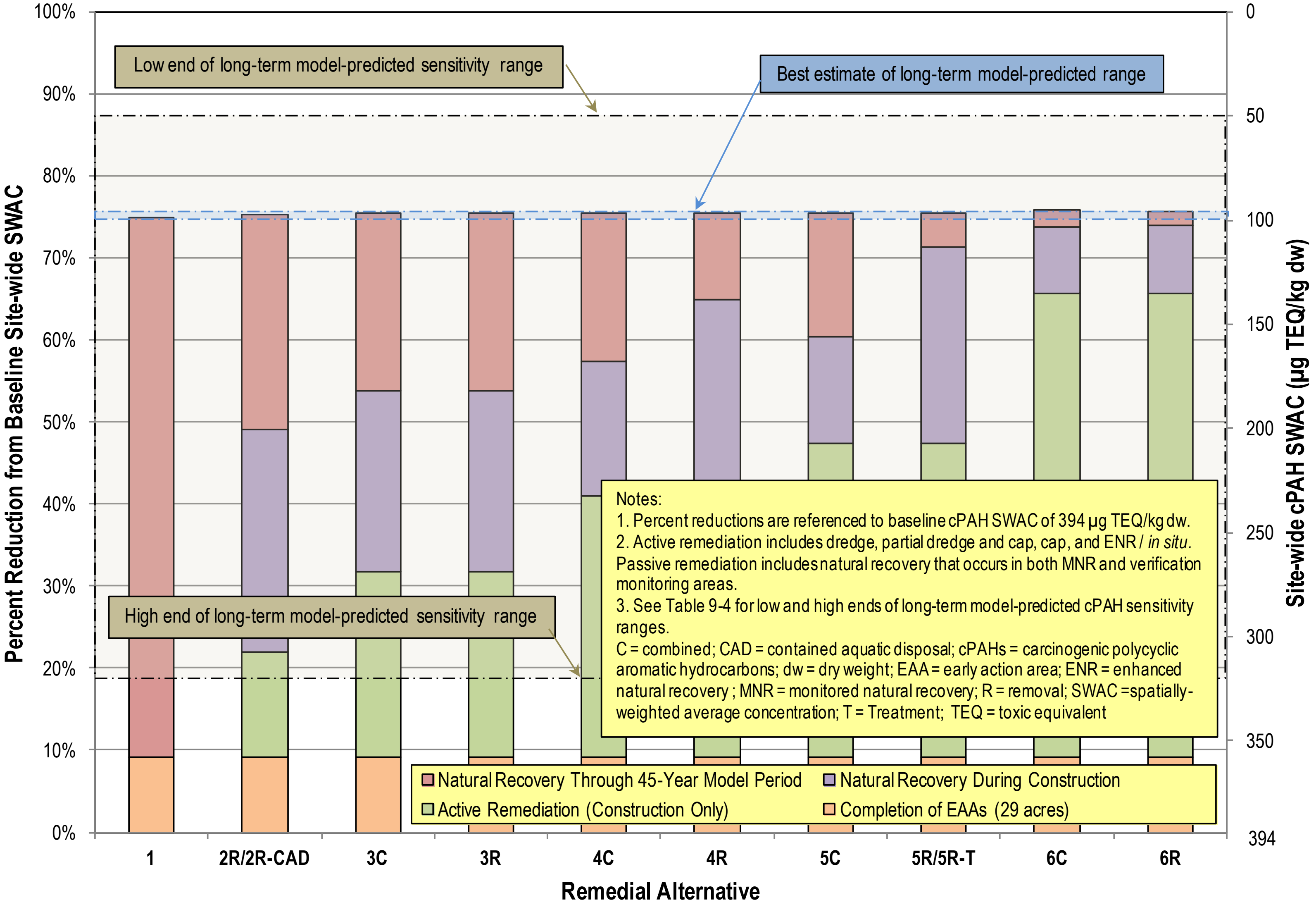
Notes:
1. Percent reductions are referenced to baseline PCB SWAC of 346 µg/kg dw.
2. Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ*. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.
3. Seafood consumption excess cancer risk estimates for total PCBs are based on tissue PCB concentrations predicted by the food web model (FWM).
4. See Table 9-4 for low and high ends of long-term model-predicted total PCB sensitivity ranges.
C = combined technologies; CAD = contained aquatic disposal; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; MNR = monitored natural recovery; PCB = polychlorinated biphenyl; R = removal emphasis; R-T = removal with treatment; SWAC = spatially-weighted average concentration

Figure 10-1b Reduction of Arsenic SWAC by Active Remediation and Natural Recovery



Notes:
1. Percent reductions are referenced to baseline arsenic SWAC of 16 mg/kg dw.
2. Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ*. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.
3. See Table 9-4 for low and high ends of long-term model-predicted arsenic sensitivity ranges.
C = combined; CAD = contained aquatic disposal; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; MNR = monitored natural recovery; R = removal; SWAC = spatially-weighted average concentration; T = treatment

Figure 10-1c Reduction of cPAHs SWAC by Active Remediation and Natural Recovery



Low end of long-term model-predicted sensitivity range

Best estimate of long-term model-predicted range

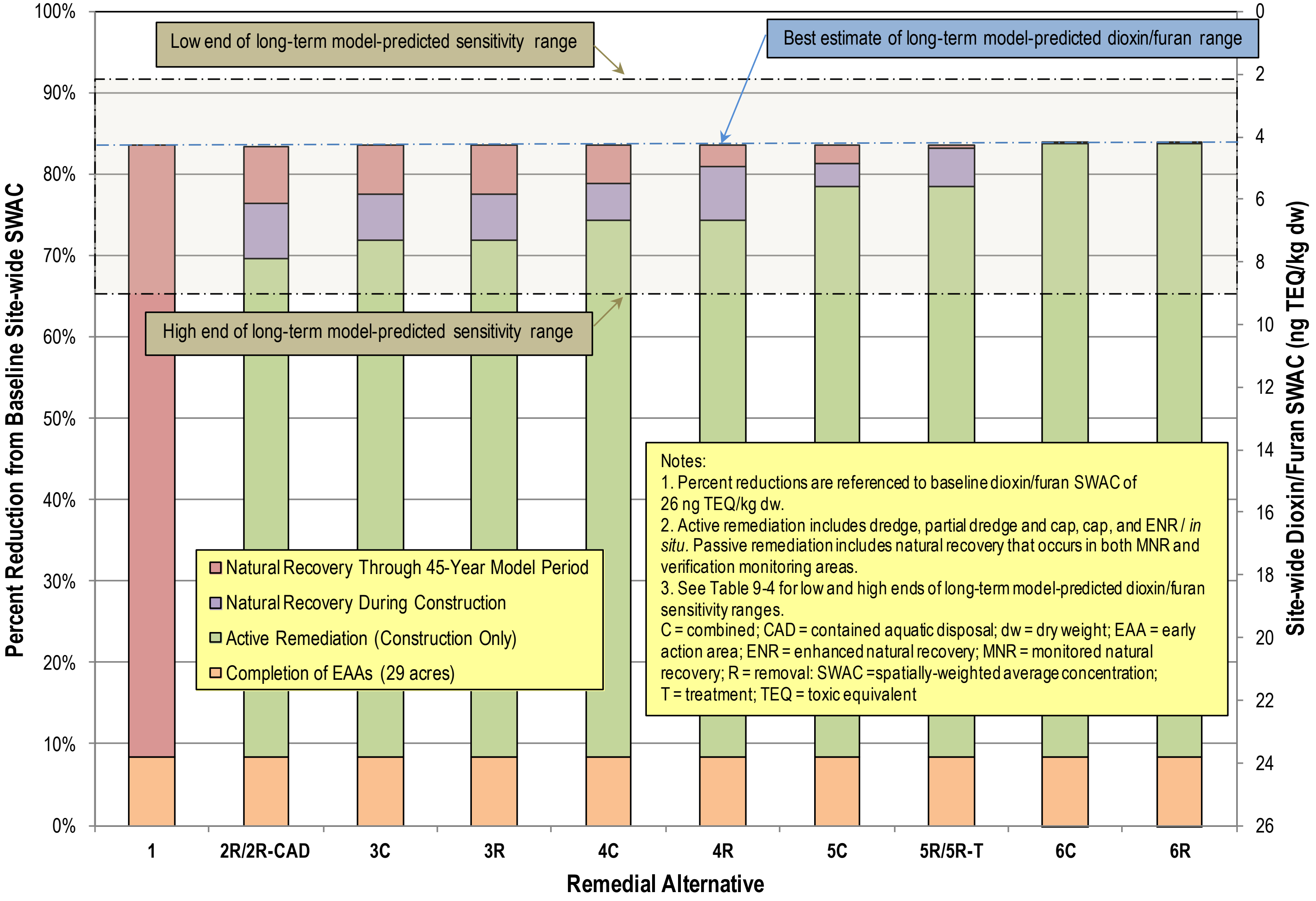
High end of long-term model-predicted sensitivity range

Notes:

1. Percent reductions are referenced to baseline cPAH SWAC of 394 µg TEQ/kg dw.
2. Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ*. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.
3. See Table 9-4 for low and high ends of long-term model-predicted cPAH sensitivity ranges.

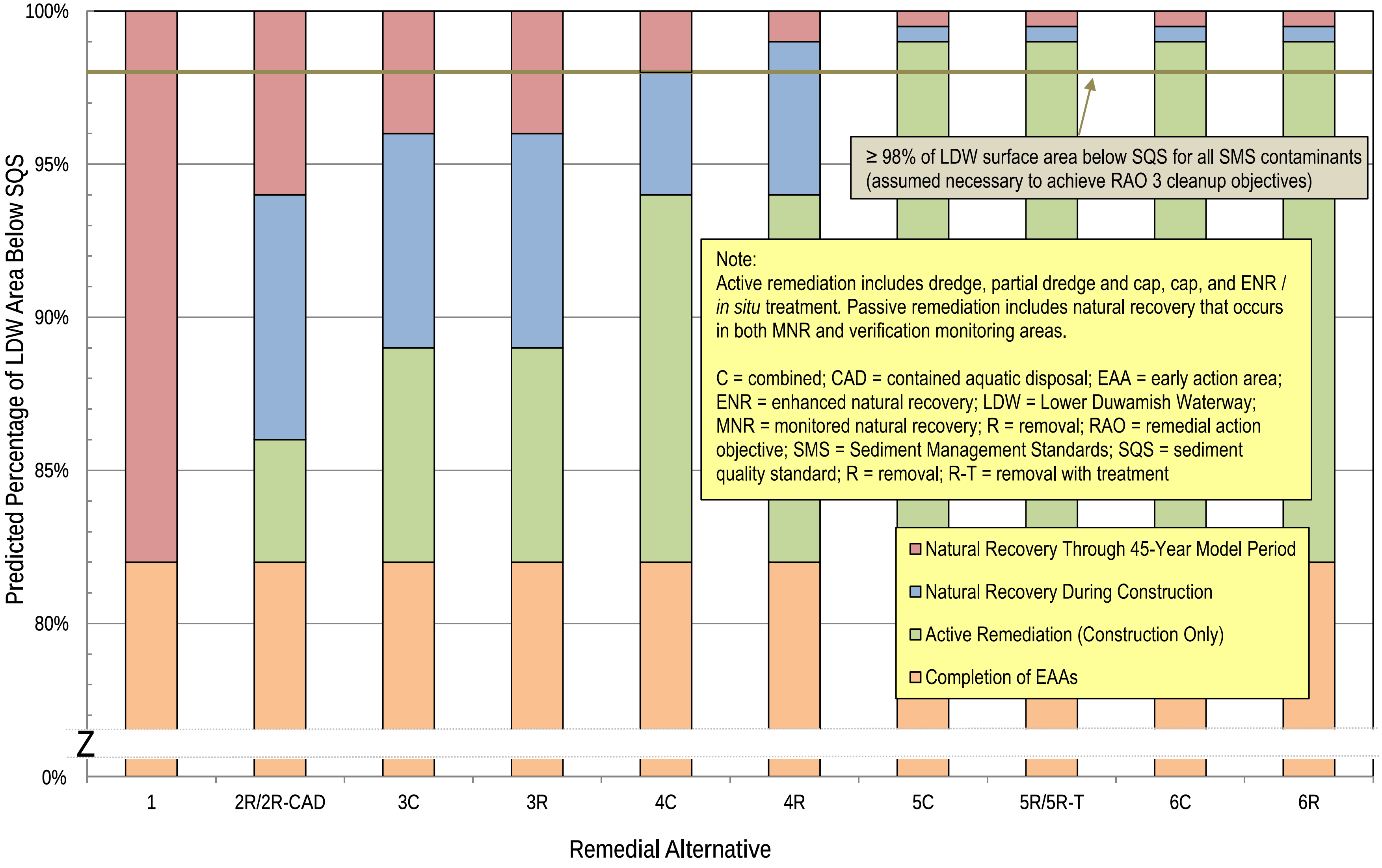
C = combined; CAD = contained aquatic disposal; cPAHs = carcinogenic polycyclic aromatic hydrocarbons; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery ; MNR = monitored natural recovery; R = removal; SWAC =spatially-weighted average concentration; T = Treatment; TEQ = toxic equivalent

Figure 10-1d Reduction of Dioxin/Furan SWAC by Active Remediation and Natural Recovery



Notes:
1. Percent reductions are referenced to baseline dioxin/furan SWAC of 26 ng TEQ/kg dw.
2. Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ*. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.
3. See Table 9-4 for low and high ends of long-term model-predicted dioxin/furan sensitivity ranges.
C = combined; CAD = contained aquatic disposal; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; MNR = monitored natural recovery; R = removal: SWAC =spatially-weighted average concentration; T = treatment; TEQ = toxic equivalent

Figure 10-2 Contributions to Achievement of RAO 3 Cleanup Objective by Active Remediation and Natural Recovery

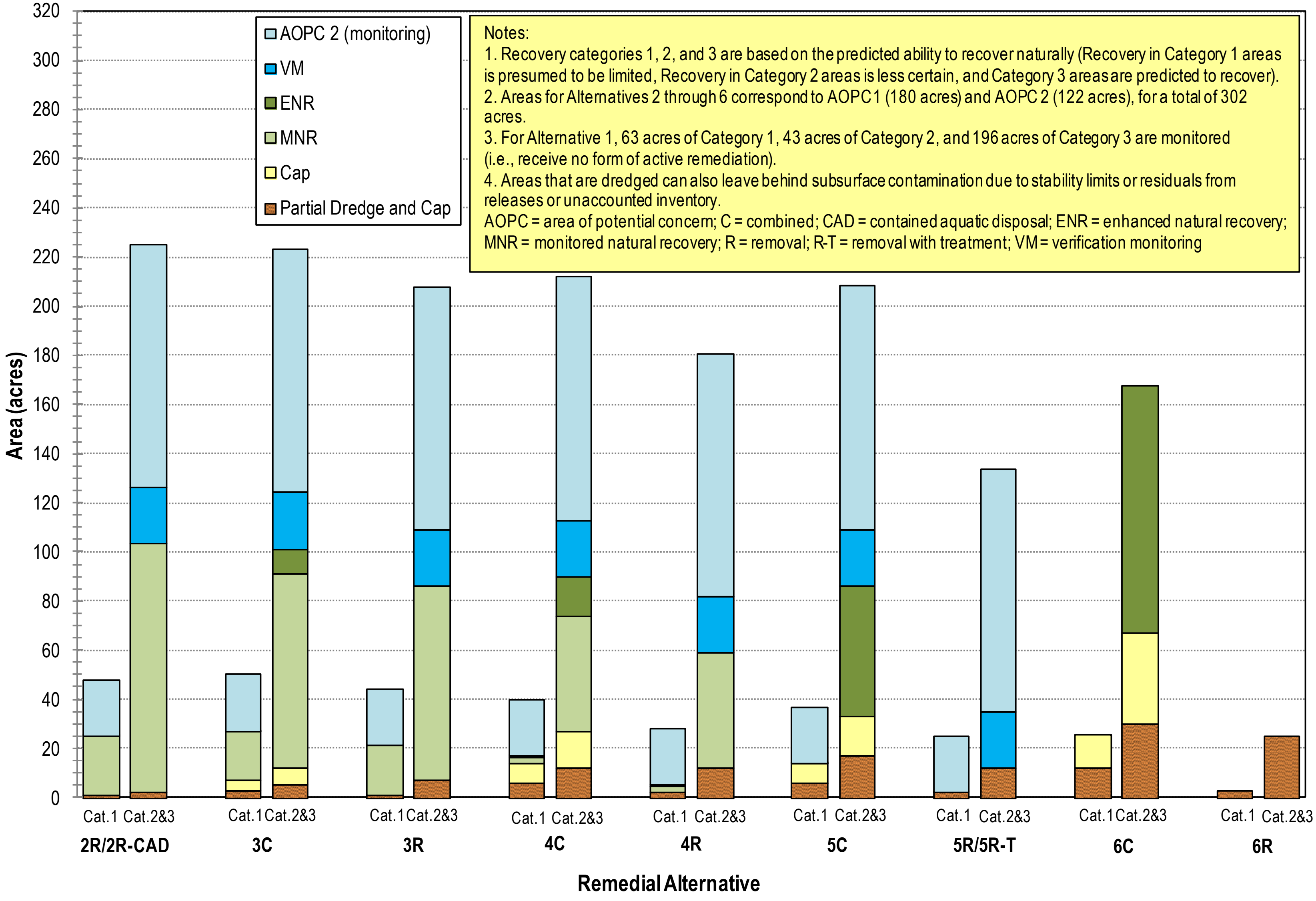


≥ 98% of LDW surface area below SQS for all SMS contaminants (assumed necessary to achieve RAO 3 cleanup objectives)

Note:
Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ* treatment. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.

C = combined; CAD = contained aquatic disposal; EAA = early action area; ENR = enhanced natural recovery; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery; R = removal; RAO = remedial action objective; SMS = Sediment Management Standards; SQS = sediment quality standard; R = removal; R-T = removal with treatment

Figure 10-3 Areas that are not Dredged Corresponding to Technology Assignments for Each Recovery Category

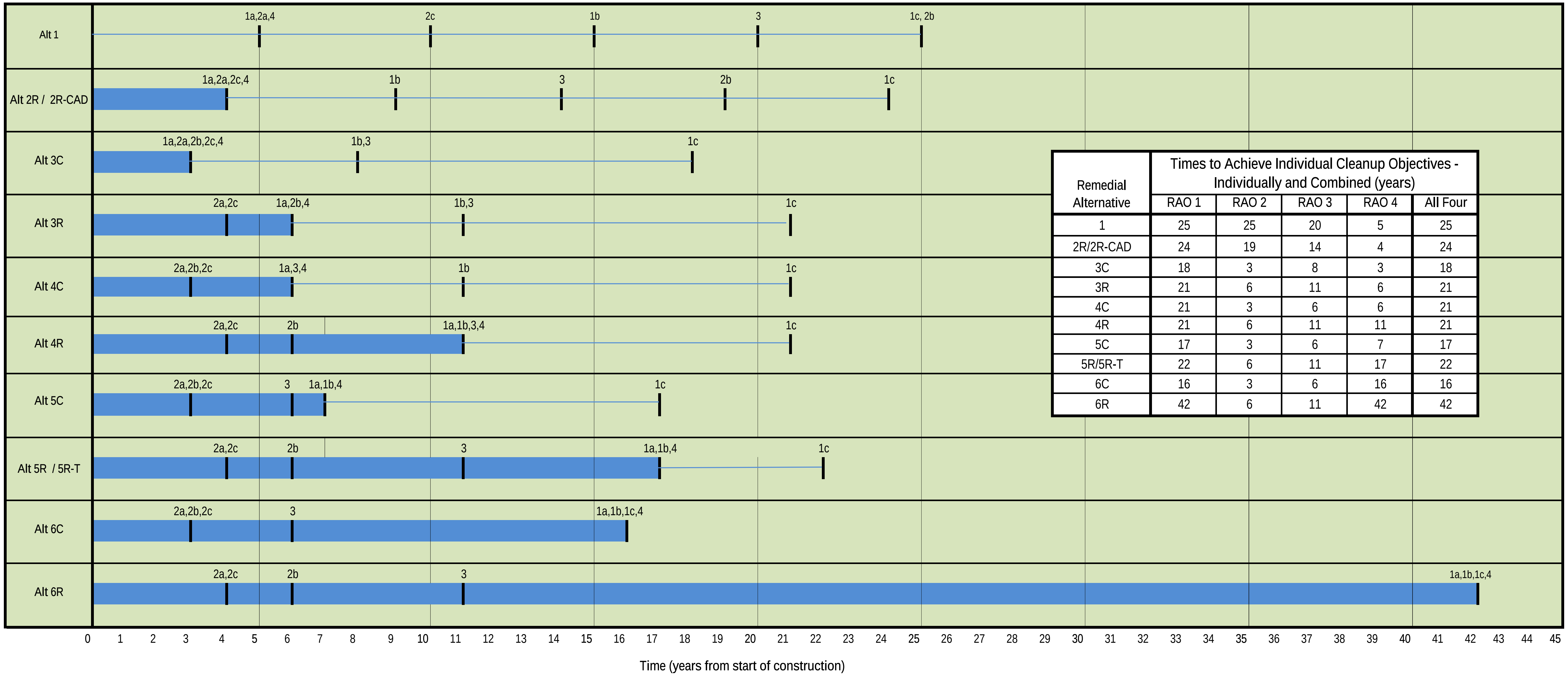


Notes:

1. Recovery categories 1, 2, and 3 are based on the predicted ability to recover naturally (Recovery in Category 1 areas is presumed to be limited, Recovery in Category 2 areas is less certain, and Category 3 areas are predicted to recover).
2. Areas for Alternatives 2 through 6 correspond to AOPC 1 (180 acres) and AOPC 2 (122 acres), for a total of 302 acres.
3. For Alternative 1, 63 acres of Category 1, 43 acres of Category 2, and 196 acres of Category 3 are monitored (i.e., receive no form of active remediation).
4. Areas that are dredged can also leave behind subsurface contamination due to stability limits or residuals from releases or unaccounted inventory.

AOPC = area of potential concern; C = combined; CAD = contained aquatic disposal; ENR = enhanced natural recovery; MNR = monitored natural recovery; R = removal; R-T = removal with treatment; VM = verification monitoring

Figure 10-4 Time to Achieve Cleanup Objectives for RAOs for All Alternatives



Remedial Alternative	Times to Achieve Individual Cleanup Objectives - Individually and Combined (years)				
	RAO 1	RAO 2	RAO 3	RAO 4	All Four
1	25	25	20	5	25
2R/2R-CAD	24	19	14	4	24
3C	18	3	8	3	18
3R	21	6	11	6	21
4C	21	3	6	6	21
4R	21	6	11	11	21
5C	17	3	6	7	17
5R/5R-T	22	6	11	17	22
6C	16	3	6	16	16
6R	42	6	11	42	42

🟦 Construction Period

— Post-construction natural recovery period

2b ▌ Year the risk reduction metric is achieved

RAO	Chart Symbol	Metric(s)
1	1a	10^{-4} magnitude risk for Adult Tribal, Child Tribal, and Adult API RME seafood consumption scenarios (only total PCBs)
	1b	10^{-5} magnitude risk for Child Tribal RME seafood consumption scenario (only total PCBs)
	1c	Total PCBs and dioxin/furans reach long-term model-predicted ranges of site-wide SWACs
3	3	SQS (≥ 98% of LDW area below SQS)
4	4	HQ <1 (River Otter)

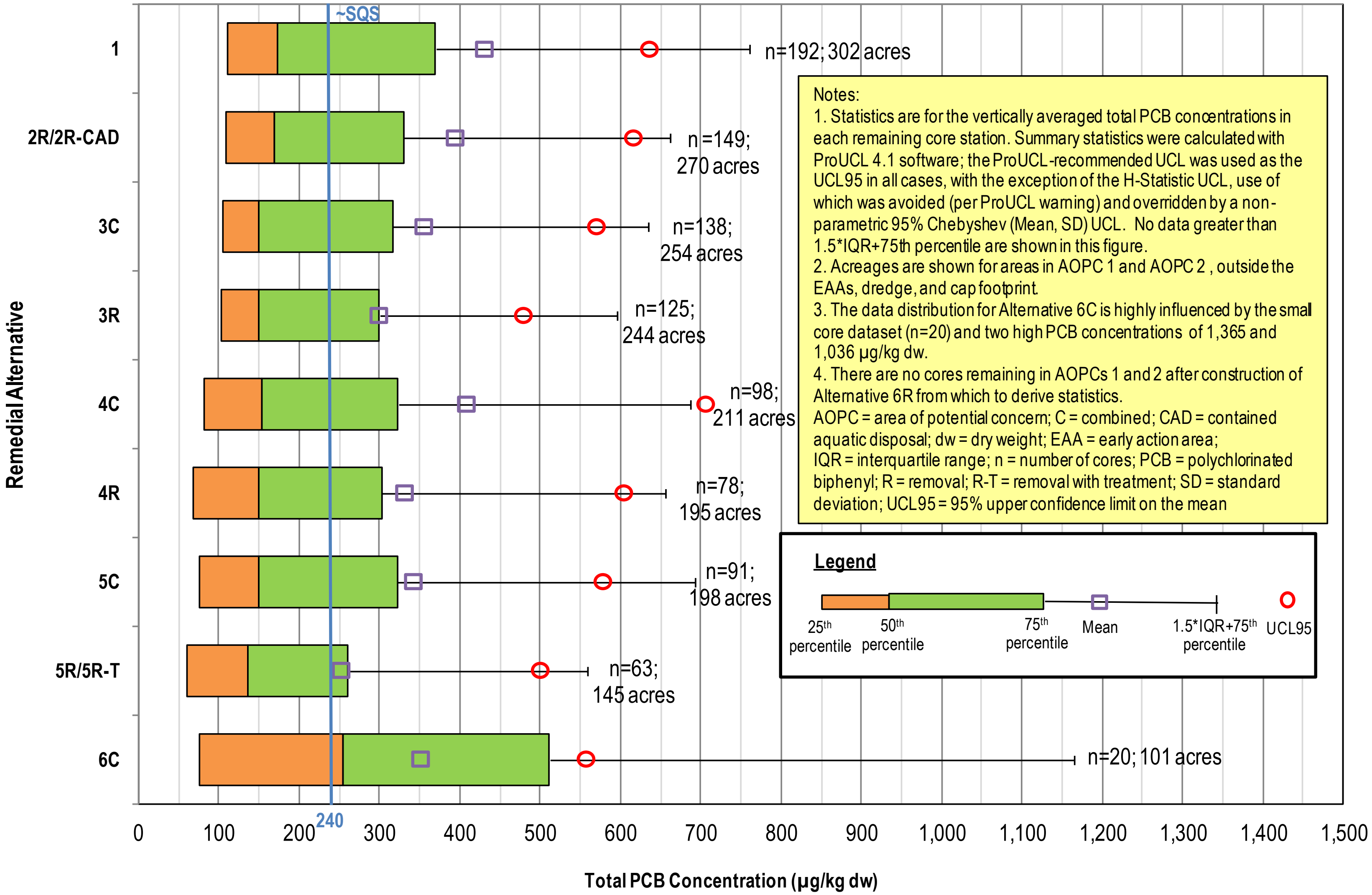
RAO	Chart Symbol	Metric(s)
2	2a	$\leq 1 \times 10^{-5}$ total direct contact risk and HQ <1 in all exposure areas
		$\leq 1 \times 10^{-6}$ direct contact risk from total PCBs in all areas
		$\leq 1 \times 10^{-5}$ and $> 1 \times 10^{-6}$ direct contact risk from arsenic in all areas
	2b	$< 1 \times 10^{-6}$ direct contact risk from dioxins/furans in all areas
		$\leq 1 \times 10^{-6}$ direct contact risk from cPAHs in all areas except Beach 3
	2c	Arsenic reaches long-term model-predicted range of site-wide SWACs

Notes:

1. None of the alternatives are predicted to achieve a non-cancer HQ below 1 for three RME seafood consumption scenarios (see Table 9-7b of Final FS for details).
2. None of the alternatives are predicted to achieve sediment PRGs that are based on natural background: total PCBs and dioxins/furans - seafood consumption (RAO 1); arsenic - direct contact all scenarios (RAO 2).
3. Fish/shellfish tissue total PCB concentrations are expected to remain elevated for up to 2 years after construction completion as a result of construction impacts (e.g., sediment resuspension). This applies to cleanup objectives for RAOs 1 and 4.
4. The direct contact risk from total PCBs is $\leq 1 \times 10^{-6}$ risk in all areas following completion of EAAs except at Beach 4. Beach 4 is actively remediated by Alternative 2R.

API = Asian and Pacific Islander; C = combined; CAD = contained aquatic disposal; cPAH = carcinogenic polyaromatic hydrocarbon; EAA = early action area; FS = feasibility study; HQ = hazard quotient; LDW = Lower Duwamish Waterway; PCB = polychlorinated biphenyl; PRG = preliminary remediation goal; R = removal; R-T = removal with treatment; RAO = remedial action objective; RME = reasonable maximum exposure; SQS = sediment quality standard; SWAC = spatially-weighted average concentration

Figure 10-5 Summary Statistics of Subsurface Total PCB Concentrations Remaining in AOPC 1 and AOPC 2 (Outside of the EAAs, Dredge and Cap Footprint) for All Categories in the 0- to 2-ft Depth Interval

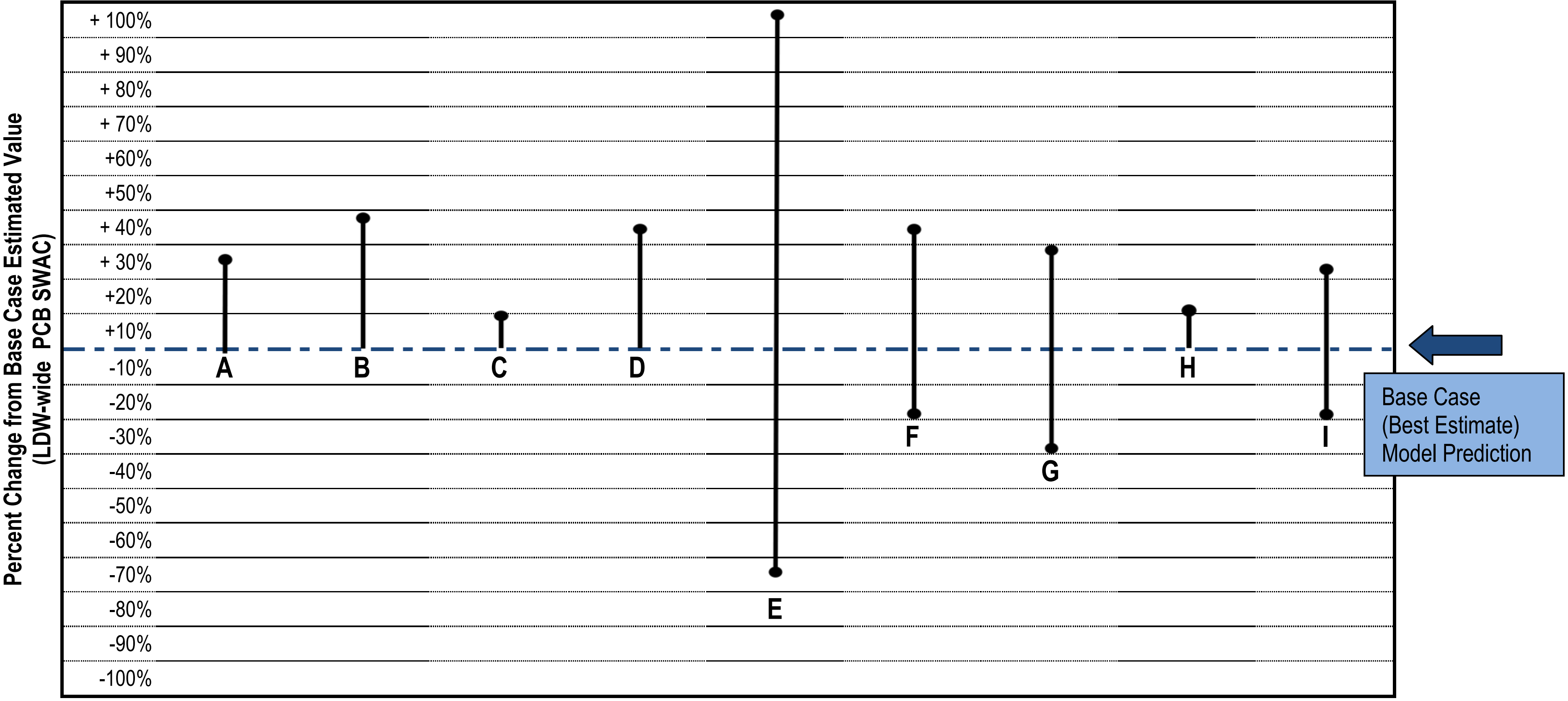


Notes:

1. Statistics are for the vertically averaged total PCB concentrations in each remaining core station. Summary statistics were calculated with ProUCL 4.1 software; the ProUCL-recommended UCL was used as the UCL95 in all cases, with the exception of the H-Statistic UCL, use of which was avoided (per ProUCL warning) and overridden by a non-parametric 95% Chebyshev (Mean, SD) UCL. No data greater than 1.5*IQR+75th percentile are shown in this figure.
2. Acreages are shown for areas in AOPC 1 and AOPC 2 , outside the EAAs, dredge, and cap footprint.
3. The data distribution for Alternative 6C is highly influenced by the small core dataset (n=20) and two high PCB concentrations of 1,365 and 1,036 µg/kg dw.
4. There are no cores remaining in AOPCs 1 and 2 after construction of Alternative 6R from which to derive statistics.

AOPC = area of potential concern; C = combined; CAD = contained aquatic disposal; dw = dry weight; EAA = early action area; IQR = interquartile range; n = number of cores; PCB = polychlorinated biphenyl; R = removal; R-T = removal with treatment; SD = standard deviation; UCL95 = 95% upper confidence limit on the mean

Figure 10-6 Estimates of Sensitivity of Model-Predicted SWAC to Various Factors



Definitions:

A Do not sequence remedial actions by alternative; instead remediate Alternative 6 footprint from upstream to downstream (Section 10.2.3.4).

B Do not account for natural recovery predicted by the BCM; estimate SWACs for Alternative 3 after construction using the post-remedy bed sediment replacement value (Section 10.2.4).

C Hold cells constant (no natural recovery) in Recovery Category 1 scour and berthing areas: Compare against 10-year base case results for Alternative 3 (Section 5.5.9).

D Subsurface exposure scenario: Compare PCB SWAC results assuming 25 acres of persistent disturbance for Alternative 3. Alternatives 1 through 5 ranged from 15 to 55% SWAC difference from base case SWAC (40 µg/kg dw) at 25 acres of persistent disturbance (Appendix M, Part 5).

E BCM sensitivity for all alternatives, 30-year results (range from all low input parameters to all high input parameters; Table 9-4).

F STM reasonable bounding runs; +/- net sedimentation rate of 1 cm/year from STM 10-year base case results. (Appendix C and Section 5).

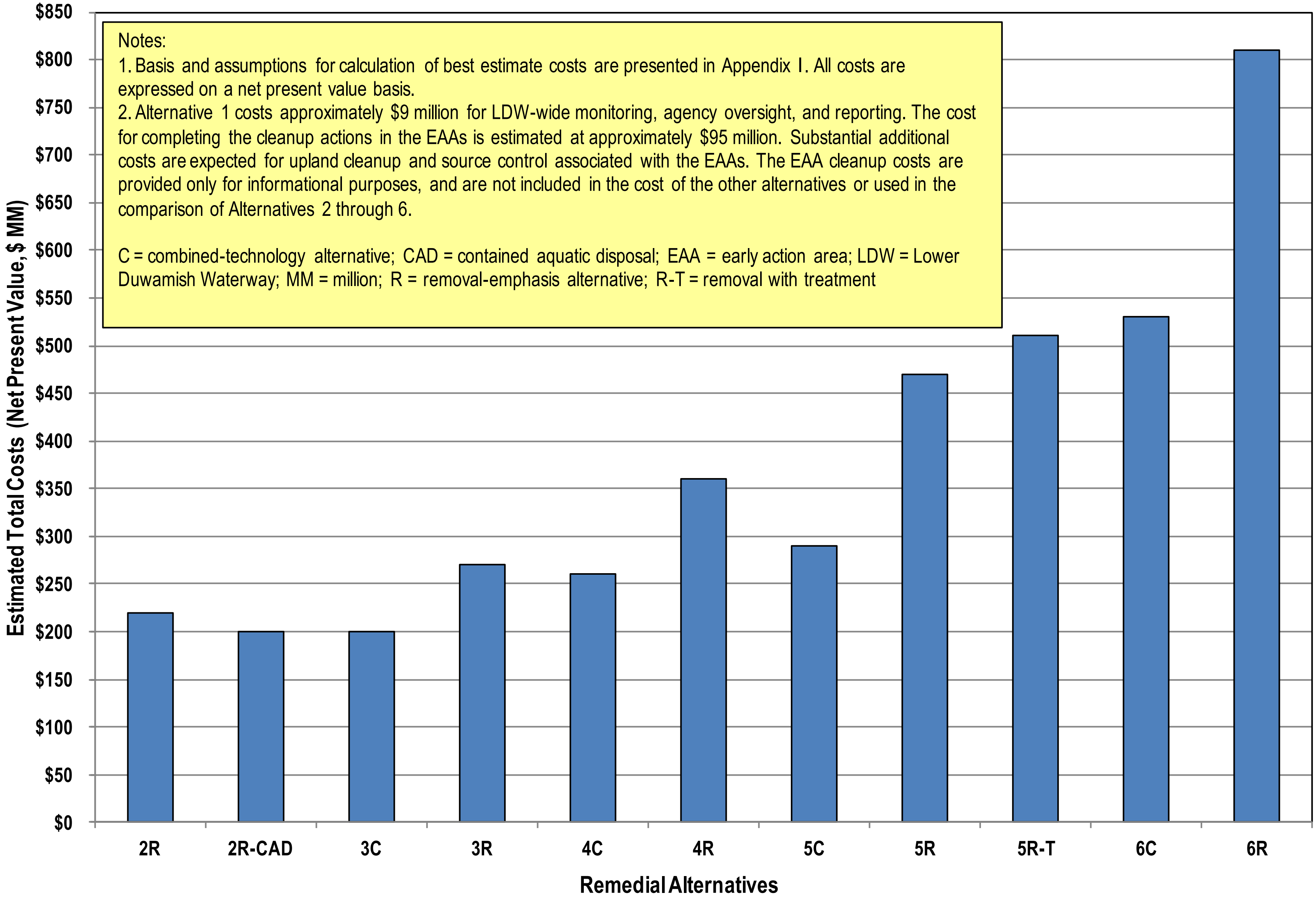
G BCM sensitivity for lateral values (mid input values for upstream and post-remedy bed sediment replacement value, high input value for lateral). Compare 30-year output for all alternatives (Table 9-4 with natural recovery, and Appendix J without natural recovery during construction).

H Resuspension and redeposition of total PCBs during active dredging (literature-based estimate).

I Spatial interpolation method uncertainty (Appendices A and H).

BCM = bed composition model; LDW = Lower Duwamish Waterway; PCB = polychlorinated biphenyl; STM = sediment transport model; SWAC = spatially-weighted average concentration

Figure 10-7 Estimated Total Costs of the Remedial Alternatives



Notes:

1. Basis and assumptions for calculation of best estimate costs are presented in Appendix I. All costs are expressed on a net present value basis.
2. Alternative 1 costs approximately $9 million for LDW-wide monitoring, agency oversight, and reporting. The cost for completing the cleanup actions in the EAAs is estimated at approximately $95 million. Substantial additional costs are expected for upland cleanup and source control associated with the EAAs. The EAA cleanup costs are provided only for informational purposes, and are not included in the cost of the other alternatives or used in the comparison of Alternatives 2 through 6.

C = combined-technology alternative; CAD = contained aquatic disposal; EAA = early action area; LDW = Lower Duwamish Waterway; MM = million; R = removal-emphasis alternative; R-T = removal with treatment

11 MTCA Evaluation of Remedial Alternatives

This section of the feasibility study (FS) evaluates the remedial alternatives[1] under the State of Washington Model Toxics Control Act (MTCA) requirements for conducting an FS. As stated within the Washington Administrative Code (WAC) 173-340-350, the purpose of an FS is to develop and evaluate remedial alternatives that will enable a remedial action to be selected for the site. This purpose is similar to that stated under the Comprehensive Environmental Response, Conservation, and Liability Act (CERCLA) of 1980. The Washington State Department of Ecology (Ecology) either conducts or oversees cleanup actions by liable parties under MTCA, as state law, but may also conduct or oversee such actions under CERCLA. The U.S. Environmental Protection Agency (EPA) either conducts cleanup actions or oversees such actions by responsible parties under CERCLA (with more stringent substantive MTCA requirements as applicable or relevant and appropriate requirements [ARARs]). EPA does not conduct cleanup actions under state law. Both Ecology and EPA are reviewing the FS and EPA will select the remedial alternative for the Lower Duwamish Waterway (LDW) in a Record of Decision (ROD).

The LDW FS is structured using the CERCLA guidance framework for developing, evaluating, and presenting the analysis of remedial alternatives. This approach is appropriate because MTCA and CERCLA are fundamentally similar. This section evaluates information developed and presented elsewhere in the FS, using the specific methodology and criteria set forth in MTCA (WAC 173-340-360). EPA provided limited input into the disproportionate cost analysis (DCA), because it will be relying on the nine criteria analysis required under CERCLA to select a cleanup alternative in the ROD. Ecology co-issued the remedial investigation (RI)/FS Administrative Order on Consent (AOC) and has overseen its implementation with EPA. The FS anticipates that Ecology will work with EPA to select the preferred remedy published in the Proposed Plan and will similarly work with EPA on the ROD. This evaluation is similar to the CERCLA comparative analysis evaluation in Section 10.

11.1 MTCA Requirements for Content of the FS

The general content and requirements under MTCA for an FS include:

- Developing cleanup standards applicable to the site. These standards are similar to preliminary remediation goals (PRGs) presented in Section 4.
- Assembling remedial alternatives that protect human health and the environment by eliminating, reducing, or otherwise controlling risks posed through each exposure pathway and migration route identified for the site.

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[1] MTCA refers to remedial alternatives as cleanup action alternatives. For consistency with the rest of the FS, the term “remedial alternatives” is retained in this section.

Remedial alternatives were assembled in Section 8. Section 9 presented the predicted outcomes of each remedial alternative.

- Using remediation levels to define when particular remedial alternative components will be used. Remedial action levels (RALs), which are essentially the same as remediation levels, are developed in Section 6.
- Using remedial action components that reuse or recycle, destroy or detoxify, immobilize or solidify hazardous substances, or provide for on-site or off-site disposal in an engineered, lined, and monitored facility or on-site isolation or containment of the hazardous substances with attendant engineering controls, and institutional controls and monitoring. The remedial alternatives incorporate a reasonable array of remedial technologies, which were screened in Section 7.
- Developing a reasonable number and types of alternatives, taking into account the characteristics and complexity of the LDW, including current site conditions and physical constraints. Eleven remedial alternatives were developed in Section 8 using 5 sets of RALs (Alternatives 2 through 6), two sets of technology options (combined technology ["C"] and removal emphasis ["R"]), two disposal options (upland disposal [default disposal option for all alternatives] and contained aquatic disposal [CAD] for Alternative 2R-CAD), and one treatment option (soil washing). The complete set of alternatives, including the no further action alternative, is: 1, 2R, 2R-CAD, 3C, 3R, 4C, 4R, 5C, 5R, 5R-Treatment, 6C, and 6R.
- Evaluating the residual threats that would accompany each remedial alternative to determine if alternatives are protective of human health and the environment. The risk-based outcomes and restoration time frames for each alternative are described in Section 9 and are incorporated into Sections 11.4 and 11.5.
- Using a standard point of compliance for alternatives unless it is not practicable, and using, as appropriate, alternatives with conditional points of compliance. Points of compliance for each alternative were discussed in Section 8 and are summarized in Section 11.3.
- Evaluating alternatives, using the "minimum requirements," which include threshold requirements, other requirements, additional minimum requirements, and identifying those alternatives, e.g., Alternative 6R, for which costs are disproportionate as shown by the DCA. Sections 11.2 through 11.5 present the MTCA evaluation of the remedial alternatives.

11.2 MTCA Minimum Requirements for Remedial Actions

Under MTCA, remedial alternatives are evaluated within the framework of minimum requirements, including threshold requirements, other requirements, and additional minimum requirements, as specified in WAC 173-340-360. Table 11-1 provides a schematic of the MTCA remedy selection process, which illustrates the process of screening the remedial alternatives against minimum requirements, and then comparing them using a DCA. Table 11-2 cross-references the minimum requirements to sections of the FS where relevant information and analyses are presented.

11.2.1 Threshold Requirements

WAC 173-340-360(2)(a) lists four threshold requirements for remedial actions. All remedial actions must:

- Protect human health and the environment.
- Comply with cleanup standards.
- Comply with applicable state and federal laws.
- Provide for compliance monitoring.

An evaluation of the remedial alternatives against these threshold requirements is presented in Section 11.3.

11.2.2 Other Requirements

Under MTCA, alternatives that achieve the threshold requirements must also achieve the following “other requirements” (WAC 173-340-360(2)(b)):

- Provide for a reasonable restoration time frame.
- Use permanent solutions to the maximum extent practicable, as determined by the DCA.
- Consider public concerns.

Each of these other requirements is described below.

11.2.2.1 Reasonable Restoration Time Frame

MTCA requires that remedial alternatives provide for a reasonable restoration time frame (i.e., determining reasonable time to achieve cleanup standards based upon requirements and procedures in WAC 173-340-360(4)). MTCA provides no specific reasonable restoration time requirement but allows for a comparison of restoration time frames among the remedial alternatives; these are discussed in the context of the remedial alternatives in Section 11.4. The Washington State Sediment Management Standards (SMS) require an evaluation of the practicability of achieving a 10-year restoration time frame after construction, but allows restoration time frames to exceed 10 years where it is not practicable to achieve the cleanup standards within 10 years.

11.2.2.2 Disproportionate Cost Analysis (DCA)

MTCA specifies that, when selecting a remedial alternative, preference shall be given to actions that are permanent solutions to the maximum extent practicable. Multiple actions to achieve cleanup standards are possible for the LDW. Identifying an alternative that is permanent to the maximum extent practicable requires weighing the costs and benefits of each. MTCA uses a DCA (WAC 173-340-360(3)(e)) as the tool for comparing each remedial alternative's incremental environmental benefits with its incremental costs. The following criteria, which are further defined under WAC 173-340-360(3)(f), are used to evaluate and compare remedial alternatives when conducting a MTCA DCA:

- Protectiveness
- Permanence
- Long-term effectiveness
- Short-term risk management
- Implementability
- Consideration of public concerns
- Cost.

This DCA is not an ARAR under CERCLA; it is a procedure required by MTCA to evaluate and potentially screen out alternatives for which the implementation costs are disproportionate to the benefits achieved. According to WAC 173-340-360(3)(e)(i), costs are considered disproportionate to benefits when the incremental costs of the alternative exceed the incremental benefits achieved by the alternative compared to that achieved by other lower-cost alternatives.

11.2.2.3 Consider Public Concerns

MTCA requires that public concerns solicited throughout the cleanup process pursuant to WAC 173-340-660 be considered. Consideration of community acceptance (including concerns of individuals, community groups, local governments, tribes, and federal and state agencies) has been a consistent part of the process of developing the FS, which includes review cycles, periods of public comment, community technical advisory groups, and community meetings. Consideration of public concerns to date has been qualitatively incorporated into the DCA in this FS. EPA and Ecology invited the public to review and comment on the Draft Final FS for the LDW, which was published October 15, 2010. More than 300 letters were received from individuals, businesses, interest groups, tribes, and government agencies. Key topics from these letters are summarized in Section 9.1.3. In addition, the ROD will include a formal response to public comments on the Proposed Plan. In contrast, while EPA often receives public comment on CERCLA remedial actions before EPA issues a Proposed Plan, the Proposed Plan is the only document for which EPA is required by CERCLA to solicit public comment (other than a consent decree to implement a remedial action).

11.2.3 Additional Minimum Requirements

Additional minimum requirements are described in MTCA as relevant for comparing and evaluating alternatives. These are described below and listed in Table 11-2.

11.2.3.1 Institutional Controls

Institutional controls are required by MTCA for all sites where hazardous substances remain at concentrations that exceed cleanup levels for unrestricted use (WAC 173-340-440(4)). All of the alternatives presented in Section 8 rely in part on institutional controls to protect human health, because none of the alternatives can achieve the total polychlorinated biphenyls (PCB) and dioxin/furan PRGs that are set at natural background for the human seafood consumption scenario. Institutional controls may also be required to protect certain elements of the remedial alternatives (e.g., engineered caps) to protect both human health and the environment.

MTCA (WAC 173-340-360(2)(e) and 173-340-440) requires that remedial alternatives that include institutional controls satisfy the following provisions:

- Remedial alternatives shall meet each of the minimum requirements in WAC 173-340-360 (2).
- The institutional controls should demonstrably reduce risks to ensure a protective remedy. This demonstration should be based on a quantitative scientific analysis where appropriate.
- Remedial alternatives shall not rely primarily on institutional controls and monitoring where it is technically possible to implement a more permanent remedial alternative for all or a portion of the site.
- Compliance with institutional controls requirements is part of periodic reviews specified in WAC 173-340-420.

Sections 11.2 through 11.5 address the first provision and evaluate the alternatives against the minimum requirements. Section 7 of this FS provides a detailed discussion of institutional controls, including a discussion of how they would reduce risks. The third provision is addressed within the DCA presented in Section 11.5. The fourth provision is included in compliance monitoring, as described in Appendix K.

11.2.3.2 Releases and Migration

Remedial alternatives shall prevent or minimize present and future releases and migration of hazardous substances in the environment (WAC 173-340-360(2)(f)). Pertinent factors that are considered for this evaluation include:

- Releases during implementation (e.g., during dredging or contained aquatic disposal)
- Releases associated with treatment residuals
- Potential future releases from scour in passive remediation and enhanced natural recovery (ENR) areas
- Potential future releases from failure of engineered containment remedies (e.g., caps)
- Control of ongoing sources of sediment contamination, including media that have been contaminated from historical releases or practices.

Construction best management practices and proper residuals management are designed into the engineering and construction management of the remedial alternatives to limit resuspension of contaminated sediment and recontamination of adjacent areas. Although minimized to the maximum extent practicable, resuspension from dredging still figures significantly in the short-term risk impacts. Capping with appropriately engineered armoring is considered in locations with the potential for significant erosion from high flows or vessel traffic. Capping limits the potential for future exposure of buried contaminated sediment. Application of ENR/*in situ* treatment[2] and monitored natural recovery (MNR) is limited in areas with potential scour (see Section 8 for details). In addition, a preliminary analysis of migration of hydrophobic organics (e.g., PCBs and polycyclic aromatic hydrocarbons [PAHs]) through caps (Section 7.1.4), shows that these contaminants of concern (COCs) would not migrate through a cap even in areas with low rates of sedimentation (less than 0.5 centimeters per year [cm/year]), and that caps can be engineered to retard breakthrough of COCs for 100 years or more in the absence of sedimentation (see Appendix C, Part 8). Maintenance and monitoring of the remedial actions will continue in an effort to minimize future releases.

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[2] For remedial alternatives with combined technologies, ENR/*in situ* treatment areas will be remediated with a thin-layer sand placement (ENR) or a thin-layer sand placement with carbon amendments (*in situ* treatment). The decision of whether to use ENR with or without *in situ* treatment would be made during remedial design. The FS assumes that 50% of the area designated for ENR would warrant the use of *in situ* treatment.

Source control and potential ongoing releases from sources are key considerations in all alternatives (see Section 2.4 and Section 8.4.1). Sediment remedies must be integrated with other actions to control sources of contamination to the sediments and water. Numerous actions are underway to clean up facilities near the LDW and control sources of contamination to the maximum extent practicable. Control of sources that caused sediment contamination or have the potential to cause recontamination is a critical element of all alternatives. Actions to control contaminant releases and migration are beyond the scope of this FS, but must be integrated with sediment remedies during the design of remedial actions (Ecology 2004). Generally, the control of sources to the maximum extent practicable is a MTCA expectation wherever attenuation of hazardous substances is part of a cleanup action (WAC 173-340-370(7)(a)).

11.2.3.3 Dilution and Dispersion

Remedial alternatives shall not rely primarily on dilution and dispersion unless the incremental costs of any active remedial measure over the costs of dilution and dispersion grossly exceed the incremental degree of benefits of active remedial measures over the benefits of dilution and dispersion (WAC 173-340-360(2)(g)).

The alternatives presented in this FS do not rely primarily on dilution and dispersion.

11.2.3.4 Remediation Levels

The MTCA term "remediation level (REL)" is essentially synonymous with "remedial action level (RAL)" used in previous sections of this FS. Remedial alternatives that use remediation levels shall meet the following requirements:

- Remedial alternatives shall meet each of the minimum requirements in WAC 173-340-360(2), including a determination that the remedial action is protective of human health and the environment
- Selection of a remedial alternative that uses remediation levels requires a determination that a more permanent remedial alternative is not practicable based on the DCA.

Each alternative uses RALs developed in Section 6 and institutional controls to protect human health and the environment.

11.3 Evaluation of Alternatives against Threshold Requirements

This section evaluates each remedial alternative with respect to the threshold requirements set forth in WAC 173-340-360. Table 11-3 summarizes the evaluation of remedial alternatives against each threshold and other requirement. For any alternative, the four threshold criteria must be achieved to be considered viable as a remedial alternative for the LDW and be carried forward in the evaluation. Ultimately, Alternatives 2 through 6 are designed to satisfy the four threshold requirements with critical differences in degree of certainty, reliance on institutional controls, and remediation time frames.

11.3.1 Protect Human Health and the Environment

Protection of human health and the environment is measured by each alternative's ability to achieve MTCA cleanup standards, while considering factors such as:

- The comparative permanence derived from removing contamination from the LDW system that would otherwise have to be managed and/or potentially addressed in the future, and
- Short-term impacts to human health and the environment (e.g., benthic community and habitat loss, increased fish and shellfish tissue contaminant concentrations during dredging and resulting increased risk to seafood consumers and river otters, community impacts from traffic, noise, and emissions) that may result from active remediation to achieve greater permanence.

In the LDW, risk reduction is measured by the achievement of the MTCA cleanup standards (Table 11-3). Detailed predicted outcomes expressed as contaminant concentrations and associated risk estimates are provided in Section 9 and Appendix M. Tables 9-2a and 9-3 present predicted human health risk-driver concentrations in surface sediments that are achieved over time by the alternatives. Tables 9-7a, 9-7b, and 9-8 present the predicted human health risks for each remedial alternative. Tables M-5a through M-5d in Appendix M, Part 1 present predicted risks for individual contaminants for the direct contact scenarios.

As indicated in Table 11-3, risk reduction for remedial action objectives (RAOs) 1 through 4 is achieved for Alternatives 2 through 6 using different combinations of active remediation, natural recovery, source control, and institutional controls to reduce exposures. As discussed in Sections 9 and 10, the overall improvement in the quality of the LDW aquatic environment for Alternatives 2 through 6 is predicted by modeling to be similar over the 10- to 30-year time frame with varying degrees of certainty and permanence. Remedy construction can result in related environmental risks (see Table 10-1). For example, dredging activities that remove contaminants from the LDW and therefore provide greater long-term protectiveness and permanence are also associated with relatively higher short-term risk of water quality inputs, elevated concentrations of COCs in fish and shellfish tissue, and potential sediment recontamination, compared to other remedial technologies such as capping, ENR, and MNR. Some short-term risks can be reduced through prudent design practices and best management practices during construction.

Alternatives 2 through 6 pass the threshold criteria of protecting human health and the environment although the alternatives achieve protectiveness by different means. Long-term risks and short-term (i.e., construction-related) risks are further evaluated as part of the DCA in Section 11.5.

As stated elsewhere in the FS, the LDW is a complex and dynamic system. This FS is intended to provide a best estimate of the comparative risks to human health and the environment that would remain after remediation under various alternatives. However, uncertainty is inherent in predictions of future environmental conditions. To attempt to address these uncertainties, a sensitivity analysis was performed using the bed composition model (BCM) to try to bound the range of potential outcomes after remediation. The analysis is presented in Section 9, additional sensitivity results are included in Appendix M, and model uncertainty is further discussed in Section 9.3.5. The potential range of outcomes for the remedial alternatives was produced by varying the BCM parameter input values. In addition, an estimate of the degree of certainty that the remedial alternatives will be successful is incorporated into Metric 3a of the DCA (Table 11-6 and Section 11.5.2.3).

11.3.2 Comply with Cleanup Standards

For remedial alternatives to be considered viable, the alternatives must comply with cleanup standards. Cleanup standards in MTCA have three components: cleanup levels, points of compliance, and ARARs. Cleanup standards will be set by EPA and Ecology in the ROD. For this FS, the cleanup levels are the PRGs, which were developed considering both risk-based cleanup levels and ARARs along with practical quantitation limits (PQL) and background concentrations. The point of compliance for sediments throughout the LDW is a 10-cm depth, except in potential clamming and beach play areas when addressing PRGs for direct contact pathways. In those areas, the FS assumes the point of compliance is a 45-cm depth to be protective of direct contact exposures (RAO 2).

The PRGs developed in Section 4 considered MTCA requirements for cleanup levels. MTCA requires that cleanup levels achieve a hazard index of 1 or less and a total excess cancer risk of 1×10^{-5} or less. MTCA also requires that the excess cancer risk for each individual hazardous substance must be 1×10^{-6} or less. MTCA allows an upward adjustment of the cleanup level to natural background or the PQL, whichever is greater, if the cleanup level is below natural background or the PQL. All PRGs and the basis for each are listed in Tables 4-7 and 4-8.

Table 11-3 summarizes predicted outcomes for the remedial alternatives with respect to the RAOs and PRGs, based on the information presented in Section 9. Most PRGs are predicted to be achieved at the end of construction or within 10 years after construction, depending on the alternative and risk endpoint (e.g., natural background-based PRGs).

None of the alternatives are predicted to achieve the PRGs for RAO 1; however, risk reduction is managed for PCBs and dioxins/furans through a combination of active remediation, natural recovery, and institutional controls (e.g., seafood consumption advisories) to reduce exposures (as discussed in Section 9). To the extent that all practicable remediation cannot achieve PRGs, the alternatives would rely on institutional controls to reduce human exposure to COCs in resident fish and shellfish. Some institutional controls, such as seafood advisories, are not enforceable and therefore have limited reliability.

For RAO 2, all alternatives are predicted to achieve a total direct contact excess cancer risk (from all risk drivers combined) of less than or equal to 1×10^{-5} and a hazard index of less than 1. All alternatives are predicted to achieve a direct contact excess cancer risk of less than 1×10^{-6} for total PCBs, dioxins/furans, and carcinogenic polycyclic aromatic hydrocarbons (cPAHs) (except for Beach 3).

For cPAHs, the PRG for the beach play direct contact scenario (90 micrograms toxic equivalent per kilogram dry weight [µg TEQ/kg dw]) is not predicted to be achieved at some beaches by any remedial alternative. This PRG is based on achieving 1×10^{-6} excess cancer risk or less for beach play areas. All of the alternatives are predicted to achieve a risk threshold of 1×10^{-6} or less[3] except for Beach 3, which is likely influenced by lateral sources. Alternatives 1 and 2 are predicted to achieve this risk threshold of 1×10^{-6} within approximately 25 and 10 years after construction, respectively. Alternatives 3 through 6 are predicted to achieve the 1×10^{-6} risk threshold prior to or immediately following construction, except for Beach 3, as discussed above.

For arsenic, none of the alternatives are predicted to achieve the arsenic PRG of 7 milligrams (mg)/kg dw, which is based on natural background; however, concentrations are predicted to be close to the PRG and are predicted to be within the long-term model-predicted concentration range at or before the end of construction for Alternatives 2 through 6.

For RAO 3, Alternatives 2 through 6 are predicted to achieve the SQS within 10 years after construction. Alternative 1 may need more than 10 years of natural recovery to achieve the SQS.

For RAO 4, Alternatives 2 through 6 are predicted to achieve a hazard quotient of less than 1 following construction and Alternative 1 is predicted to achieve a hazard quotient of less than 1 within 5 years following construction.

11.3.3 Comply with Applicable State and Federal Laws

This criterion is discussed in Section 9.1.1.2. All remedial alternatives would likely comply with the applicable state and federal laws, except for federal and state water quality criteria and standards for some COCs. (Note that Sections 9 and 10 discuss

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[3] As a result of rounding, predicted cPAH concentrations of up to 134 µg TEQ/kg result in an excess cancer risk estimate of 1×10^{-6} or lower.

compliance with MTCA requirements as CERCLA ARARs, whereas this section discusses MTCA requirements in Section 11.3.2, Comply with Cleanup Standards. MTCA requirements are not literally MTCA ARARs.)

11.3.4 Provide for Compliance Monitoring

Section 8.2.4 describes the MTCA requirements for protection, performance, and confirmation monitoring. The monitoring program included in Alternatives 2 through 6 allows the progress toward achieving cleanup standards to be assessed on a periodic basis. The conceptual monitoring program as presented in Appendix K complies with the MTCA requirements and Table 8-10 cross-references the MTCA monitoring terms with the CERCLA monitoring terms used in this FS.

11.3.5 Threshold Requirements Summary

The remedial alternatives are not predicted to ultimately achieve compliance with some cleanup levels; thus, institutional controls must be included to reduce human exposure to COCs in resident fish and shellfish to the extent all practicable remedial measures cannot achieve them. Some institutional controls, such as seafood advisories, are not enforceable and therefore have limited reliability. The estimated time required to achieve compliance and the degree of certainty in these estimates vary among the alternatives. The extent to which Alternatives 2 through 6 comply with the applicable state and federal laws is discussed above in Section 11.3.3, and all of these alternatives incorporate the compliance monitoring required for evaluating whether cleanup standards are being achieved.[4]

11.4 Provide for a Reasonable Restoration Time Frame

WAC 173-340-360(4)(b) presents several "factors" to consider when determining whether a remedial alternative has a reasonable restoration time frame. Relevant factors (i) potential risks posed by the site to human health and the environment; (iii) and (iv) current and potential future use of the site and associated resources affected by the releases; (vi) likely effectiveness of and reliability of institutional controls; (vii) ability to control and monitor migration of hazardous substances; (viii) toxicity of hazardous substances; and (ix) natural recovery are generally evaluated as part of the CERCLA nine criteria analysis. The SMS standards in WAC 173-204-580(3)(a) list similar factors when determining if a remedial alternative has a reasonable "cleanup time frame" (applicable to RAO 3) including "the practicability of achieving the site cleanup standards in less than a 10-year period [after construction]." Natural recovery processes may be used to meet these cleanup standards after remedy completion.

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[4] Alternative 1 also includes monitoring outside of the early action areas (EAAs), but it does not include contingency actions outside of the EAAs to ensure cleanup standards are being achieved.

Table 11-3 summarizes the restoration time frames based on the analysis in Section 9. The values for "restoration time frame" are identical to the values for "time to achieve cleanup objectives" presented in Sections 9 and 10. As discussed in Sections 9 and 10, no alternative achieves the PRGs for RAO 1; thus, an alternative measure of the lowest long-term model-predicted concentrations is used to represent levels as close as practicable to PRGs for the purpose of this analysis. Alternatives 3C, 4C, 5C, and 6C are predicted to achieve cleanup objectives for the four RAOs in the shortest time (16 to 18 years after construction begins). Alternatives 2R, 2R-CAD, 3R, 4R, 5R, and 5R-Treatment are predicted to take moderately longer (21 to 24 years after construction begins) to achieve the cleanup objectives because of their reliance on dredging, which takes longer to implement than capping and ENR/*in situ*. Finally, Alternative 6R takes the longest time (42 years) because of its long construction period and the ongoing impacts to fish and shellfish tissue concentrations during construction.

Alternative 6R is the only alternative considered to not have a reasonable restoration time frame. Alternatives 2 through 6C are assumed to have reasonable restoration time frames based on the nine factors in WAC 173-340-360(4)(b). All of the alternatives are retained for the DCA evaluation.

As discussed elsewhere in this FS, many uncertainties are associated with the estimated restoration time frames. To some degree, these uncertainties could be managed through monitoring coupled with adaptive management, which would provide information during construction to assess risks and progress toward achieving the MTCA cleanup levels. This assessment could allow for adjustments in cleanup technologies to try to practicably achieve these levels in locations where the initial effort did not achieve RALs. Adaptive management measures are included in Alternatives 2 through 6 to allow additional areas to be identified and managed by alternative means as needed, including areas that may still exceed SMS criteria after 10 years. These measures are incorporated into the cost estimates for the alternatives, but are not incorporated into construction time frames or restoration time frames, and thus may increase remediation times beyond those predicted in this FS.

11.5 Disproportionate Cost Analysis

MTCA requires that remedial alternatives use permanent solutions to the maximum extent practicable. For example, alternatives that include more dredging remove more contaminated sediment from the LDW, which provides a more permanent solution than alternatives that leave more contaminated sediment in the LDW. However, dredging is more expensive than capping, and capping is more expensive than ENR, which is in turn more expensive than MNR. The DCA is a MTCA procedure to evaluate tradeoffs, including costs, among technologies that is more specific than CERCLA's general nine criteria analysis. It was specifically created to weigh incremental environmental benefits against the incremental cost of such benefits. This determination is made based on the DCA process in which: 1) the most practicable, permanent remedial alternative serves as the baseline; and 2) the benefits of the remedial alternatives to human health and the environment are evaluated and compared to the costs. This analysis uses the evaluation criteria listed in WAC 173-340-360(3)(f). Both quantitative measures and more qualitative best professional judgments are used in assessing benefits (WAC 173-340-360(3)(e)(ii)(C)). The metrics used in the DCA are described in Table 11-4. Results of the DCA are summarized in Table 11-5. Table 11-6 provides the detailed metrics and scoring for each evaluation criterion.

Each aspect of the DCA scoring requires professional judgment. Quantitative measures were used where possible.

11.5.1 Weighting of MTCA Evaluation Criteria

The MTCA evaluation criteria presented in WAC 173-340-360 (3)(f) were weighted in consultation with Ecology (Table 11-4). The weightings emphasize the core purpose of protecting human health and the environment and reflect site-specific considerations, such as the size, complexity, uncertainty, and potential restoration time frames involved in the remedial alternatives. The sum of the weightings equals 100%.

"Protectiveness" represents the ultimate objective of implementing a remedial alternative. Therefore, overall protectiveness ratings were weighted 25%.

A weighting of 20% was assigned to the "permanence" criterion. In evaluating the alternatives under this criterion, MTCA focuses on the degree that the toxicity, mobility, or volume of hazardous substances is reduced, and considers the extent to which contamination is removed from the LDW rather than leaving it buried in place.

"Effectiveness over the long term" is an important requirement because it addresses how well the remedy reduces risks, for example, whether contamination is removed or left in place to be managed over the long term, and whether controls are adequate to maintain protection against exposures to contamination left in place in the long term. This criterion therefore received a weighting of 30%.

A weighting of 15% was assigned to the "management of short-term risk" criterion. This weighting considers the relatively long durations of most of the remedial alternatives. Because of the extended time frames for alternatives with larger active remediation footprints, short-term risks to workers, the community, and the environment can extend for many years. Generally, short-term risks are actively monitored during the period the risks exist.

A weighting of 5% was assigned to the "technical and administrative implementability" criterion. This weighting reflects the fact that implementability is less associated with environmental concerns than with the relative difficulty and uncertainty of implementing the project. It includes both technical factors and the administrative factors associated with permitting and completing the cleanup.

Consideration of public concerns is assigned a weighting of 5%. This weighting reflects that most public concerns are embodied by the other criteria of the DCA. In other words, the degree of risk reduction, the long-term reliability, the community and environmental impacts during construction, and cost to the local economy are all represented in public comments and in the other metrics of the DCA. Public concern rankings in the DCA provide a summary of these community concerns, based on public comments and stakeholder meetings for the FS.

Cost is not a weighted benefit, but is used in the DCA to evaluate the benefit of each alternative relative to its cost.

11.5.2 DCA Evaluation for Remedial Alternatives

Table 11-5 provides a summary of how well the remedial alternatives rate on a scale from 0 to 10 for each MTCA criterion. The following evaluations provide the basis for the numerical ratings in the DCA. These ratings are then weighted and summed for an overall measure of the benefits achieved by the alternatives, presented in Table 11-5, along with the cost estimates (as net present value) for each remedial alternative. Table 11-6 provides the metrics used to develop the ratings summarized in Table 11-5. Each metric includes the unit used for each alternative (e.g., years, cubic yards, or acres), as well as the representative value that would receive a score from 0 to 10. In general, a score of 0 represents a poor-performing alternative for that metric, and a score of 10 represents an optimal performing alternative for that metric. Note that depending on the basis for a metric’s scale, the alternatives may not always cover the full range (0 to 10) if they all have less than optimal results for that measure.

The goal of Table 11-6 is to select benefit metrics for each DCA evaluation criterion such that the benefit metrics reasonably reflect the DCA criteria. Some metrics appear more than once because the selected metric is a surrogate measure of the value statement for each line item in the DCA, or because the same metric is directly applicable to multiple MTCA-defined criteria. For example, risks during implementation appear under both overall protectiveness and management of short-term risks. This ensures that each DCA criterion is quantified and contributes to the overall benefit scoring.

A significant number of choices were made in selecting each metric and selecting the scoring range (defining what 0 and 10 represent). These choices were made using best professional judgment; however, scoring the “benefit” of each remedial alternative is somewhat subjective. These scores provide a useful tool for comparing remedial alternatives, but do not provide an absolute or precise measurement of benefit. Small differences in overall benefit scores should therefore be considered to have limited significance.

The following subsections describe the MTCA DCA criteria as defined by WAC 173-340-360 and the metrics that were used to evaluate each alternative’s performance relative to that metric in the DCA.

11.5.2.1 Protectiveness

In MTCA, protectiveness is evaluated based on the degree to which existing site risks are reduced, the time required to reduce those risks and to achieve cleanup standards, and on-site and off-site risks resulting from implementing the alternative, and improvement of the overall environmental quality. For the LDW, protectiveness was quantified using three metrics: total human health exposure risks, cumulative benthic exposure risks, and risks during implementation.

Degree to which Existing Risks are Reduced, Overall Improvement in Environmental Quality, and the Time to Achieve Cleanup (Metrics 1a and 1b: Cumulative Exposure and Cumulative Benthic Exposure)

Metrics for assessing the degree to which LDW-wide risks are reduced, the overall improvement in environmental quality, and the time to achieve cleanup standards were based on milestones for RAOs 1 and 3. This equal weighting assumes that protection of human health and protection of benthic invertebrates are of equal importance; a different balance could well have been used, elevating the importance of one above the other. This choice, like the choice to eliminate RAOs 2 and 4 from this criterion, and other choices throughout the DCA, illustrate how different users may validly apply the DCA tool differently. To assess these criteria for each remedial alternative, the predicted total PCB spatially-weighted average concentration (SWAC) (RAO 1; Figure 10-1a) and the predicted number of SQS point exceedances (RAO 3, Figure 10-2) were integrated over a 45-year time span based on the restoration time frame for Alternative 6R. This 45-year period includes both the time required to construct each alternative (see Table 11-3) and a post-construction recovery period that varies from 42 years (Alternative 3) to 3 years (Alternative 6R).

For Metric 1a, total PCB SWACs were used as a surrogate for cumulative exposure for seafood consumption risk from fish and shellfish tissue contaminant concentrations over time. The BCM 5-year outputs presented in Table 9-2a were used to calculate the SWACs. A low score of 0 represented natural recovery without construction (i.e., Alternative 1), and a high score of 10 represented an unlikely achievable site-wide PCB SWAC equivalent to the long-term model-predicted SWAC (39 µg/kg dw) within 5 years after the start of construction, and held at 39 µg/kg dw for the next 40 years (although it is possible that a lower level will be achieved at some point in the future). Fish and shellfish contaminant concentrations (and the associated seafood consumption risks) are predicted to increase during dredging activities. These calculations do not include these effects and therefore may understate risks throughout the construction period, particularly for alternatives with larger dredging footprints.

In Metric 1b, predicted SQS exceedances were integrated over a 45-year time span. A score of 0 represented natural recovery without construction (i.e., Alternative 1), and a score of 10 represented SQS exceedances reduced to 0 within 5 years after the start of construction, and held at no exceedances for the next 40 years.

Alternatives 5C and 6C score highest for these two metrics because they strike a balance between relatively large areas actively remediated and relatively short construction time frames. Alternatives with smaller active remedial footprints and longer construction time frames scored lower.

Risks from Implementation (Metric 1c)

As noted in Section 11.3.1, implementing the remedial alternatives causes construction-related environmental risks such as mobilization of contaminants during construction. Risks from implementation include a number of factors that are proportional to the total construction time. Risks to the community, construction workers, and the environment are simplified into one metric (the construction time) that represents several metrics, such as:

- Impacts to workers and the community from dredging and transporting sediment and capping materials
- Air pollution generated and depletable resources consumed (environmental impacts)
- The expected short-term increases of contaminant concentrations in fish and shellfish tissue in and near the LDW and associated increased risks to people who consume resident seafood during that period (community risks)
- Releases of contaminants from the site, and disruptions to aquatic habitat (environmental risks).

The implementation risks to the community are largely attributable to the increased construction-related traffic through local communities, along with risks to those people who choose to consume resident seafood that will have elevated tissue concentrations during the construction period despite the existing Washington State Department of Health advisory warning not to eat any. The latter risks could perhaps be reduced by using more robust seafood consumption advisories to reduce exposure to contaminants in resident seafood during construction.

The evaluation of environmental risks includes the quantitative impacts on the environment both from air pollution generated by construction activities and depletable resources consumed, as well as the expected short-term increases of contaminant concentrations in fish and shellfish tissues, and physical destruction and necessary restoration of aquatic habitat. Increased resuspension of sediment associated with construction is anticipated to result in higher contaminant concentrations in fish and shellfish tissues during construction. In addition, the recovery time of benthic habitat in areas may be greatly affected by the degree to which the existing sediment habitat is impacted, the total area impacted, and the degree to which the habitats are contiguous.

For the purposes of this analysis, all of these risks are assumed to be directly proportional to the duration of active construction. This is appropriate because the amount of construction activity (and associated impacts) per construction season would be similar for all of the alternatives. Therefore, the net impacts from implementation would be proportional to the construction time frame for each alternative. A score of 0 represents the longest construction time frame of the remedial alternatives (Alternative 6R: 42 yrs); a score of 10 represents no construction following the remediation of the early action areas (Alternative 1).

For Metric 1c, Alternatives 1 through 6 score progressively lower, and removal alternatives score lower than combined alternatives, indicating greater risks during implementation for the removal-emphasis alternatives with larger active footprints.

Overall Scores for Protectiveness

The preceding three metrics (1a, 1b, and 1c) are averaged using the weighting factors shown in Table 11-6. These weighting factors express the relative importance of the metrics using best professional judgment. Overall, the combined alternatives score slightly higher than the removal alternatives because they are predicted to achieve comparable risk reduction in shorter time frames with fewer implementation risks. The alternatives with larger active footprints tend to score higher than alternatives with smaller active footprints (e.g., Alternative 6C versus Alternative 3C). The exceptions are Alternatives 5R and 6R, which score the same or lower than Alternative 4R because of the greater impacts over their longer construction periods.

11.5.2.2 Permanence

MTCA defines permanence as the degree to which the alternative permanently reduces the toxicity, mobility, or volume of hazardous substances, including the adequacy of the alternative in destroying hazardous substances, the reduction or elimination of hazardous substance releases and sources of releases, the degree of irreversibility of waste treatment processes, and the characteristics and quantity of waste residuals generated.

For the LDW, rating the alternatives for permanence is not completely straightforward because none of the remedial alternatives destroys contaminants; rather, they do one of the following: 1) contain the contaminated material within the LDW thereby reducing its toxicity and mobility; 2) remove it to a landfill (all alternatives in varying degrees), thereby eliminating its toxicity, mobility, and volume with respect to site receptors; 3) move it to a CAD (Alternative 2R-CAD); or 4) segregate it into more and less contaminated fractions before sending the higher contaminated material to the landfill and placing the less contaminated material back into the environment (soil washing in Alternative 5R-Treatment). Removal of contaminated sediments to a landfill ranks higher for this criterion than leaving contamination within the LDW where it could potentially be exposed due to anthropogenic events (e.g., excavation or ship scour) or natural events (e.g., an earthquake).

For this analysis, two metrics were selected to represent permanence. The first metric (2a) is volume of sediment removed from the LDW. This metric was scaled from 0 cy (score 0), based on no sediment removal, to 3.9 million cy (score 10), based on the removal of material above the Alternative 6 RALs for Alternative 6R. For this metric, the removal-emphasis alternatives score significantly higher than the combined-technologies alternatives, and alternatives with larger active footprints score higher than alternatives with smaller active footprints (e.g., Alternative 6R versus Alternative 2R).

The second metric (2b) ranks the reduction in contaminant mobility in the LDW based on the acres of each remedial technology used. For this analysis, dredging (removal) and capping were assumed to reduce mobility more than the other technologies (scores of 9 and 8 respectively), *in situ* treatment was assumed to reduce mobility more than a moderate amount (score 7), ENR was assumed to reduce mobility a moderate amount (score 4), and MNR and verification monitoring were assumed to reduce mobility to a lesser degree (score 2). Burial is the mechanism by which ENR, MNR, and verification monitoring reduce mobility; monitoring and adaptive management (i.e., contingency actions) ensure that contaminated sediment is immobilized sufficiently. *In situ* treatment further reduces mobility by adding amendments that bind or retard contaminants. This metric scores similar to the previous metric: the removal-emphasis alternatives score significantly higher than the combined-technologies alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints.

11.5.2.3 Effectiveness over the Long Term

The effectiveness of the remedial alternatives over the long term is evaluated under MTCA by considering the following components:

- Degree of certainty that the remedial alternative will be successful
- Reliability of the alternative over the period during which risk-driver contaminants remain on site (including subsurface contamination) at concentrations higher than PRGs (or cleanup levels)
- The magnitude of residual risk
- Reliability of institutional controls and engineering controls used to manage risks to the extent they are necessary
- Cleanup and disposal methods hierarchy listed in WAC 173-340-360(3)(f)(iv).

For the LDW, these components are simplified and scored by the weighted average of two metrics: 1) the degree of certainty that the remedial alternatives will be successful and 2) the reliability of controls to manage risks. These metrics are shown in Table 11-6 and summarized below.

Degree of Certainty that the Remedial Alternatives Will Be Successful (Metric 3a)

As noted in Section 9.3.5 and elsewhere in the FS, the predicted outcomes and success of remediation for all remedial alternatives have some uncertainty, particularly those that rely more on natural recovery. Uncertainties include the effectiveness of source control, the rates of natural recovery, concentrations of incoming sediment from upstream and lateral sources, and the effectiveness of remedial technologies (see discussion in Sections 8.4 and 9.3.5). Some of these uncertainties are the same for all remedial alternatives, such as the actual contaminant concentrations in upstream sediment. However, uncertainties related to the effectiveness of specific remedial technologies (including MNR) will affect the alternatives to different degrees. Therefore, the remedial alternatives were scored based on the remedial technologies that would be employed.

For this metric (3a), each remedial technology is weighted based on best professional judgment. This analysis assumed that the remedial technologies that depend on construction only (i.e., capping and dredging) have a higher degree of certainty of success than remedial technologies that depend on natural recovery (i.e., ENR and MNR). Dredging scores a 9 because, while it would remove a significant degree of contamination from the LDW, removal would not be perfect in practice and some contamination would be left following dredging (e.g., due to dredge residuals or losses during dredging). Capping scores 9 because it would isolate contaminated sediment, but contaminated sediment would remain on site with a chance of exposure. *In situ* treatment scores 7 because it would not provide full containment, like a cap, but would reduce the possibility of contaminant breakthrough and uptake by adding a carbon amendment. ENR scores 6 because it depends on natural recovery, but also achieves additional protectiveness with a thin layer of sand. MNR and verification monitoring score 3 because they depend on natural recovery. However, monitoring and adaptive management could improve areas that do not achieve performance goals. (As noted above, adaptive management measures are incorporated into the cost estimates for the alternatives, but are not incorporated into construction time frames or restoration time frames, and thus may increase remediation times beyond those predicted in this FS.) The remedial alternatives are scored based on the weighted average of the acreage for each technology used in Area of Potential Concern 1 (AOPC 1). For example, if an alternative assigned dredging to all of AOPC 1, then the alternative would score a 9, and if the alternative assigned MNR to all of AOPC 1, it would score a 3. Half dredging and half MNR would score a 6.

Table 11-6 shows the scores for Metric 3a for the remedial alternatives. The removal-emphasis alternatives score higher than the combined-technologies alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints (e.g., Alternative 6 scores higher than Alternative 2).

Reliability of Institutional Controls and Engineering Controls Used to Manage Risks (Metric 3b)

All remedial alternatives would use similar institutional and engineering controls to manage risk. However, the degree to which they need to use these controls would differ. Institutional controls include seafood consumption advisories, public outreach and education programs, and environmental covenants and restricted navigation areas as described in Section 7. Alternatives 2 through 6 would all rely on seafood consumption advisories to address residual risks associated with RAO 1. Seafood consumption advisories would remain in effect for all remedial alternatives. However, the alternatives vary significantly in the degree to which environmental covenants would be relied upon.

Therefore, reliability was mainly scored based on engineering controls, which would be needed to manage and monitor contaminants remaining on site. Alternatives with more dredging received higher scores both because removal of contaminants is a more reliable technology in the long term and because it does not rely on covenants or other devices to address potential exposure of contaminants left in place. This metric (3b) is scored as a proportion of the surface area where buried contamination potentially remains on site. For this metric, the acres with caps, ENR/*in situ*, MNR, and verification monitoring in AOPC 1 are summed for each alternative. Alternative 2R-CAD includes the CAD area. The metric is scored from none of AOPC 1 removed (score 0) to all of AOPC 1 removed (score 10). The removal-emphasis alternatives score higher than the combined-technologies alternatives for this metric, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints.

Overall Score for Effectiveness over the Long Term

Metrics 3a and 3b were averaged using the weighting factors shown in Table 11-6. These weightings show the relative importance of the metrics using best professional judgment. Overall, the result is that the removal-emphasis alternatives score higher than the combined-technologies alternatives, and the alternatives with larger active footprints score higher than the alternatives with smaller active footprints.

11.5.2.4 Management of Short-term Risks

Short-term risks to human health and the environment occur during construction and implementation. This criterion uses two components: the risks presented by the implementation of the remedial alternative and the effectiveness of the protective measures used to manage those short-term risks. These components are the metrics used in the FS to compare the remedial alternatives.

Implementation Risks (Metric 4a)

Implementation risks (Metric 4a) are assumed to be equivalent to the metric for risks from implementation (Metric 1c) discussed in Section 11.5.2.1, which are directly proportional to construction time frames.

Effectiveness of Protective Measures to Manage Short-term Risks (Metric 4b)

The second metric (4b) rates the effectiveness of protective measures such as institutional controls and best management practices that would be used to mitigate the risks associated with the remedial alternatives during construction.

For this analysis, the FS assumes that the same types of protective measures are used for all alternatives; therefore, the effectiveness of these protective measures is inversely proportional to the construction time frame of the remedial alternative. The alternatives with the shortest construction time frame ranked the highest and those with the longest construction time frames ranked the lowest.

Overall Score for Management of Short-Term Risks

The construction time frames and relative rankings of the alternatives are shown in Table 11-6. Alternatives rate progressively lower from Alternatives 2 through 6 and rate lower for removal-emphasis alternatives than for combined-technologies alternatives.

11.5.2.5 Technical and Administrative Implementability

Implementability under MTCA has several components, including technical feasibility; availability of necessary off-site facilities, services, and materials; administrative and regulatory requirements; scheduling, size, and complexity; monitoring requirements; access for construction and operation and maintenance monitoring; and integration with existing facility operations and other remedial actions. Each component is taken into account and a rating is given to each remedial alternative based on best professional judgment.

Alternatives 5R-Treatment and 6R are rated lowest because they are considered more challenging to implement: Alternative 5R-Treatment because of the difficulty of treating and reusing contaminated sediment and Alternative 6R because of the very large scope of remediation. Alternatives 2R-CAD, 5R, and 6C are rated in the middle: Alternative 2R-CAD because of the difficulty of implementing a CAD in the LDW and Alternatives 5R and 6C because of the relatively large scope of dredging. Alternatives 2R, 3C, and 3R are rated higher because of reliance on MNR to achieve cleanup objectives. Alternatives 4C, 4R, and 5C score the highest because of the relative balance between reliance on MNR and the scope of dredging.

11.5.2.6 Consideration of Public Concerns

The public involvement process under MTCA and CERCLA is used to identify public preferences and concerns regarding the remedial alternatives. This includes concerns raised by individuals, community groups, local governments, local businesses, tribes, federal and state agencies, and anyone who may have an interest in the site. Issuance of the Proposed Plan will provide an additional opportunity for identifying public comments, concerns, and feedback. This criterion will ultimately be evaluated by EPA and Ecology in the selection of the preferred alternative in the ROD.

Based on preliminary feedback to date on the draft final FS, Alternative 6R scores the highest because most of the comments received favored more removal. Remedial alternatives that have relatively large cleanup scopes and rely less on MNR (Alternatives 5C, 5R, 5R-Treatment, and 6C) are scored high because they also had large volumes removed. The smaller cleanups (Alternatives 2R, 2R-CAD, and 3R) were rated lower. Alternative 3C also received favorable comments and was therefore scored higher. Although Alternatives 3C has a smaller active footprint (along with 4C and 4R), it achieves the greatest risk reduction of all of the alternatives within the shortest construction time frame.

11.5.2.7 Costs

Estimated costs to implement the remedial alternatives are presented in Appendix I (on a net present value basis). These cost estimates and their associated total weighted benefits can be used by the Agencies to determine whether a remedial alternative's costs are disproportionate to the benefits provided by the alternative. The costs are presented in Tables 11-3 and 11-5 and are shown with the total benefits ratings on Figures 11-1 through 11-3. While EPA does not use the DCA methodology in its consideration of costs in remedy selection, EPA may consider it. Among the factors EPA would most critically consider is the extent to which accurate values are believed to have been assigned to the various DCA criteria.

11.5.3 Relative Benefits and Costs for Treatment Technology

By comparing Alternative 5R with Alternative 5R-Treatment, a direct comparison of upland landfill disposal and soil washing treatment can be made. A review of the scoring of the two alternatives shows that Alternative 5R scores slightly higher for benefit and is slightly lower in cost, indicating that soil washing treatment benefits may be slightly disproportionate to costs.

For informational purposes, the estimated additional cost associated with adding soil washing treatment to all alternatives is shown in Table 11-7.

11.5.4 Summary of DCA Results

Table 11-5 summarizes the DCA and calculated cost/benefit ratios for Alternatives 2 through 6. Considering all of the ratings from the DCA evaluation, the total benefit scores range from 3.8 to 6.6 for the remedial alternatives. The total benefit scores indicate that more dredging has other adverse effects that do not result in higher overall scores, even though more dredging scores the highest in permanence and effectiveness over the long term. More reliance on containment has other benefits that result in higher scores, especially short construction times relative to dredging and reduction of potential resuspension that occurs during dredging.

Weighted benefits that differ by small amounts should be considered equivalent because the large degree to which best professional judgment plays a role in the analysis does not allow for precision and because simplifying assumptions used in evaluating criteria may obscure some differences among alternatives.

A series of figures are provided that interpret the results of the DCA. Figure 11-1 shows the weighted benefit score for each alternative with an overlay of cost. The total benefits for the remedial alternatives range from 3.8 to 6.6, and costs range from $200 to $810 million net present value (see Appendix I for cost details). More expensive alternatives do not necessarily show proportional increases in overall benefit.

Figure 11-2 plots benefits versus the cost for the alternatives. This graphic shows the same benefit rankings as Figure 11-1, but provides a visual representation of the spread of costs. This figure also indicates that added cost does not necessarily translate into proportional overall benefits.

Figure 11-3 plots benefits versus the cost for the alternatives, but normalizes the benefits and costs from the lowest to the highest of the remedial alternatives on a scale from 1 to 10. For example, the least expensive alternatives, Alternatives 2R-CAD and 3C ($200 million), are shown as a 0, and the most expensive alternative, Alternative 6R ($810 million), is shown as a 10. The other alternatives are plotted on the same 1 to 10 scale.

The analysis presented in this section is intended to support Ecology in its evaluation of the remedial alternatives relative to MTCA. Figures 11-1 through 11-3 provide various approaches to identify where costs may be disproportionate to benefits. The final identification of the remedial alternative that uses "permanent solutions to the maximum extent practicable" will be made in the ROD.

MTCA states that "costs are disproportionate to benefits if the incremental costs of the alternative over that of a lower alternative exceed the incremental degree of benefits achieved by the alternative over that of the lower cost alternative" (WAC 173-340-360(3)(e)(i)), and that "Where two or more alternatives are equal in benefits, the department shall select the less costly alternative" (WAC 173-340-360(3)(e)(ii)(C)). Although the results of the DCA should be interpreted with caution, the results indicate that, at a minimum, Alternative 6R is disproportionately costly compared to its benefits in relation to the other remedial alternatives.

Table 11-1 Schematic of the MTCA Remedy Selection Process

MTCA Minimum Requirements for Cleanup Actions (WAC 173-340-360(2))	MTCA Cleanup Regulation	Description and Applicability	Evaluation Procedure
Threshold Requirements			Alternatives are initially screened against "threshold requirements"
Protect human health and the environment	WAC 173-340-360(2)(a)(i)	Threshold requirements are the initial screening of remedial alternatives. Threshold requirements are addressed in Section 11.3.	
Comply with cleanup standards	WAC 173-340-360(2)(a)(ii)		
Comply with applicable state and federal laws	WAC 173-340-360(2)(a)(iii)		
Provide for compliance monitoring	WAC 173-340-360(2)(a)(iv)		
Other Requirements (except using permanent solutions to the maximum extent practicable, which is evaluated last)			Alternatives are screened against the additional "minimum requirements"
Provide for a reasonable restoration time frame	WAC 173-340-360(2)(b)(ii)	Remedial alternatives are screened for reasonable restoration time frame in Section 11.4.	
Consider public concerns	WAC 173-340-360(2)(b)(iii)	Considerations of public concerns are included in the MTCA process and are not addressed in a separate part of Section 11. The FS will be open to public comment for a period following publication, and public concerns will be incorporated into the final decision documents.	
Additional Minimum Requirements			
Groundwater cleanup actions	WAC 173-340-360(2)(c)	Not applicable to the FS.	
Soil at residential areas, schools, and child care centers	WAC 173-340-360(2)(d)		
Institutional controls	WAC 173-340-360(2)(e)	These additional minimum requirements serve to screen remedial alternatives and are addressed in Sections 11.2.3.	
Releases and migration	WAC 173-340-360(2)(f)		
Dilution and dispersion	WAC 173-340-360(2)(g)		
Remediation levels	WAC 173-340-360(2)(h)		
Additional Other Requirement (DCA) (evaluated last)			Alternatives that pass other "minimum requirements" are compared using the DCA.
Use of permanent solutions to the maximum extent practicable – disproportionate cost analysis (DCA)	WAC 173-340-360(2)(b)(i)	The DCA provides a tool for the comparison of alternatives that pass the other "minimum requirements," and is addressed in Section 11.5.	

Notes:

DCA = disproportionate cost analysis; FS = feasibility study; MTCA = Model Toxics Control Act; WAC = Washington Administrative Code

Table 11-2 Cross Reference of MTCA Threshold and Other Minimum Requirements to Sections of the FS

MTCA Minimum Requirements for Remedial Alternatives (WAC 173-340-360(2))	MTCA Evaluation Factors	FS Section in Which Requirement is Evaluated
Threshold Requirements (WAC 173-340-360 (2)(a))		
i. Protect human health and the environment WAC 173-340-360(3)(f)(i)	• Degree to which existing risks are reduced • Time required to reduce risks and achieve cleanup standards • On-site and off-site risks from implementing alternative • Improvement in overall environmental quality	• Alternatives are evaluated in Section 11.3. • Tables 9-2 through 9-8 and alternative summary tables and figures in Section 9 provide the predicted numerical reductions in risk-driver concentrations for each alternative over time. • Section 9 contains evaluations of on-site and off-site risks, as well as time to achieve cleanup objectives for the RAOs.
ii. Comply with cleanup standards WAC 173-340-760	• Remediation levels (WAC 173-340-355) • No significant health risk to humans (site specific) (173-340-320 (4)) SMS criteria: • Cleanup objective 173-204-570 (2) • No adverse effects on biological resources (173-204-320 (2)) • Minimum Cleanup Level (173-204-570(3))	• Alternatives are evaluated in Section 11.3. • RAOs and PRGs are presented and discussed in Section 4. • RALs developed in Section 6 are used to develop alternatives in Section 8. • Section 11.2 discusses MTCA cleanup standards, and remediation levels compared to PRGs and RALs.
iii. Comply with applicable state and federal laws. WAC 173-340-710	• ARARs	• Alternatives are evaluated in Section 11.3. • ARARs are discussed in Section 9.1.1.2.
iv. Provide for compliance monitoring WAC 173-340-410 and 173-340-760	• Protection Monitoring • Performance Monitoring • Confirmational Monitoring	• Alternatives are evaluated in Section 11.3. • Conceptual monitoring scope is developed in detail in Appendix K for costing purposes, and is discussed in Section 8 for each remedial alternative.

Table 11-2 Cross Reference of MTCA Threshold and Other Minimum Requirements to Sections of the FS (continued)

MTCA Minimum Requirements for Remedial Alternatives (WAC 173-340-360(2))	MTCA Evaluation Factors	FS Section in Which Requirement is Evaluated
Other Requirements (WAC 173-340-360(2)(b))		
i. Use permanent solutions to the maximum extent practicable	• Disproportionate Cost Analysis 173-340-360(3)(e)	• Discussed in Section 11.5 "Practicability" determined through the Disproportionate Cost Analysis (DCA).
ii. Provide for a reasonable restoration time frame	• 173-340-360(4)(b) • Potential risks posed by the site • Practicability of achieving a shorter restoration time frame • Uses & resources that are or may be affected by releases from the site • Effectiveness & reliability of institutional controls • Ability to control and monitor migration • Toxicity of the hazardous substances at the site • Natural processes that reduce concentrations and have been documented to occur at the site or under similar site conditions	• Restoration time frame is evaluated in Section 11.4. • Potential baseline site risks are summarized in Section 3. • Restoration time frames are discussed in Section 9 and are presented in Table 11-3. • The potential for elevated fish and shellfish tissue concentrations during and after construction activities is discussed in Section 9 for each alternative. • Institutional controls, monitoring, and adaptive management are discussed in detail in Appendix K and Section 7, and discussed in Section 8 for each alternative. • Time to achieve cleanup objectives for alternatives that rely on MNR is discussed in Section 9 for each alternative. The BCM (Section 5) is used to predict recovery potential.
iii. Consider public concerns	• Consideration of public concerns is part of the FS process and will be formally evaluated during development of the Record of Decision.	• Discussed in Section 9.1.3.

Notes:

ARAR = applicable or relevant and appropriate requirements; BCM = Bed Composition Model; DCA = disproportionate cost analysis; FS = Feasibility Study; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; PRG = preliminary remediation goal; RAL = remedial action levels; RAO = remedial action objectives; WAC = Washington Administrative Code

Table 11-3 Compliance with Minimum Requirements

	Requirement			Remedial Alternative											
				1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Threshold Requirements	**Protection of human health and the environment and compliance with cleanup standards (Sections 11.3.1 and 11.3.2)**														
	Risk Pathway Category		**Preliminary Cleanup Standard[a]**	**Compliance**											
	Human Health	RAO 1: Human Health – Seafood Consumption	Preliminary CULs = PRGs with a POC of the upper 10 cm of site-wide sediment on a SWAC basis	Not achieved	Cleanup standards achieved through a combination of active remediation, source control, natural recovery, and institutional controls; see Table 10-1										
		RAO 2: Human Health – Direct Contact	Preliminary CULs = PRGs with a POC of the upper 45 cm of sediment as a SWAC in beaches and potential clamming areas, and the upper 10 cm of site-wide sediment on a SWAC basis	Cleanup standards achieved; see Table 10-1[b]											
	Environment	RAO 3: Ecological Health – Benthic	Preliminary CULS = PRGs (SQS) with a POC of the upper 10 cm of site-wide sediment on a point basis	Cleanup standards achieved; see Table 10-1											
		RAO 4: Ecological Health – Seafood Consumption – River Otter	Preliminary CULS = PRGs with a POC of the upper 10 cm of site-wide sediment on a SWAC basis	Cleanup standards achieved; see Table 10-1											
	Compliance with applicable local, state, and federal laws (Section 11.3.3)			Not achieved	Complies with all applicable local, state, and federal laws; see Table 10-1										
	Provide for compliance monitoring (Section 11.3.4)			Not achieved	Conceptual monitoring plan for Remedial Alternatives 2 through 6 is provided in Appendix K										
	Achieves threshold requirements? (Section 11.3.5)			**No**	**Yes**										
Other Requirements	**Restoration Time Frames (RTF; years)[c] (Section 11.4)**														
	Duration of construction period			n/a	4	4	3	6	6	11	7	17	17	16	42
	RAO 1				24	24	18	21	21	21	17	22	22	16	42
	RAO 2 (total/individual risk drivers)				4/19	4/19	3/3	4/6	3/3	4/6	3/3	4/6	4/6	3/3	4/6
	RAO 3				14	14	8	11	6	11	6	11	11	6	11
	RAO 4				4	4	3	6	6	11	7	17	17	16	42
	Consideration of public concerns (Section 11.5.2.6)			n/a	Consideration of public concerns is part of the Feasibility Study process and is evaluated as part of the DCA.										
Additional Minimum Requirements	**Groundwater cleanup actions**			n/a	Not applicable to Feasibility Study										
	Soil at residential areas, schools, and child care centers				Not applicable to Feasibility Study										
	Institutional controls (Section 11.2.3)				Achieved										
	Releases and migration (Section 11.2.3)				Achieved										
	Dilution and dispersion (Section 11.2.3)				Achieved										
	Remediation levels (Section 11.2.3)				Achieved										
DCA	Weighted Benefit Points (score from Table 11-6)			n/a	4.2	3.8	5.0	4.9	5.8	5.8	6.5	6.4	6.2	6.6	6.2
	Cost ($millions net present value) (Section 11.5.2.7)				220	200	200	270	260	360	290	470	510	530	810
	Benefit points per $billion (Section 11.5.3)				19	19	25	18	22	16	22	14	12	12	7.7

Notes:

a. Preliminary cleanup standards are considered to be equivalent with PRGs.

b. Alternatives achieve total direct contact excess cancer risk of 1×10^{-5} for all scenarios. Total PCBs and dioxins/furans achieve direct contact excess cancer risk of 10^{-6} for all scenarios. Arsenic PRGs are equal to natural background, with excess cancer risks between 1×10^{-6} and 1×10^{-5} for all scenarios. cPAHs achieve 1×10^{-6} excess cancer risk for all scenarios except in Beach 3 for beach play direct contact, due to lateral loads.

c. Estimated restoration time frame is equivalent to the time to achieve cleanup objectives developed in Section 9. The restoration time frame is the longest duration shown in Table 9-24 for each RAO.

C = combined-technology alternatives; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CUL = cleanup level; DCA = disproportionate cost analysis; n/a = not applicable; PCB = polychlorinated biphenyl; POC = point of compliance; PRGs = preliminary remediation goals; R = removal-emphasis alternatives with upland disposal; RAO = remedial action objective; R-CAD = removal-emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with soil washing; RTF = restoration time frame; SQS = sediment quality standards; SWAC = spatially-weighted average concentration

Table 11-4 Framework and Weighting of Factors in the MTCA Disproportionate Cost Analysis

Evaluation Criterion and WAC Citation	Benefit Weighting Percentages and Rationale	Rating Metrics Used
Protectiveness: WAC 173-340-360(3)(f)(i)	**25%:** Protectiveness has a high weighting because it represents the ultimate goal of the cleanup.	• Cumulative exposure risk • Cumulative benthic exposure risk • Risks from implementation
Permanence WAC 173-340-360(3)(f)(ii)	**20%:** Permanence receives a relatively high weighting value because it addresses the degree to which the remedial alternatives reduce exposure potential in the LDW.	• Reduction in volume of contaminated sediment • Reduction in mobility of hazardous substances
Effectiveness over the long term: WAC 173-340-360(3)(f)(iv)	**30%:** This category receives a relatively high weighting value because it addresses how well the remedy reduces risks and whether controls are adequate to maintain protection against exposures to contamination left in place in the long term.	• Degree of certainty that the remedial alternative will be successful • Reliability of institutional and engineering controls used to manage risk
Management of short-term risk: WAC 173-340-360(3)(f)(v)	**15%:** This category receives a relatively low weighting value because impacts to both human health and the environment are predictable and manageable. However, these risks are of significant magnitude for remedial alternatives that extend over long durations.	• Implementation risks • Effectiveness of protective measures used to manage short-term risks
Technical and administrative implementability: WAC 173-340-360(3)(f)(vi)	**5%:** This category receives a relatively low weighting value because it is not directly related to the goals of the environmental cleanup. Further, the alternatives are all considered to be implementable.	• Degree of technical complexity (access, size, availability of materials) and administrative (legal, regulatory, and monitoring) requirements; summarized as one metric
Consideration of Public Concerns: WAC 173-340-360(3)(f)(vii)	**5%:** This weighting reflects the fact that the primary public concerns are generally embodied by the other 5 criteria. Public concern rankings provide a summary of the input from the public during public comment periods and public meetings for the FS.	• Estimate of the degree of public support for each alternative
Costs (see Appendix I): WAC 173-340-360(3)(f)(iii)	This criterion is used to compare against the benefits for the disproportionate cost analysis.	• Net present value; see Appendix I

Notes:

FS = Feasibility Study; LDW = Lower Duwamish Waterway; MTCA = Model Toxics Control Act; WAC = Washington Administrative Code

Table 11-5 Summary of Disproportionate Cost Analysis – Alternative Benefits Scores

		Remedial Alternatives and Scores[a]										
	Evaluation Criteria	2R	2R–CAD	3C	3R	4C	4R	5C	5R	5R– T	6C	6R
1	Protectiveness – total weighting factor: 25%	4.0	4.0	5.2	5.0	5.9	5.2	7.0	5.2	5.2	7.5	4.2
2	Permanence – total weighting factor: 20%	2.4	1.9	2.6	3.1	3.7	4.6	4.4	6.1	6.1	5.9	9.5
3	Effectiveness Over the Long Term – total weighting factor: 30%	3.6	3.3	4.2	4.5	5.6	6.3	6.6	8.2	8.2	7.4	9.0
4	Management of Short-term Risk – total weighting factor: 15%	8.8	8.3	8.9	8.3	8.1	7.1	7.9	5.8	5.0	5.4	0.0
5	Technical and Administrative Implementability – total weighting factor: 5%	6.0	4.0	6.0	6.0	8.0	8.0	8.0	4.0	2.0	4.0	2.0
6	Consideration of Public Concerns – total weighting factor: 5%	1.0	0.0	5.0	3.0	5.0	5.0	7.0	7.0	7.0	7.0	8.0
7	Total Weighted Benefits	4.2	3.8	5.0	4.9	5.8	5.8	6.5	6.4	6.2	6.6	6.2
8	Cost ($millions net present value)	220	200	200	270	260	360	290	470	510	530	810
9	Benefit/cost (Benefit points per $billion)	19	19	25	18	22	16	22	14	12	12	7.7

Notes:

a. A score of 0 represents the lowest benefit or a poor performing alternative for the given metric. A score of 10 represents the highest benefit or an excellent performing alternative for the given metric. Scores of 0 and 10 do not represent the lowest and highest alternatives in the suite of alternatives, but represent the high and low values shown in the Benefit Scoring Basis columns on Table 11-6. The alternatives are scored on a linear scale between the end points shown in Table 11-6.

C = combined-technology; R = removal-emphasis; R-CAD = removal emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with treatment (soil washing)

Table 11-6 Disproportionate Cost Analysis – Alternative Benefits Metrics and Scores

	Evaluation Criteria		Weighting Factor	Benefit Scoring Basis[a]		Units	Site-wide Remedial Alternatives										
				Score 0	Score 10		2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
1	**Overall Protectiveness of Human Health and the Environment**		**25%**			**Overall Score**	**4.0**	**4.0**	**5.2**	**5.0**	**5.9**	**5.2**	**7.0**	**5.2**	**5.2**	**7.5**	**4.2**
1a	Cumulative exposure	Concentration of total PCBs integrated over time. Assume total PCBs is a surrogate for all risk drivers.[b]	**50%**	1,158	353	(µg/kg dw) yrs	1,035	1,035	950	950	863	903	768	898	898	595	808
	Score 0 represents predicted exposure with natural recovery but without construction (i.e., Alt 1: 1,158 (µg/kg dw) yrs); score 10 represents no action at the start of construction, followed by the asymptote (39 µg/kg dw) from 5 to 45 years following initiation of construction (353 (µg/kg dw) yrs).					**Score**	**1.5**	**1.5**	**2.6**	**2.6**	**3.7**	**3.2**	**4.9**	**3.2**	**3.2**	**7.0**	**4.4**
1b	Cumulative benthic exposure	SQS exceedances integrated over time.[c]	**25%**	2,055	560	exceedance yrs	1,465	1,465	1,090	1,090	900	975	560	830	830	560	830
	Score 0 represents predicted exposure with natural recovery but without construction (i.e., Alt 1: 2,055 exceedance-yrs); score 10 represents no action at the start of construction, followed by no exceedances from 5 to 30 years following initiation of construction (585 exceedance-yrs).					**Score**	**3.9**	**3.9**	**6.5**	**6.5**	**7.7**	**7.2**	**10.0**	**8.2**	**8.2**	**10.0**	**8.2**
1c	Risks from implementation	Construction time. Assume that impacts during dredging are proportional to construction time when comparing remedial alternatives.	**25%**	42	0	yrs	4	4	3	6	6	11	7	17	17	16	42
	Score 0 represents construction time for Alt 6R (42 years); score 10 represents no additional construction after the EAAs (i.e., Alt 1: 0 yrs)					**Score**	**9.0**	**9.0**	**9.3**	**8.6**	**8.6**	**7.4**	**8.3**	**6.0**	**6.0**	**6.2**	**0.0**
2	**Permanence**		**20%**			**Overall Score**	**2.4**	**1.9**	**2.6**	**3.1**	**3.7**	**4.6**	**4.4**	**6.1**	**6.1**	**5.9**	**9.5**
2a	Reduction in volume of contaminated sediment	Volume of sediment removed from LDW. Performance contingency volume minus volume contained by CAD for Alt 2R-CAD	**50%**	0	3.90	million cy	0.58	0.27	0.49	0.76	0.69	1.20	0.75	1.60	1.60	1.60	3.90
	Score 0 represents no volume removed after the EAAs (i.e., Alternative 1: 0 cy); score 10 represents the maximum amount of sediment removed for the remedial alternatives (i.e., Alt 6R: 3.9 million cy).					**Score**	**1.5**	**0.7**	**1.3**	**1.9**	**1.8**	**3.1**	**1.9**	**4.1**	**4.1**	**4.1**	**10.0**
2b	Reduction in mobility of hazardous substances	Immobility rating based on the acres weighted by type of technology applied in AOPC 1 normalized to acres in AOPC 1.	**50%**	Weighted average based on the following:													
		dredge		weighting: 9		acres of AOPC 1	29	5	29	50	50	93	57	143	143	69	164
		cap/partial dredge and cap (Alternative 2R–CAD includes 24 acres of CAD; acreage subtracted from the dredge area)		weighting: 8		acres of AOPC 1	3	27	19	8	41	14	47	14	14	61	16
		in situ treatment		weighting: 7		acres of AOPC 1	0	0	5.0	0	8	0	26.5	0	0	25.0	0
		ENR		weighting: 4		acres of AOPC 1	0	0	5.0	0	8	0	26.5	0	0	25.0	0
		MNR and VM		weighting: 2		acres of AOPC 1	148	148	122	122	73	73	23	23	23	0	0
	Weightings for each technology are based on best professional judgment. MNR and VM do not score a 0 because monitoring and contingency actions would mitigate mobility of contaminated sediment. Dredging does not score a 10 because some amount of contamination is lost during the dredging process. Therefore, 0 and 10 represent idealized alternatives in which sediments either are not remediated (0), or are removed completely from the LDW (10).					**Score**	**3.2**	**3.1**	**4.0**	**4.2**	**5.6**	**6.1**	**6.8**	**8.0**	**8.0**	**7.7**	**8.9**

Table 11-6 Disproportionate Cost Analysis – Alternative Benefits Metrics and Scores (continued)

Evaluation Criteria			Weighting Factor	Benefit Scoring Basis[a]		Units	Site-wide Remedial Alternatives										
				Score 0	Score 10		2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
3	**Effectiveness Over the Long Term**		**30%**			**Overall Score**	**3.6**	**3.3**	**4.2**	**4.5**	**5.6**	**6.3**	**6.6**	**8.2**	**8.2**	**7.4**	**9.0**
3a	Degree of certainty that the remedial alternative will be successful	Degree of certainty rating based on weighted benefit of remedial technologies normalized to acres of AOPC 1.	**80%**	Weighted average based on the following:													
		dredge			weighting: 9	acres of AOPC 1	29	5	29	50	50	93	57	143	143	69	164
		cap/partial dredge and cap (Alternative 2R–CAD includes 24 acres of CAD; acreage subtracted from the dredge area)			weighting: 9	acres of AOPC 1	3	27	19	8	41	14	47	14	14	61	16
		in situ treatment			weighting: 7	acres of AOPC 1	0.0	0.0	5.0	0.0	8.0	0.0	26.5	0.0	0.0	25.0	0.0
		ENR			weighting: 6	acres of AOPC 1	0.0	0.0	5.0	0.0	8.0	0.0	26.5	0.0	0.0	25.0	0.0
		MNR and VM			weighting: 3	acres of AOPC 1	148	148	122	122	73	73	23	23	23	0	0
	Weightings for each technology are based on best professional judgment. MNR and VM do not score a 0 because monitoring and contingency actions would mitigate mobility of contaminated sediment. Dredging does not score a 10 because some amount of contamination is lost during the dredging process. Therefore, 0 and 10 represent idealized alternatives in which sediments either are not remediated (0), or are removed completely from the LDW (10).					**Score**	**4.1**	**4.1**	**4.8**	**4.9**	**6.3**	**6.6**	**7.5**	**8.2**	**8.2**	**8.3**	**9.0**
3b	Reliability of ICs and engineering controls used to manage risk	Score inversely proportional to total acres of caps, ENR, MNR, and VM in AOPC 1 (EAAs not included). Assume reliability of ICs and engineering controls is inversely proportional to the area of technologies that leave contamination on site.	**20%**	180.0	0.0	acres of AOPC 1	151	175	151	130	130	87	123	37	37	111	16
	Score of 0 represents capping, ENR/*in situ*, MNR, or VM all of AOPC 1; score of 10 represents dredging all of AOPC 1.					**Score**	**1.6**	**0.3**	**1.6**	**2.8**	**2.8**	**5.2**	**3.2**	**7.9**	**7.9**	**3.8**	**9.1**
4	**Management of Short-term Risks**		**15%**			**Overall Score**	**8.8**	**8.3**	**8.9**	**8.3**	**8.1**	**7.1**	**7.9**	**5.8**	**5.0**	**5.4**	**0.0**
4a	Implementation risks[d]	Assume risk is proportional to removal and handling volume; equals dredge volume plus placement volume (including capping, ENR, backfill, dredge residuals management, and CAD construction). Assume double handling for Alt 5R-T for half of sediment removed for treatment.	**50%**	5.1	0	million cy	0.71	1.2	0.76	1.0	1.2	1.6	1.3	2.2	3.0	2.8	5.1
	Score of 0 represents maximum amount of material handled out of the remedial alternatives (i.e., Alt 6R; 5.1 million cy); score 10 represents no material handled (i.e., Alt 1)					**Score**	**8.6**	**7.6**	**8.5**	**8.0**	**7.6**	**6.9**	**7.5**	**5.7**	**4.1**	**4.5**	**0.0**
4b	Effectiveness of protective measures to manage short-term risks	Assume that impacts during dredging are proportional to construction time.	**50%**	42	0	years	4.0	4.0	3.0	6.0	6.0	11.0	7.0	17.0	17.0	16.0	42.0
	Score 0 represents construction time for Alt 6R (42 yrs); score 10 represents no additional construction after the EAAs (i.e., Alt 1; 0 yrs)					**Score**	**9.0**	**9.0**	**9.3**	**8.6**	**8.6**	**7.4**	**8.3**	**6.0**	**6.0**	**6.2**	**0.0**
5	**Technical and Administrative Implementability**		**5%**			**Overall Score**	**6.0**	**4.0**	**6.0**	**6.0**	**8.0**	**8.0**	**8.0**	**4.0**	**2.0**	**4.0**	**2.0**
	Best professional judgment based on experience with other remediation sites. Higher score represents more feasible and lower score represents less feasible.																
6	**Consideration of Public Concerns**		**5%**			**Overall Score**	**1.0**	**0.0**	**5.0**	**3.0**	**5.0**	**5.0**	**7.0**	**7.0**	**7.0**	**7.0**	**8.0**
	Best professional judgment based on meetings with the public. Higher score represents more public support and lower score represents less public support.																
7	**Total Weighted Benefits**					**Score**	**4.2**	**3.8**	**5.0**	**4.9**	**5.8**	**5.8**	**6.5**	**6.4**	**6.2**	**6.6**	**6.2**
8	**Cost**					**$millions net present value - excluding EAAs**	**220**	**200**	**200**	**270**	**260**	**360**	**290**	**470**	**510**	**530**	**810**

Notes:

a. A score of 0 represents the lowest benefit or a poor performing alternative for the given metric. A score of 10 represents the highest benefit or an excellent performing alternative for the given metric. Scores of 0 and 10 do not represent the lowest and highest alternatives in the suite of alternatives, but represent the high and low values shown in the Benefit Scoring Basis columns. The alternatives are scored on a linear scale between these end points.

b. Total PCB SWAC based on the best estimate (mid input values) BCM output. Cumulative exposure = (Average PCB concentration over 45 years - 39 µg/kg dw) x 45 years.

c. Cumulative benthic exposure = (Average number of SQS point exceedances over 30 years) x 30 years for representative SMS contaminants.

d. Implementation risks include release of residual contamination into the water column during dredging, landfill usage, environmental impacts due to transportation of material and mining of sand, worker safety, greenhouse gas emissions, particulate emissions, and other factors. For the purpose of this metric, the volume of material handled is used as a surrogate for these risks.

Alt = alternative; AOPC = area of potential concern; BCM = bed composition model; BPJ = best professional judgment; C = combined technology; CAD = contained aquatic disposal; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; ICs = institutional controls; MNR = monitored natural recovery; MTCA = Model Toxics Control Act; PDC = partial dredge and cap; R = removal focused; RAO = remedial action objective; R-CAD = removal-emphasis alternative with contained aquatic disposal; R–T = removal-emphasis alternative with treatment (soil washing); SQS = sediment quality standard; SWAC = spatially-weighted average concentration; VM = verification monitoring

Table 11-7 Estimated Additional Costs for Soil Washing for All Remedial Alternatives

Remedial Alternative	Baseline Estimated Cost ($million net present value)	Removal Volume (million cy)	Estimated Additional Cost for Treatment with Beneficial Reuse[a] ($million net present value)	Estimated Additional Cost for Treatment without Beneficial Reuse[b] ($million net present value)
1	9[c]	n/a	n/a	n/a
2R	220	0.58	29	57
2R-CAD	200	0.58	n/a	n/a
3C	200	0.49	25	51
3R	270	0.76	30	66
4C	260	0.69	28	60
4R	360	1.2	40	88
5C	290	0.75	30	64
5R	470	1.6	45	102
5R-T	510	1.6	n/a	58
6C	530	1.6	48	109
6R	810	3.9	76	180

Notes:

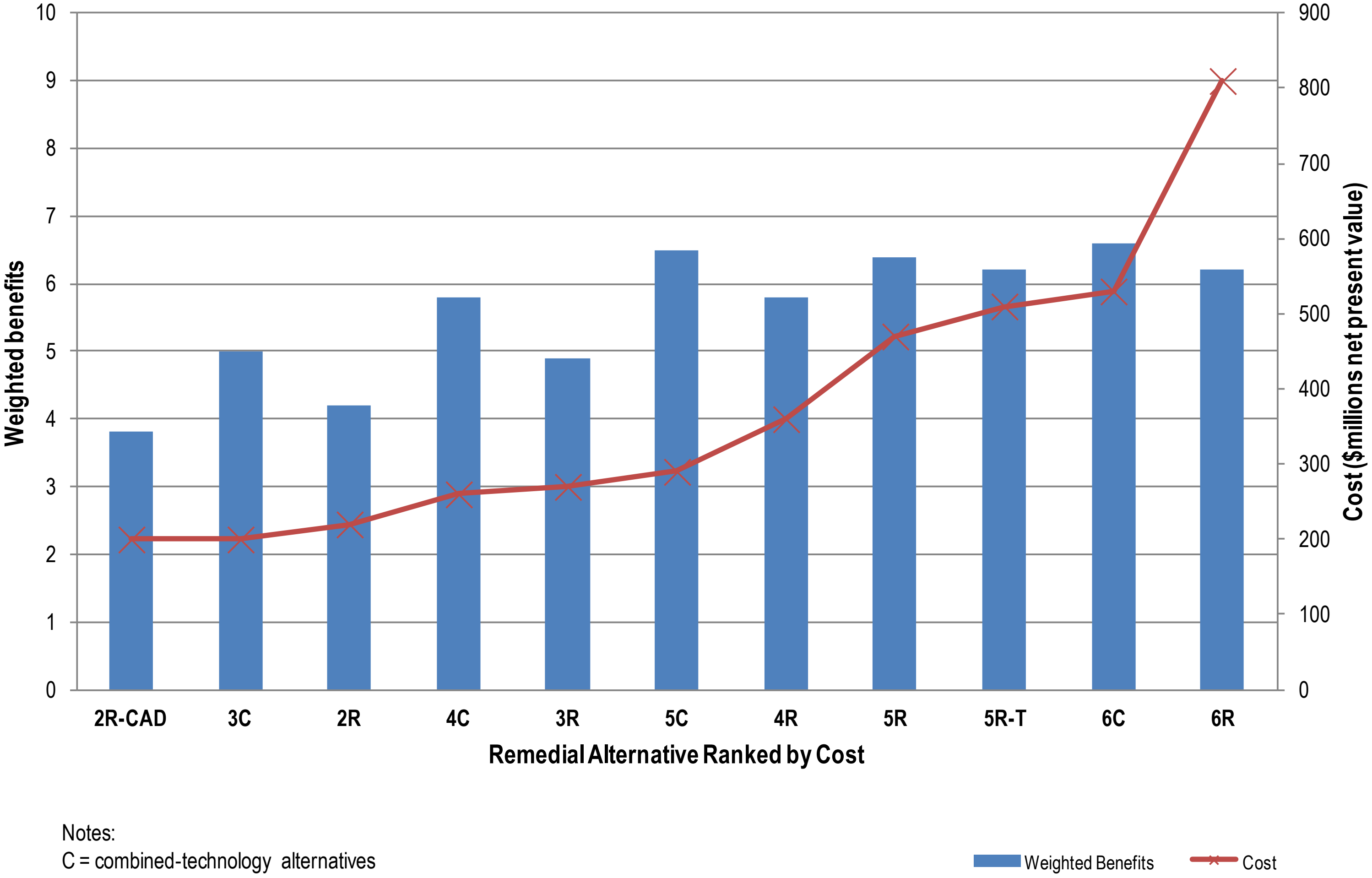
a. Cost for treatment with beneficial reuse assumes the cost for mobilization, soil washing treatment operations including water management, upland disposal of fine fraction of treated sediment, and reuse of sand fraction at no cost. 50% of dredged sediment is assumed to be viable for soil washing.

b. Cost for treatment without beneficial reuse assumes the cost for mobilization, soil washing treatment operations including water management, and upland disposal of both fine fraction and sand fraction of treated sediment. 50% of dredged sediment is assumed to be viable for soil washing.

c. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting and do not include operation and maintenance. The cost of cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided for informational purposes and are not used in the comparison of alternatives.

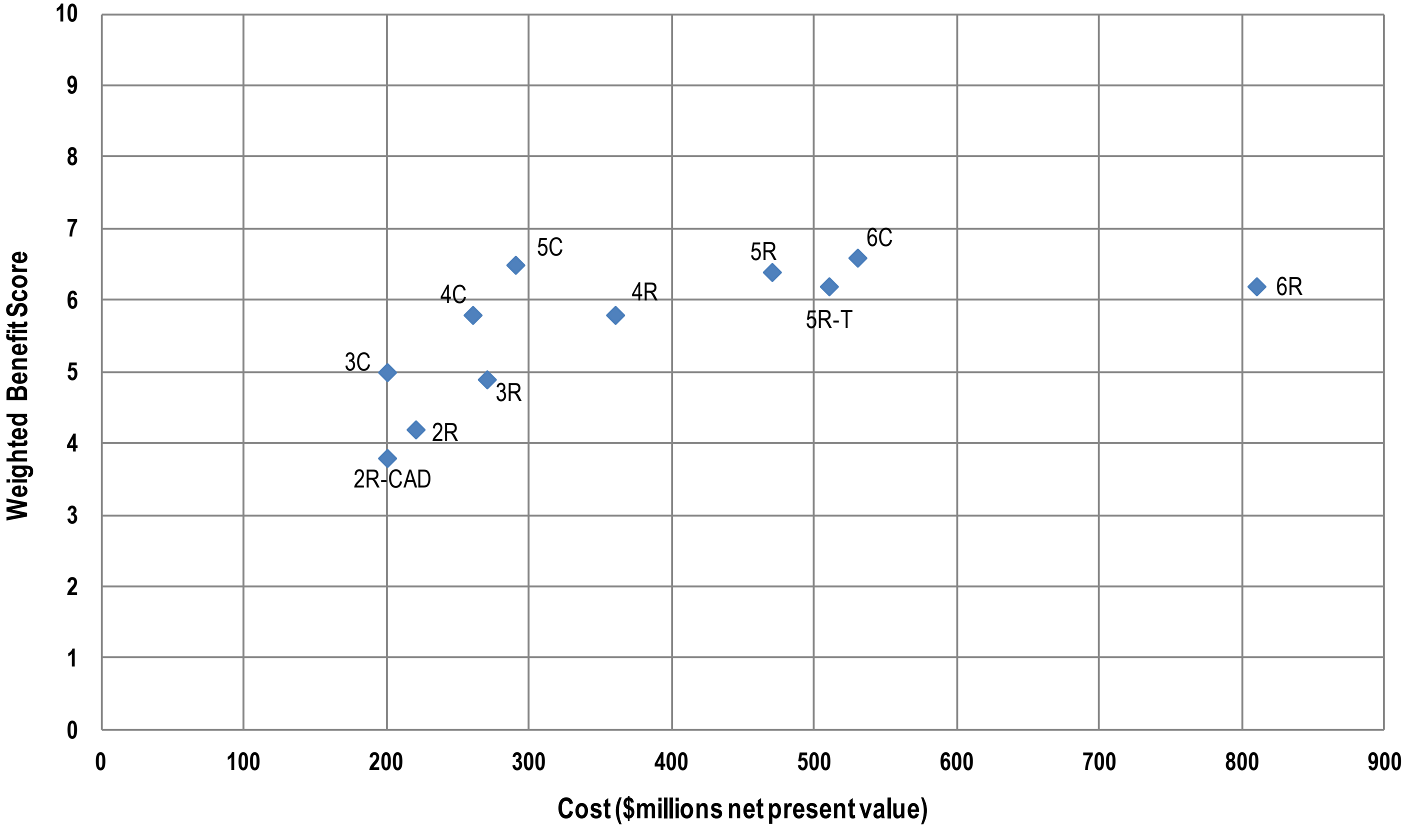
C = combined-technology alternative; cy = cubic yard; EAA = early action area; n/a = not applicable; LDW = Lower Duwamish Waterway;
R = removal-emphasis alternative. R-CAD = removal alternative with contained aquatic disposal; R-T = removal alternative with treatment

Figure 11-1 Benefits and Costs for Remedial Alternatives (Ranked by Cost)



Notes:
C = combined-technology alternatives
R = removal-emphasis alternatives with upland disposal
R-CAD = removal-emphasis alternative with contained aquatic disposal
R-T = removal-emphasis alternative with soil washing treatment

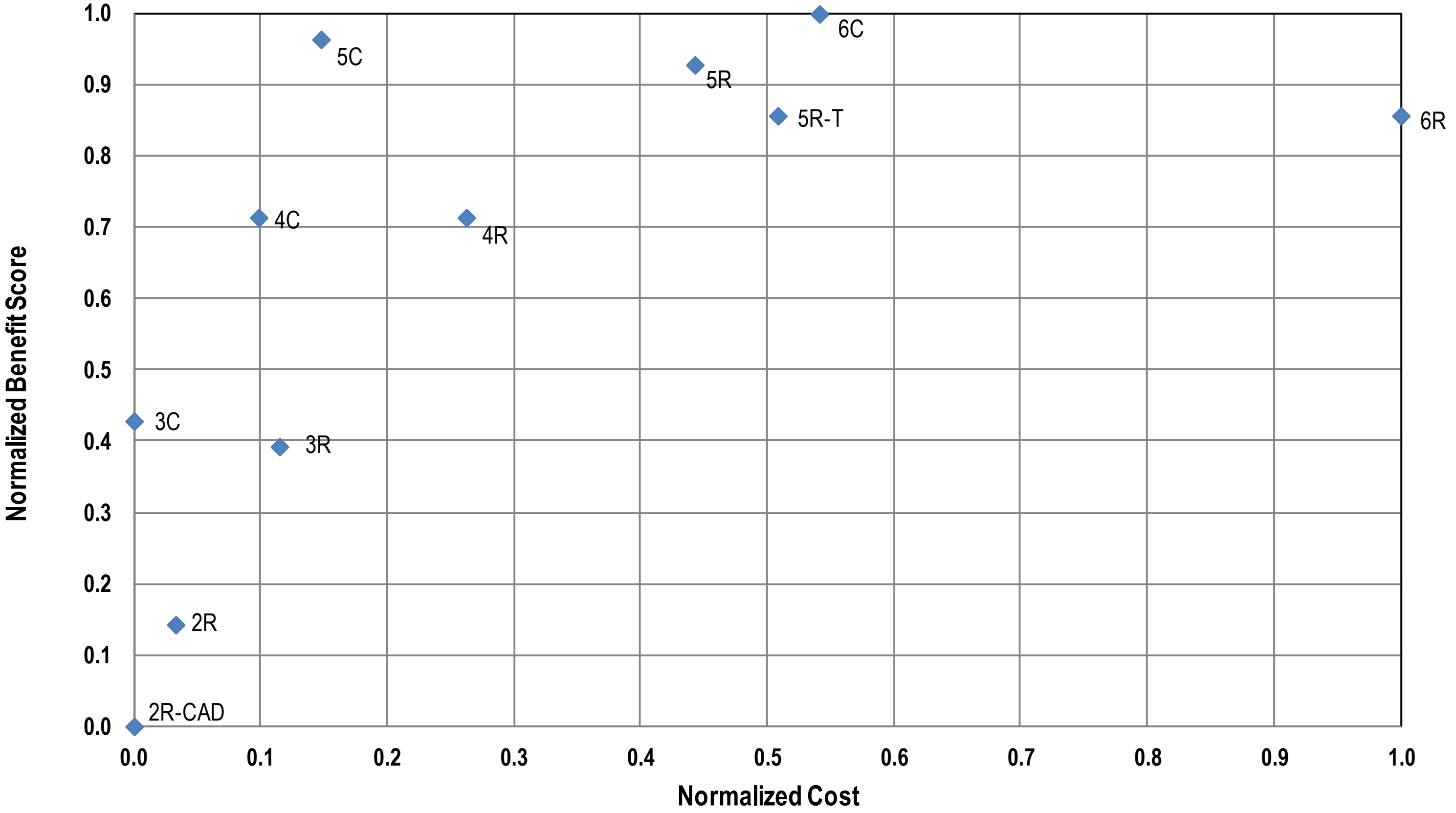
Figure 11-2 Benefits vs. Costs for Remedial Alternatives



Notes:

C = combined-technology alternative; R = removal-emphasis alternatives with upland disposal; R-CAD = removal-emphasis alternative with contained aquatic disposal; R-T = removal-emphasis alternative with soil washing treatment.

Figure 11-3 Normalized Benefits vs. Normalized Costs for Remedial Alternatives



Notes:

1. Costs and benefits were normalized as the difference between the value for an alternative and the minimum value of the alternatives divided by the range in values for all the alternatives.

Normalized value = ((value)-(min alt))/((max alt)-(min alt))

C = combined-technology alternatives; R = removal-emphasis alternatives with upland disposal; R-CAD = removal-emphasis alternative with contained aquatic disposal;
R-T = removal-emphasis alternative with soil washing treatment

12 Conclusions

Cleanup of the Lower Duwamish Waterway (LDW) is a complex, large-scale undertaking that seeks to accomplish important human health and environmental objectives in a challenging urban/industrial setting. This feasibility study (FS) evaluated several factors to develop and compare a full range of remedial alternatives for the LDW that are protective over the long term. These factors include estimating the deposition of new sediments from upstream and their associated contaminant concentrations, forecasting the timing and future results of upland source control in numerous locations along the LDW, estimating dredge volumes and costs, estimating post-remediation surface contaminant concentrations and the uncertainties around those values, and predicting the time needed to implement cleanup and achieve cleanup objectives. However, uncertainties exist for each of these factors.

The National Research Council (NRC) published a report in 2007 on sediment cleanups at large Superfund sites that identifies similar challenges elsewhere in the country, and suggests how to move forward in selecting remedies for sites as large and complex as the LDW. The report concludes with the following excerpt:

> *If there is one fact on which all would agree, it is that the selection and implementation of remedies at contaminated sediment sites are complicated. Many large and complex contaminated sediment sites will take years or even decades to remediate and the technical challenges and uncertainties of remediating aquatic environments are a major obstacle to cost-effective cleanup.*
>
> *Because of site-specific conditions – including hydrodynamic setting, bathymetry, bottom structure, distribution of contaminant concentrations and types, geographic scale, and remediation time frames – the remediation of contaminated sediment is neither simple nor quick, and the notion of a straightforward "remedial pipeline" that is typically used to describe the decision-making process for Superfund sites is likely to be at best not useful and at worst counterproductive.*
>
> *The typical Superfund remedy-selection approach, in which site studies in the remedial investigation and feasibility study establish a single path to remediation in the record of decision, is not the best approach to remedy selection and implementation at these sites owing to the inherent uncertainties in remedy effectiveness. At the largest sites, the time frames and scales are in many ways unprecedented. Given that remedies are estimated to take years or decades to implement and even longer to achieve cleanup goals, there is the potential – indeed almost a certainty – that there will be a need for changes, whether in response to new knowledge about site conditions, to changes in site conditions from extreme storms or flooding, or to advances in technology (such as improved dredge or cap design or in situ treatments). Regulators and others will need to adapt continually to evolving conditions and environmental responses that cannot be foreseen.*
>
> *These possibilities reiterate the importance of phased, adaptive approaches for sediment management at megasites. As described previously, adaptive management*

> *does not postpone action, but rather supports action in the face of limited scientific knowledge and the complexities and unpredictable behavior of large ecosystems.*

In that context, this section discusses:

- Key conclusions related to protecting human health and the environment by comparing the remedial alternatives with respect to their compliance with Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Model Toxics Control Act (MTCA) criteria
- A comparison of the analysis in this FS to the most recent national guidance regarding remedy selection for contaminated sediment sites
- Uncertainties identified and addressed in the LDW.

Similarities and differences among the alternatives and how they compare under CERCLA and MTCA are described in Section 12.1, along with the key findings. Risk management principles and national guidance are discussed next in Section 12.2. Section 12.3 briefly describes the uncertainties associated with the alternatives and their predicted outcomes. The final section, 12.4, discusses the next steps in the process for selecting the remedy for the LDW in coordination with other LDW cleanup activities.

12.1 Summary of the Comparative Analysis under CERCLA and MTCA

Twelve alternatives were individually evaluated against the CERCLA criteria in Section 9, compared to each other in Section 10, and evaluated against the MTCA criteria in Section 11, including a disproportionate cost analysis (DCA). CERCLA provides a set of prescribed criteria against which the remedial alternatives are evaluated (Table 9-1). MTCA has a similar framework for evaluating alternatives, with a few important distinctions (Tables 11-1 and 11-2) that have been incorporated into the following discussions.

Table 12-1 summarizes each alternative's remedial technologies, the size of the active remedial footprint, the volumes and costs, the time frame predicted for achieving the cleanup objectives, and residual risks (predicted outcomes). Differences in overall protectiveness of Alternatives 2 through 6 are largely in the context of short-term and long-term effectiveness. The lower numbered/smaller alternatives rely more on a passive remediation technology (monitored natural recovery [MNR]) to achieve cleanup objectives, while higher numbered/larger alternatives rely more on active remediation technologies such as dredging, capping, enhanced natural recovery (ENR), and ENR with *in situ* treatment (ENR/*in situ*). The major differences among the alternatives with the same remedial action levels (RALs) are the reliance on dredging for the active portion of the removal-emphasis alternatives versus a combination of dredging, capping, and ENR/*in situ* for the active portion of the combined-technology alternatives.

Figure 12-1 presents a summary of the comparative analysis under the CERCLA evaluation criteria. Alternative 1 failed to meet CERCLA threshold criteria but was retained for comparative purposes as the No Action Alternative. A high ranking (full red dot) means that the alternative ranks relatively high compared to other alternatives, whereas a low ranking (full black dot) means the alternative ranks low compared to other alternatives. In many cases, the evaluation did not identify substantial differences among the alternatives and therefore the rankings are the same for those criteria.

Figure 12-2 presents a summary of the comparative analysis under the MTCA evaluation criteria. Overall, the MTCA analysis yielded results similar to the CERCLA analysis. However, MTCA has specific differences in the factors that were considered under each evaluation criterion, and unlike CERCLA, MTCA adds the DCA to screen out alternatives with disproportionately higher costs. For DCA purposes only, the metrics used in the comparative analysis are converted to numerical scores. These scores are combined for a total weighted benefit score. Based on the MTCA analysis, Alternatives 5C, 5R, and 6C have the highest weighted benefit scores among the alternatives (Figure 12-2). Alternatives 4C, 4R, 5R-Treatment, and 6R have lower weighted benefit scores, and Alternatives 2R and 2R-CAD (contained aquatic disposal) have the lowest scores (see Figure 12-2). The total benefit scores are then considered relative to the cost of each alternative as a means of comparing the benefit of each alternative relative to its cost (i.e., the DCA) (see Figure 12-2). The analysis indicates that the additional costs incurred for alternatives beyond Alternative 5C do not add appreciably greater benefits.

The following sections summarize the key points of the comparative analyses and the performance of the remedial alternatives related to both the CERCLA and MTCA requirements. The following discussion is organized by the nine CERCLA criteria (two threshold criteria, five balancing criteria, and two modifying criteria). The last two modifying criteria, state/tribal and community acceptance, are discussed in Section 12.2.

12.1.1 Overall Protection of Human Health and the Environment

Predictions of whether remedial alternatives achieve cleanup objectives[1] and of the risks to remain after cleanup and natural recovery are summarized below for each alternative:

- Alternatives 1 through 6 are predicted to achieve similar levels of excess cancer risks for total polychlorinated biphenyls (PCBs). The risk levels are in the range of 1 in 10,000 (10^{-4} magnitude risk), depending on the seafood consumption reasonable maximum exposure (RME) scenario (Adult Tribal, Child Tribal, and Asian Pacific Islander, see Section 9.3.3). The outcomes are

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[1] Cleanup objective in this FS is used to mean the PRG or as close as practicable to the PRG, when the PRG is predicted to not be achievable.

presented in Table 12-1 and Figure 12-3. However, each alternative varies in: 1) the technologies used to reduce risk, 2) how quickly contaminant concentrations are reduced, and 3) the uncertainty associated with the long-term model-predicted concentrations, as discussed below. None of the alternatives reach the MTCA threshold risk of 1 × 1,000,000 (1 × 10^{-6}) for individual contaminants for the three seafood consumption RME scenarios. Non-cancer hazard quotients for total PCBs are predicted to range from 3 to 10 for all alternatives for the three seafood consumption RME scenarios, with no alternative achieving non-cancer hazard quotients of less than 1. Alternatives 1 through 5 rely to varying degrees on natural recovery to achieve these results, and the degree of model uncertainty decreases in alternatives with less passive remediation.

- None of the alternatives are predicted to achieve the total PCB and dioxin/furan preliminary remediation goals (PRGs) in sediment for the human seafood consumption scenarios (remedial action objective [RAO] 1), which are based on natural background concentrations.[2] Instead, for Alternatives 2 through 6, the cleanup objective is achieved when total PCB and dioxin/furan concentrations are as close to natural background as technically practicable. The long-term model-predicted concentrations are used in this FS to approximate these values. They are also used to estimate the time required to achieve these cleanup objectives (Table 12-1). Seafood consumption advisories are expected to remain in effect in the LDW, no matter which alternative is selected.

- While it was not possible to reliably establish arsenic and carcinogenic polycyclic aromatic hydrocarbon (cPAH) PRGs for sediment for the seafood consumption exposure pathway (RAO 1), Alternatives 1 through 6 all reduce surface sediment concentrations of these risk drivers to similar long-term model-predicted concentrations over time.

- Alternatives 3 through 6 actively remediate areas to reduce surface sediment contaminant concentrations to levels that protect humans from adverse effects associated with direct contact with sediment (RAO 2). In all cases, active remediation alone reduces total excess cancer risks from all four risk drivers under all direct contact exposure scenarios (netfishing, clamming, and beach play areas) to no higher than 1 in 100,000 (1 × 10^{-5}) and reduces non-cancer hazard quotients to less than or equal to 1. Total excess cancer risk for total PCBs, dioxins/furans, and cPAHs are reduced to 1 in 1,000,000 (1 × 10^{-6}) or below. However, the individual excess cancer risk posed by arsenic is greater than 1 × 10^{-6} because the natural background concentration of arsenic yields risks above that level. The arsenic PRG for sediment for all

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[2] There are no RAO 1 PRGs for cPAHs and arsenic. See Section 4.4 for details.

direct contact scenarios is set to natural background, which is not technically practicable to achieve. Therefore, the cleanup objective, in this case, is as close to natural background as is technically practicable, estimated in this FS using the long-term model predicted concentration. This concentration is approximately the same for all alternatives. Alternatives 1 and 2 rely on natural recovery to achieve the same risk reductions; model predictions for these alternatives suggest that levels of performance similar to the other alternatives can be achieved over time.

- Alternatives 1 through 6 are predicted to achieve RAO 3 PRGs (the sediment quality standards [SQS] of the Washington State Sediment Management Standards [SMS]) for protection of the benthic community. Alternatives 3 through 6 are predicted to achieve RAO 3 PRGs in 6 to 11 years, but the predicted times to achieve RAO 3 PRGs for Alternatives 1 and 2 are much longer (20 and 14 years, respectively). Alternatives 1 through 4 are predicted to need progressively less natural recovery to achieve the SQS following active remediation.
- Alternatives 2 through 6 are predicted to protect wildlife (RAO 4) by actively reducing total PCB concentrations below levels that correspond to a hazard quotient of less than 1 for wildlife that consume resident seafood. Alternative 1 is predicted to achieve the RAO 4 PRG through natural recovery within 5 years or less following completion of the early action areas (EAAs). Alternatives 2 through 6 are predicted to achieve the RAO 4 PRG immediately following construction. Resident fish and shellfish tissue contaminant concentrations are assumed to remain elevated during construction as a result of contaminants released during dredging that enter the food chain.

Alternatives that emphasize dredging leave less contaminated subsurface sediment in place after active remediation[3] is complete. Therefore, disturbance mechanisms (such as vessel scour and earthquake-induced displacements) have less potential to expose subsurface contamination in the future. However, alternatives that rely more on dredging have higher short-term impacts to human health and the environment and they are likely to maintain elevated seafood tissue contaminant concentrations over the duration of construction and for some time thereafter. Construction times are longer for dredging than for other active remediation technologies over a similar area.

Alternatives 2 through 6 meet the threshold criterion for overall protection of human health and the environment through the use of varying combinations of active cleanup, natural recovery, and institutional controls. While Alternative 1, the No Further Action Alternative, is predicted to achieve the cleanup objectives for RAOs 1,

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[3] The period of active remediation corresponds to the construction period.

2, 3, and 4 with natural recovery (over a lengthy period of time for all, except RAO 4), it does not provide for institutional controls other than the existing Washington State Department of Health (WDOH) seafood consumption advisory and institutional controls developed specifically for the EAAs. Therefore, this alternative does not satisfy this threshold criterion. However, it is retained for comparative purposes. Long-term risk reduction estimates are based primarily on the model predictions of spatially-weighted average concentrations (SWACs) in surface sediment. Uncertainties associated with SWAC predictions are discussed in Section 9.3.5.

12.1.2 Compliance with ARARs

Because this FS is being conducted under a joint CERCLA and MTCA order, provisions of MTCA and the SMS are considered to be applicable or relevant and appropriate requirements (ARARs) under CERCLA and governing requirements under MTCA/SMS.

- None of the alternatives satisfy the threshold requirement of complying with ARARs, particularly the excess cancer risk standards in MTCA for RAO 1, as described in Section 12.1.1, or MTCA’s default to natural background concentrations for final remedies where risk-based threshold concentrations (RBTCs) are more stringent than background. Specifically, human health RBTCs (total PCBs and dioxins/furans for seafood consumption [RAO 1] and arsenic for direct contact [RAO 2]) are lower than natural background concentrations, and none of the alternatives are predicted to achieve natural background sediment concentrations for these contaminants of concern.

- Alternative 1 also does not comply with other MTCA ARARs, including institutional control requirements in WAC 173-340-440.

- It is not anticipated that any alternative will comply with all federal or state ambient water quality criteria or standards, particularly those based on human consumption of bioaccumulative contaminants that magnify through the food chain, such as PCBs, because upstream concentrations (which could change over time) currently exceed those criteria or standards. However, significant water quality improvements are anticipated from sediment remediation and source control. Water quality is likely to be variable throughout the LDW, depending on the extent of local sources. Generally, the more quickly and thoroughly contaminated sediments are remediated and sources are controlled, the more quickly water quality improvements should occur.

ARAR waivers could be issued by the U.S. Environmental Protection Agency (EPA) in the future for those contaminants of concern and exposure scenarios that do not meet natural background-based PRGs, MTCA risk thresholds, or water quality criteria or standards. CERCLA requires that all ARARs be met or waived at or before completion of the remedial action. By far the most common waiver is for technical impracticability. In instances where alternatives are not predicted to comply with ARARs, the goal is to get as close as technically practicable to the ARAR, and apply a waiver only to the extent necessary. Because future conditions are difficult to predict, actual data collected upon completion of the remedial action will underlie the basis for any such waivers, which are formally documented and issued by EPA. For this reason, more definitive statements on whether, and perhaps more significantly to what extent, ARARs will be achieved or potentially waived cannot be made at this time, but must be made at the completion of cleanup and source control work at the site.

12.1.3 Long-term Effectiveness and Permanence

Long-term effectiveness and permanence considers the relative magnitude and type of residual risks that would remain in the LDW after the cleanup objectives have been achieved. It also assesses the extent and effectiveness of the controls that may be required to manage these residual risks. The comparative analysis found:

- Post-remediation residual surface sediment contaminant concentrations and the associated risks are predicted to be similar among the alternatives based on long-term model-predicted outcomes. Active remediation alone (i.e., ignoring any contribution from natural recovery) is responsible for the majority of progress toward achieving the residual risk levels for all alternatives. However, Alternatives 1, 2, 3, and 4 rely more on natural recovery and thus have greater degrees of uncertainty in the predicted outcomes.

- An approximately 50 to 90% reduction over time in site-wide surface sediment concentrations for risk drivers is predicted for all alternatives compared to baseline conditions; about 50% of the reduction in the total PCB SWAC is predicted to result from cleanup of the EAAs (see Figure 12-3 for total PCBs; see Figures 10-1b through 10-1d for the other three risk drivers).

- Differences in the level of effort and reliability of control mechanisms to manage residual risks, once cleanup objectives are achieved, are related primarily to the areal extent of remaining subsurface contamination. The remedial alternatives differ in the amount of contaminated subsurface sediment remaining with concentrations above levels needed to achieve cleanup objectives, which, if exposed or brought to the surface, could pose human health or ecological risks (see Table 10-1 for metrics). Alternatives that dredge across a greater surface area, in particular the higher numbered and removal-emphasis alternatives, remove more subsurface contaminated sediments from the LDW over a larger area, and thus have a lower potential for subsurface sediment to be exposed compared to the lower numbered and combined-technology alternatives. Similarly, more capped surface area translates into lower risk from subsurface sediments than areas addressed by ENR/*in situ* or MNR because caps are engineered to remain structurally stable under location-specific conditions.

- Alternatives 2 through 6 require monitoring, maintenance, and institutional controls in varying degrees or durations, with periodic reviews (e.g., every 5 years) and contingency actions, as needed. In general, combined-technology alternatives and lower numbered alternatives have greater monitoring and maintenance requirements, because they leave a greater amount of contaminated subsurface sediment in place. Alternative 1 provides for site-wide monitoring as a supplement to monitoring plans developed for the EAAs. Alternative 1 provides for no institutional controls beyond those developed for the EAAs and the existing WDOH seafood consumption advisory. Alternative 1 also does not provide for contingency actions. Alternatives 2 through 6 have public education and outreach programs in addition to the WDOH seafood consumption advisory to increase seafood consumers' awareness of risks and to reduce unacceptable exposures. However, the extent to which human exposure to contaminants in resident fish and shellfish can be reduced through seafood consumption advisories, public education, and outreach programs is unknown. Outreach and notification to waterway users, review of USACE construction permit applications, and environmental covenants or similar controls to avoid disturbance of subsurface contamination will be required to varying degrees depending on the remedial alternative.

Uncertainty related to long-term effectiveness and permanence is discussed in Section 10.2.1.3. Uncertainty associated with residual risks from exposure to surface sediment is largely influenced by the quality of incoming sediment from the Green/Duwamish River, the amount of contaminant inputs from lateral sources, and the potential for future anthropogenic or natural disturbances to expose subsurface contamination. Source control is clearly an important factor in reducing the long-term contaminant concentrations to the maximum extent practicable. Processes that can disturb sediment (e.g., earthquakes, vessel scour under high power operations) have the potential to expose contaminated subsurface sediment left in place following remedial actions. Ongoing disturbances that expose contamination at depth may increase long-term surface sediment contaminant concentrations, depending on the amount of subsurface contamination left in place, the extent of disturbance, and the sedimentation rate at the disturbance locations (see Section 9.1.2.1 and Appendix M, Part 5). Some disturbances (e.g., from maneuvering of vessels) may be small and difficult to detect. This uncertainty may be partially managed by refining the monitoring plan during remedial design.

Alternatives 1 through 6 progressively rank from low to high for long-term effectiveness and permanence, and the combined-technology alternatives rank lower than the removal-emphasis alternatives. Key differences in the rankings are based on the amount of contaminated sediment removed or managed in place and the degree to which institutional controls and monitoring are needed to manage the remaining material.

12.1.4 Reductions in Mobility, Toxicity, or Volume through Treatment

Section 121(b) of CERCLA establishes a preference for the selection of remedial action "which permanently and significantly reduces the volume, toxicity, or mobility of contaminants through treatment as a principal element." This statutory preference is the basis for this balancing criterion. Section 300.430 (a)(1)(iii) of the National Contingency Plan (2007) sets forth the expectation that treatment will be used for principal threat wastes (e.g., liquids, high concentrations of toxic compounds, and highly mobile materials) wherever practicable. Most of the contaminated sediments within the LDW are low-level threat wastes (Section 9.1.2.2). The FS evaluation of reduction of mobility, toxicity, or volume through treatment had these key results:

- Alternative 5R-Treatment is the only alternative that includes an *ex situ* treatment technology (soil washing). Soil washing could decrease the volume of dredged sediment requiring upland disposal but not the mass of contaminants. Alternative 5R-Treatment ranks the highest among the alternatives for this criterion because the volume of contaminated sediment requiring disposal may be reduced.

- Although not included in the FS evaluation of alternatives, other alternatives could include treatment of material after dredging; FS-level unit costs for the addition of *ex situ* treatment (soil washing) to each alternative are shown in Table 11-7.

- *In situ* treatment, using activated carbon or other sequestering agents, was included in all of the combined-technology alternatives. This treatment lowers contaminant mobility and hence contaminant toxicity and availability to biological receptors (i.e., bioavailability). The reduction of mobility achieved by *in situ* treatment was assumed to be proportional to the area where treatment is applied (50% of the ENR footprint). Alternatives 5C and 6C were ranked higher (with 26.5 and 50.5 acres, respectively, of potential *in situ* treatment*)* compared to Alternatives 3C and 4C (with 5 and 8 acres, respectively, of potential *in situ* treatment*)*. The removal-emphasis alternative counterparts (except for 5R-Treatment, as noted above) ranked the lowest for this criterion.

- All of the alternatives make use of one or more of the following technologies: removal, disposal, containment, ENR, and natural recovery. Although none of these are treatment technologies under CERCLA, removal and off-site disposal do reduce the toxicity, mobility, and volume of contaminants remaining in the LDW compared to Alternative 1, and other technologies, notably engineered capping (and, to a lesser extent, ENR/*in situ*), also reduce the mobility and toxicity of contaminants.

12.1.5 Short-term Effectiveness

Short-term effectiveness is a measure of the time required to achieve the cleanup objectives, the risks and impacts to the community and environment that may occur during that time, and the effectiveness and reliability of measures to reduce these impacts. This FS evaluates risks and impacts to the community and environment, which may be elevated for many years until the cleanup objectives are achieved (both during construction and any needed period of natural recovery following construction). The FS evaluation of short-term effectiveness had these key results:

- Alternatives with longer construction times and greater dredge volumes present proportionately larger risks to workers, the community, and the environment, and therefore generally rank lower for these short-term effectiveness factors. Although best management practices will be used to reduce impacts to the extent practicable, longer construction periods increase equipment and vehicle emissions, noise, and other resource uses. Larger actively remediated footprints increase the short-term disturbance of the existing benthic community and other resident aquatic life and generate greater releases of bioavailable contaminants into the water column over a longer period of time. This keeps resident fish and shellfish tissue contaminant concentrations elevated during construction.
- No alternative is predicted to achieve the low RAO 1 PRGs of natural background for total PCBs and dioxins/furans (there are no RAO 1 PRGs for arsenic or cPAHs). Further, it cannot be known with certainty or precision what concentrations will ultimately be as close as practicable to these natural background PRGs (i.e., the cleanup objectives). Therefore, the long-term model-predicted concentration ranges of site-wide SWACs are the best available estimates and are used in this FS as the surrogate metric for achieving the cleanup objectives. Alternatives 1 through 5 require a period of natural recovery to reach the long-term model-predicted SWAC, ranging from 17 to 25 years (with Alternative 1 having the longest time frame) (Table 12-1). Alternative 6 is predicted to achieve the long-term model-predicted SWAC immediately after construction (16 years for Alternative 6C and 42 years for Alternative 6R).
- For RAO 2, all alternatives are predicted to achieve the cleanup objectives through engineering controls and varying degrees of natural recovery over periods of 3 to 25 years. Alternatives 3, 4, 5, and 6 achieve the RAO 2 cleanup objectives in the shortest times (varying between 3 and 6 years). Alternatives 1 and 2 require additional time for natural recovery after construction (25 and 19 years, respectively).

- For RAO 3, all alternatives are predicted to achieve the cleanup objectives (the SQS) through engineering controls and varying degrees of natural recovery over periods of 6 to 20 years. Alternatives 4C, 5C, and 6C are predicted to achieve the SQS in 6 years. Alternative 3C is predicted to achieve the SQS in 8 years. Alternatives 3R, 4R, 5R/5R-Treatment, and 6R are predicted to achieve the SQS in 11 years. Alternatives 2R/2R-CAD are predicted to achieve the SQS in 14 years. Alternative 1 is predicted to achieve the SQS through natural recovery processes in about 20 years after cleanup of the EAAs.
- For RAO 4, all alternatives are predicted to achieve the cleanup objective through engineering controls and varying degrees of natural recovery over periods of 3 to 42 years. Alternatives 1, 2, 3, 4C, and 5C have the shortest times (varying between 3 and 7 years), while Alternatives 4R, 5R/5R-Treatment, and 6 require longer times (varying between 11 and 42 years) to achieve the cleanup objective).
- When viewed collectively, Alternatives 5C and 6C are predicted to achieve cleanup objectives for all 4 RAOs, including the long-term model-predicted concentrations, in the shortest time frames (16 to 17 years).

Uncertainty related to short-term effectiveness is associated with several factors, including: 1) the model predictions for natural recovery, 2) duration of construction, and 3) sequencing of remedial actions (see Section 10.2.3.4). Natural recovery is a source of uncertainty influencing predictions of the time to achieve cleanup objectives. The bed composition model (BCM) does not account for disturbance of contaminated subsurface sediments except by high-flow scour; thus disturbances caused by other mechanisms (e.g., vessel scour) add to the uncertainty in time to achieve cleanup objectives, especially for alternatives that rely more on MNR.[4]

Alternatives 3C, 4C, and 5C are ranked relatively high compared to other alternatives for short-term effectiveness. Key differences in these rankings are based on the construction periods (shorter construction periods for active remediation have lower impacts) and the time to achieve cleanup objectives.

12.1.6 Implementability

This criterion considers both the technical and administrative ability to implement each alternative. Each alternative involves various combinations of technologies that have been successfully implemented at numerous sites in the Puget Sound region and throughout the country. The required equipment and appropriately skilled personnel

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[4] While the FS assumes that contingency actions may be necessary to address unacceptable performance in some MNR and ENR areas, the time to complete those actions was not factored into the time to achieve cleanup objectives.

are readily available and coordination of the activities among agencies can be achieved. Based on the comparative analysis:

- Alternatives with shorter construction periods are easier to implement than those with longer construction periods. This reduces the overall level of difficulty both technically and administratively (e.g., coordination with agencies) and the potential for technical problems leading to schedule delays. In this context, Alternative 1 is the most implementable of the alternatives. The only long-term action undertaken for Alternative 1 is monitoring; no contingency actions are assumed to be undertaken outside the EAAs in response to monitoring data.
- Alternatives with more stringent (i.e., lower) RALs require more active remediation and are therefore more complex, have longer construction periods, and require more administrative coordination than do alternatives that have less stringent or higher RALs, less active remediation, and shorter construction periods. Similarly, removal-emphasis alternatives have longer construction periods and will likely be more complex to implement than equivalent combined-technology alternatives. Therefore, Alternatives 5R, 5R-Treatment, 6C, and 6R (with lower RALs) rank lower than the other alternatives.
- The CAD (2R-CAD) and treatment (5R-Treatment) alternatives have technical and administrative challenges associated with siting, permitting, operating, and maintaining either CAD facilities or a soil washing facility, and in addition for Alternative 5R-Treatment, finding an acceptable use for the clean fraction of treated sediment.
- Alternatives that rely more on MNR to achieve cleanup objectives have an increased potential for requiring actions in the future (e.g., more dredging or capping). This results in an increased technical and administrative burden of evaluating monitoring data over time, considering the need for contingency actions if cleanup objectives are not achieved in the predicted time frame, and implementing contingency actions. In this context, alternatives that rely to a greater extent on active construction to achieve cleanup objectives rank higher for administrative implementability.

Alternatives 4C, 4R, and 5C receive the highest rankings for implementability because they represent the best balance of the implementability factors. They are technically reliable and administratively feasible, and their large actively remediated surface areas are less likely to trigger additional actions.

Project sequencing is an important consideration from a recontamination perspective. The larger dredging alternatives (4R, 5R, and 6R) are more difficult to sequence in a specific order, because of the difficulties in coordinating multiple remediation projects and source control actions, administrative delays, and associated programmatic difficulties. Section 12.4.3 discusses an adaptive management approach for managing the sediment cleanup, and Section 10.2.3.4 evaluates the potential effects that sequencing may have on predicted site-wide sediment concentrations.

12.1.7 Cost

This criterion evaluates the capital, operation and maintenance, and monitoring costs of each alternative. Detailed cost estimates for each remedial alternative are presented in Appendix I, and summarized in Figure 10-7. The comparative analysis concluded that the alternatives differ significantly in costs (all costs are expressed as net present value at a discount rate of 2.3%):

- Alternative 6R has the highest costs ($810 million) and therefore ranks the lowest for this criterion (Table 12-1). Alternative 1 has the lowest cost at $9 million.[5] The estimated costs for the remaining alternatives range from Alternative 2R-CAD and 3C with the lowest cost and highest rank ($200 million) up to Alternative 6C ($530 million).
- Alternatives with a focus on combined technologies for a large portion of the active remediation (combined-technology alternatives) have lower costs than the corresponding alternatives that rely on dredging (removal) for active remediation (removal-emphasis alternatives) for the same RALs.

The cost estimates are sufficient for the purposes of this FS and fall within the +50%/-30% range of accuracy expected for an FS-level analysis. It should be noted that the uncertainties in these cost estimates are considerable, as shown in Table 12-1 and in the Appendix I cost tables.

12.1.8 State/Tribal and Community Acceptance

The last two modifying criteria, state/tribal and community acceptance, will be evaluated by EPA and the Washington State Department of Ecology (Ecology) after the FS is completed and this will include consideration of formal public comments on the Proposed Plan. However, EPA and Ecology have sought input of tribal and community groups during preparation of the FS, including quarterly meetings with resource agencies, community advisory groups, and tribal representatives, and have engaged with the community and tribes to review and comment on the remedial investigation (RI)/FS documents. In late 2010, EPA and Ecology invited the public to review and comment on the October 2010, Draft Final Feasibility Study for the Lower Duwamish

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[5] The construction of the EAAs is not considered to be part of Alternative 1 (i.e., EAAs are assumed to have been completed prior to initiating the selected LDW remedy). Alternative 1 is $9 million, which includes LDW-wide monitoring, agency oversight, and reporting. The total cost of in-water design and cleanup actions in the EAAs is estimated to be $95 million. Costs for upland cleanup and source control activities associated with the EAAs are not included. The estimated costs for completing the EAAs are provided for informational purposes and are not included in the comparison of alternatives.

Waterway. More than 300 letters were received from individuals, businesses, interest groups, tribes, and government agencies. The comments were summarized in a March 2011 fact sheet. Input from the various outreach efforts conducted to date were used as an interim assessment of these modifying criteria in the comparative analysis of alternatives in Section 10.

12.2 Risk Management Principles and National Guidance

The LDW is one of many large and complex contaminated sediment sites in the country. Many sites in other regions are addressing similar issues and uncertainties. In response, EPA released the *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002b) which can be found in Appendix A of the *Contaminated Sediment Remediation Guidance for Hazardous Waste Sites* (EPA 2005b). This FS process has attempted to develop and evaluate the alternatives for the LDW in a manner consistent with these documents, most specifically with the 11 risk management principles set forth below:

1) **Control Sources Early:** Ecology is leading the source control program currently underway in the LDW. Implementation of this program is a long-term effort, and there are uncertainties as to how effective the program can be at preventing recontamination from diffuse sources in an urban watershed. Nevertheless, modeling efforts and empirical data collected to date suggest that the effects of lateral loadings should be localized once reasonable source control is attained to the extent practicable. However, model predictions estimate a range of long-term contaminant concentrations that are above some PRGs (natural background) and are influenced by ongoing urban inputs. Model predictions are corroborated by empirical trends observed in the LDW and other urban and nonurban water bodies.

2) **Involve the Community Early and Often:** Outreach and educational efforts for both tribal and community groups were conducted during preparation of the FS. The Duwamish River Cleanup Coalition (DRCC) is a local community advisory group that has been actively engaged in both RI and FS technical issues. DRCC is supported by a Technical Assistance Grant from EPA and a Public Participation Grant from Ecology. The baseline risk assessments evaluated potential site uses by local populations, including community members, tribal members, and Asian and Pacific islanders. These risk results have been factored into developing the long-term cleanup goals for the LDW. As the remedial alternative decision draws near, LDWG and the agencies will seek input from all affected parties, including the local landowners and businesses, the neighborhoods, and the broader ratepayer and taxpayer community who may fund some of these cleanups.

3) **Coordinate with States, Local Governments, Tribes, and Natural Resource Trustees:** This FS is conducted under a joint order issued by EPA and

Ecology so state coordination is ensured. The Muckleshoot and Suquamish Tribes and the National Oceanic and Atmospheric Administration (NOAA) have all been closely involved in the studies completed to date on the LDW. EPA and Ecology have instituted a regular series of meetings with NOAA, the tribes, and the Washington State Departments of Natural Resources and Health. LDWG has participated actively in sharing key concepts and issues related to the cleanup. The input received from these parties has been very helpful in developing the FS.

4) **Develop and Refine a Conceptual Site Model that Considers Sediment Stability:** Empirical data and modeling have been used to develop a CSM of the LDW, which is summarized in Section 2 and described in detail in the RI (Windward 2010). The CSM indicates that the LDW is a net depositional system, with approximately 100,000 metric tons of sediment from upstream deposited within the LDW each year. Relatively small areas are subject to episodic scouring as a result of high-flow events or localized vessel activity within routine operating parameters. These areas have been considered in developing the alternatives, and are part of the areas designated for active management in Alternatives 2 through 6. As noted in Section 9.1.2.1 and 9.3.5, the effects of vessel maneuvering under emergency and high-power operations and marine construction are not included, and may be important factors for sediment stability and exposure of subsurface sediments. Additionally, the location of the LDW in an active earthquake area could affect sediment stability to an uncertain degree.

5) **Use an Iterative Approach in a Risk-based Framework:** Studies by the NRC (2007) and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a, Cannon 2006) conclude that substantial uncertainties exist related to cleanup of complex sites such as the LDW and point to the necessity of using adaptive management strategies. Remedial alternatives that rely primarily on dredging to achieve risk-based goals may have practical limitations as a result of the effects of sediment resuspension and recontamination. The time frames for completing source control and sediment cleanup in the LDW may span decades. Performance of passive remedial technologies such as MNR may be slower than predicted. These limitations suggest that selection of the remedial alternative for the LDW should include an iterative approach.

6) **Evaluate the Assumptions and Uncertainties Associated with Site Characterization Data and Site Models:** A multimillion dollar study, completed over the past nine years, has been conducted and includes extensive site characterization and a sophisticated model for evaluating sediment stability and long-term recovery in the LDW. The studies and modeling completed to date indicate that the LDW is recovering naturally in

many areas and focused remedial actions can increase the rate of recovery. As with any set of studies, their predictive ability has many limitations that can be improved during the remedial design and implementation phases as new information is developed. These uncertainties have been considered in evaluating the alternatives and the effects of these uncertainties have been discussed in the comparative analysis of the alternatives.

7) **Select Site-specific, Project-specific, and Sediment-specific Risk Management Approaches that Will Achieve Risk-Based Goals:** As part of assembling the alternatives, ranges of remedial actions and RALs have been presented. These have been used to evaluate the reduction in risks that may be achievable under each alternative. None of the alternatives are predicted to achieve the sediment PRGs that are based on natural background. However, the results illustrate that a combination of cleanup methods, including selective removal actions at targeted locations and various containment technologies, when coupled with natural recovery, are predicted to be the most cost-effective approach for achieving the cleanup objectives (with institutional controls to manage residual risks). All alternatives are predicted to achieve the same risk levels but at different points in time and with varying levels of uncertainty. The alternatives have been compared to one another considering temporal and spatial aspects of the LDW and the overall risk reduction achieved under each alternative.

8) **Ensure that Sediment Cleanup Levels are Clearly Tied to Risk Management Goals:** The RAOs developed for the LDW are based on the results of the baseline human health and ecological risk assessments (Windward 2007a and 2007b). The final cleanup levels will be determined by EPA and Ecology; this FS presents PRGs and cleanup objectives that form the starting point for establishing the cleanup levels. The sediment PRGs associated with each RAO are based on the results of the risk assessments or ARARs. The alternatives share the same PRGs and ultimately have the same risk management goals. The alternatives differ in the type and extent of active versus passive remediation, and hence have different levels of certainty and estimated time frames to reach these goals, with proportional long- and short-term effects.

9) **Maximize the Effectiveness of Institutional Controls and Recognize Their Limitations:** To be fully protective, the selected remedy will require institutional controls. Seafood consumption advisories are expected to continue indefinitely under all of the alternatives (potentially diminishing over time). Seafood tissue contaminant concentrations are predicted to increase in the short term as a result of dredging. Additional actions to improve the effectiveness of seafood consumption advisories were evaluated and discussed in this FS because many studies have shown

seafood consumption advisories to be of limited efficacy. Recommended actions for public education, outreach, and notification control elements are the same for Alternatives 2 through 6. Alternative 1 does not include institutional controls for managing residual risks, beyond those required under enforcement agreements governing the EAA work and the existing WDOH seafood consumption advisory. Alternatives that include significant containment components (such as capping) that leave contaminated sediment in place at depth will require additional institutional controls, such as restrictions on activities that could disturb the area with remaining subsurface contamination. Such controls have been successfully implemented at a wide range of sites regionally and nationally.

10) **Select Remedies that Minimize Short-term Risks while Achieving Long-term Protection:** FS alternatives include various combinations of active and passive remediation technologies. This allows each alternative's performance to be compared with respect to short-term risks and long-term protection. Although all the alternatives achieve similar long-term risk-reduction goals, the long-term effectiveness and permanence of the remedial alternatives are greatest for alternatives that remove larger volumes of contaminated sediments. Alternatives that provide for more engineered capping of contaminated sediments provide for greater long-term protection than those that rely on ENR and MNR. Conversely, short-term risks to the community and workers and environmental impacts are closely tied to the construction period for each alternative. Short-term risks during construction include worker safety, transportation-related impacts on communities, air emissions, habitat disruption, and increased contaminant concentrations in resident fish and shellfish tissue during dredging. In the MTCA DCA analysis, which can serve as a rough guide for evaluating total benefits versus risks, Alternatives 2 and 3 score lower, while Alternatives 4 through 6 score higher when these factors are considered collectively. The DCA analysis is used to screen disproportionately costly alternatives out of MTCA remedy selection analyses, not as a numerical ranking system for all alternatives.

11) **Monitor During and After Sediment Remediation to Assess and Document Remedy Effectiveness:** Alternatives 2 through 6 include extensive short-term and long-term monitoring programs to assess effectiveness (see Appendix K) and the cost estimates assume contingency actions based on monitoring results. Alternative 1 includes long-term site-wide monitoring but does not assume any contingency actions based on the latter monitoring. Alternatives that include a substantial natural recovery component have monitoring programs that can be used to adapt the remedial alternative as new information becomes available. Monitoring data can be evaluated against performance metrics, and contingency actions

(e.g., dredging, capping, or ENR/*in situ*) may be implemented as identified in the Record of Decision (ROD). Remedial design will refine the monitoring and maintenance plans to address uncertainties in the conceptual site model (CSM).

12.3 Managing the Key Uncertainties

In an environment that is changing over time, decision-making on a site of the size and complexity of the LDW means accommodating areas of uncertainty. This FS has sought to rely on the best information and science available at this time, and where necessary, made reasonable assumptions to evaluate different remedial alternatives. The remaining sources of uncertainty in these analyses must be factored into the selection and implementation of a remedial alternative for the LDW. The nature and potential magnitude of key uncertainties are discussed in the detailed evaluation of alternatives (see Section 9.3.5).

While uncertainty assessments using bounding-level assumptions did not have significant effect on residual risks, two of the largest effects are associated with: 1) the quality of incoming sediment from the Green/Duwamish River and 2) the potential to expose subsurface contamination left in place following remediation. The following factors emerge as particularly important for managing uncertainty relative to the time predicted for achieving cleanup objectives and the anticipated performance of the alternatives:

- The sediment transport model and BCM predictions indicate that over the 45-year model period, the sediments depositing in the LDW will be dominated by upstream Green/Duwamish River solids. Ultimately, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River and other inputs, resulting in similar levels of risk over time. While future conditions and actual contaminant concentrations are not certain (e.g., depending on the effectiveness of source control efforts), the BCM predicts that conditions will be similar in the long term, regardless of the alternative. The quantified uncertainty for modeled predictions is greater than the predicted differences in outcomes among alternatives or the differences predicted from bounding other uncertainties, as discussed below.

- Long-term SWAC predictions do not account for deep disturbances of subsurface contaminated sediments by mechanisms such as vessel scour and earthquakes. SWACs could be higher than model predictions, especially if disturbances are widespread and persistent. Alternatives 1 and 2, in particular, have the most uncertainty. The predicted SWACs for alternatives that leave less subsurface contamination (the higher numbered alternatives) are less sensitive to any increase associated with such disturbances.

However, persistence of any such increase in surface SWACs should be mitigated to some extent by making repairs as needed under the operation and maintenance (O&M) program.

- The performance of each remedial technology has some uncertainty associated with it. It is well documented that dredging produces dredge residuals that will elevate surface sediment and tissue contaminant concentrations over the short term. Capping and ENR/*in situ* may need periodic repairs and continued maintenance. MNR performance may be slower (or faster) or simply different than predicted and may require additional monitoring or contingency actions based on monitoring results. Many of these potential uncertainties have been incorporated into the cost estimates as contingency actions, repairs, or additional monitoring.
- Recent projects have shown that actual dredging volumes can be much higher than those estimated during the FS or remedial design phase. Volume estimates used in this FS incorporate additional contingency volumes based on experience at other sediment remediation sites. However, uncertainty remains and is managed in this FS by presenting a range of contaminated sediment volumes (see Appendix E) along with the cost and time impacts of dredging greater volumes.

Model assumptions are another source of uncertainty that need to be factored into the selection and implementation of a remedial alternative for the LDW. Key considerations include:

- Uncertainty in the predictions of resident seafood tissue concentrations and associated human health risks (from the total PCB SWAC estimates) are compounded by: 1) exposure assumptions from the human health risk assessment (Windward 2007b) such as seafood consumption rate, diet composition, and exposure frequency/duration and 2) assumptions used in food web model (FWM) predictions such as uptake factors and future water concentrations. The predicted future seafood tissue concentrations and associated risks for total PCBs could be overestimated or underestimated and should be viewed only as approximations. The predictions of resident seafood tissue concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties in the FWM and risk assessment methods are the same for all alternatives, and therefore all of the alternatives should be affected similarly.
- A sensitivity analysis was conducted to evaluate uncertainties associated with net sedimentation rates, which may affect the rate at which natural recovery occurs, and the contaminant concentrations of incoming sediment. Despite the uncertainties in predicting the long-term sediment contaminant concentrations, the analysis concluded that the final long-term, model-

predicted contaminant concentrations are largely insensitive to the range of RALs evaluated in Alternatives 2 through 6. Results showed that variability in the contaminant input parameters was more important to recovery than the sedimentation rate, although localized sedimentation and scour effects could be important. Areas with both contamination and significant scour potential were prioritized for remedial action in the FS.

- As the RALs decrease (i.e., for higher-numbered, larger alternatives such as Alternatives 6C and 6R), the chances for additional actions being required as a result of recontamination above the RALs from continuing urban inputs increases. The highest probability of recontamination will be in localized areas, such as near outfalls (see Appendix J). Collectively, recontamination in localized areas is predicted to have only a small effect on the site-wide SWACs that can be achieved long term.
- The BCM developed for this FS allows for a semi-quantitative evaluation of source control effects on sediments. Location-specific analyses and coordination with the source control program will be required during the remedial design phase to ensure that source control is sufficient to proceed with remedial action. Long-term monitoring and source control measures will be necessary, regardless of the remedial alternative selected. This uncertainty can affect the predicted time to achieve cleanup objectives.

12.4 Next Steps

EPA, Ecology, and LDWG solicited input on the October 2010 Draft Final FS from the public, including a broad range of stakeholders, and incorporated the input received into this Final FS. EPA will issue a Proposed Plan that identifies a preferred remedial alternative for the LDW. Formal public comment will be sought on the Proposed Plan. After these comments are received and evaluated, EPA will select the final remedial alternative and issue the ROD. The cleanup standards, objectives, and RALs will be specified in the ROD, which is anticipated to be issued with state concurrence. The ROD may also specify interim (e.g., 5-year) goals and final post-construction goals for some or all passively remediated areas. After the ROD is issued, the first 5-year period is expected to include: completing any remaining early actions; conducting extensive source identification and control activities; negotiating one or more consent decrees for performance of remedial design and cleanup; conducting predesign investigations, baseline monitoring, and remedial designs; and developing both a compliance monitoring program for active cleanup areas and an O&M monitoring program. The long-term plan will be designed to assess achievement of cleanup objectives, evaluate performance of the cleanup, and trigger contingency actions and adaptive management steps as needed.

The CERCLA remedial actions will be one part of multiple efforts to improve the quality of the LDW and surrounding watershed. These efforts are multi-disciplinary, and will include coordinated efforts by EPA, Ecology, King County, the City of Seattle, the City of Tukwila, the Port of Seattle, WDOH, affected industries in the LDW watershed, and a number of other parties with particular interests in the LDW. As briefly discussed below, these efforts are three-fold: cleanup of the EAAs, ongoing source control efforts, and remediation and adaptive management of the sediments in the LDW beyond the EAAs.

12.4.1 Cleanup of the EAAs

There are five designated EAAs in the LDW. The parties responsible for the five EAAs have conducted an intensive study of each one, and cleanup has occurred at three of the five EAAs: the Duwamish/Diagonal EAA by King County in 2003 and 2004, the Norfolk EAA by King County in 1999 and The Boeing Company in 2003, and Slip 4 by the City of Seattle in 2012. Remedy decisions have been issued by EPA for the other EAAs: Terminal 117 and Boeing Plant 2/Jorgensen Forge.[6] Together, these five EAAs cover 29 acres, representing some of the highest levels of sediment contamination in the LDW. It is anticipated that cleanup of the EAAs will be completed prior to initiating any of the cleanup alternatives in the FS.

Additional agreed orders have been negotiated, or are being negotiated, with upland property owners along the LDW that have adjacent contaminated sediments. Ecology has 18 agreed orders in place with site owners or users (see Section 2.4). The scope of work included in these agreed orders often includes upland, shoreline, and sediment investigations, evaluation of sources to the LDW surface water and sediments, including near-field recontamination modeling, and an evaluation of remedial alternatives.

12.4.2 Ongoing Source Control Efforts

The LDW source control strategy (Ecology 2004) focuses on controlling contamination that affects LDW sediments. It is based on the principles of source control for sediment sites described in *Principles for Managing Contaminated Sediment Risks at Hazardous Waste Sites* (EPA 2002b) and similar Washington State requirements.

Ecology is the lead agency for coordinating and implementing source control efforts in the LDW and works in cooperation with local jurisdictions and EPA to create and implement the source control strategy and action plans and to prioritize upland cleanup efforts in the LDW. In 2002, the LDW Source Control Work Group (SCWG) was formed, which conducts several different source control activities within the LDW area. Primary members of the group include EPA, Seattle Public Utilities, King County, and the Port of Seattle. The LDW source control strategy also identifies various regulatory programs at EPA and Ecology that are called upon as needed for source control as well as several

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[6] Note that Boeing Plant 2 and Jorgensen Forge are considered to be a single EAA, although the investigations and cleanups of those two sites are being conducted under separate regulatory authorities.

ad hoc members of the SCWG, including the City of Tukwila, Puget Sound Clean Air Agency, and the Washington State Departments of Transportation and Health. All LDW SCWG members are public entities with various source control roles, and the collective purpose is to share information, identify issues, develop action plans for source control tasks, coordinate implementation of various source control measures, and share progress reports on these activities.

Ecology developed the LDW source control strategy (Ecology 2004) to identify and manage sources of contaminants to LDW sediments and those activities are coordinated with the sediment cleanups addressed in the EAAs and in this FS. The strategy and associated Source Control Action Plans (SCAPs) for 24 individual drainage basins around the LDW provide the framework and process for identifying source control issues and implementing practical control of contaminant sources.

It is important to note that in some localized areas, some recontamination may occur even with aggressive source control because of the difficulty in identifying and completely controlling all potential sources of certain contaminants that are widely released by urban activities. The LDW source control strategy (Ecology 2004) describes how recontamination of LDW sediments will be controlled to the extent practicable. The goal is to limit sediment recontamination that exceeds location-specific standards, where feasible. The strategy also serves three other primary functions. First, it sets up the reporting process for tracking and documenting all of the source control work performed throughout the LDW source area. This information is necessary for EPA's administrative records and remedial decisions. Second, the strategy broadly prioritizes source control work according to the schedules proposed for sediment cleanups (e.g., EAAs, other areas to be identified in the ROD). Finally, the strategy identifies the following basic steps for performing source control: 1) identify, 2) characterize, and 3) control sources and pathways of contamination to the LDW.

EPA's (2002) sediment guidance recommends "control sources early, before sediment cleanup begins," but that may not always be practical. Delaying sediment cleanup until all sources have been identified and controlled, regardless of their contribution in terms of contaminant loading, may delay achieving many of the benefits that sediment cleanup alone can accomplish.

The LDW source control efforts have been developed in parallel with the RI and FS and will continue before, during, and after the implementation of the remedial alternatives discussed in this FS.

Source tracing and control efforts include:

- Mapping storm drain systems and conducting chemical analyses of samples collected therein
- Managing discharges from storm drains and combined sewer overflows (CSOs)

- Inspecting local businesses that discharge or otherwise contribute to storm drains, CSOs, or directly to the LDW, and implementing best management practices
- Conducting upland cleanups, including remediating contaminated soils, groundwater, and storm drain solids.

SCAPs document and prioritize source control activities for each source control area. Ecology's first priority was to address sources contributing to contamination in EAAs. Because of the dynamic nature of many source control activities, it is essential to maintain flexibility when adapting source control efforts to specific needs within source control areas. The success of source control depends on cooperation of all members of the SCWG and the active participation of businesses that must make changes to accomplish source control goals. This adaptive strategy for prioritizing source control work will continue throughout selection, design, and implementation of the long-term remedy for the LDW.

12.4.3 Adaptive Management for In-Water Sediment Remediation (Outside of the EAAs)

Remediation of contaminated sediments in the LDW under CERCLA should be undertaken in a flexible, iterative, and adaptive manner. Remediation should focus on cleaning up the most contaminated areas first to reduce risks the fastest, consistent with recommendations for remediation of contaminated sediment sites nationwide (NRC 2007, EPA 2005b). Next, learning from each incremental cleanup experience, further actions should be adjusted based on what has been learned. The cleanup process of the LDW should:

1) Remediate the most contaminated sediment areas first to reduce risks the fastest.
2) Continue source control efforts, sequenced to the sediment remediation.
3) Address uncertainties and provide flexibility in the design elements as more data become available. Use the results of early actions to inform further sediment cleanup.
4) Monitor performance and changing conditions in both the remediation and source control efforts.
5) Implement contingency actions that may become needed over time.

Experience at other complex sediment sites points to the necessity of using adaptive management strategies, as recommended by EPA guidance (EPA 2005b), the NRC (2007), and other independent, scientific peer reviews of sediment sites throughout the country (USACE 2008a, Cannon 2006). For adaptive management to work effectively, it must be informed by data. Further actions can be adjusted based on what has been learned from each incremental cleanup experience. A long-term monitoring plan will be established with metrics and analyses that meet clearly articulated data quality objectives. Baseline monitoring will be conducted prior to beginning the initial remedial activities to establish a benchmark for evaluating the effectiveness of the remediation. Collecting monitoring information during and after cleanup will help evaluate the effectiveness of the selected remedial alternative, and trigger the planning and execution of contingency actions as needed. Because remediation and source control efforts may take years if not decades to occur, and biological response may take even longer, monitoring the changes in contaminant inputs and responses of various media in the LDW will be important to help determine when and to what extent contingency actions may be needed. Contingency actions may include more sediment remediation, source control efforts, or in particular, changes to interim or final objectives of the remedy that reflect the best that can be practicably accomplished.

EPA will evaluate the effectiveness of the selected remedial alternative no less frequently than once every five years. The 5-year reviews can integrate comprehensive evaluations of the seafood consumption advisories, outreach and education programs, source control work, and changes in overall waterway health. These periodic reviews can be used by EPA in conjunction with the performance monitoring program to identify the need for any additional course corrections (e.g., contingency actions, review endpoints, modify technologies, conduct more monitoring, etc.) in the cleanup.

Table 12-1 Summary of Alternatives: Costs, Technologies, and Overall Protection of Human Health and the Environment

		Analysis Parameters	Remedial Alternative											
			1	2R	2R-CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Costs and Technology Application Summary	***Costs ($Millions)***													
	Capital, O&M, and Monitoring Costs (best estimate based on net present value)		9 [a]	220	200	200	270	260	360	290	470	510	530	810
	Cost Accuracy Range of -30% to +50% [b]		n/a	150 – 320	140 – 290	140 – 300	190 – 400	180 – 390	250 – 540	200 – 440	330 – 700	360 – 760	370 – 790	570 – 1,200
	Remedial Footprint (Area in acres)													
	Dredge		n/a	29	29	29	50	50	93	57	143	143	108	274
	Partial Dredge and Cap; Cap		n/a	3	3 [c]	19	8	41	14	47	14	14	93	28
	ENR/*in situ*		n/a	0	0	10	0	16	0	53	0	0	101	0
	MNR		n/a	125	125	99	99	50	50	0	0	0	0	0
	Verification Monitoring		n/a	23	23	23	23	23	23	23	23	23	0	0
	Total Active Area [d]		n/a	32	32	58	58	107	107	157	157	157	302	302
	Volume and Construction Time Frame													
	Total Dredge Volume (cubic yards)		n/a	580,000	580,000	490,000	760,000	690,000	1,200,000	750,000	1,600,000	1,600,000	1,600,000	3,900,000
	Construction Period (years)		0	4	4	3	6	6	11	7	17	17	16	42
Overall Protection of Human Health and the Environment	***Time to Achieve Cleanup Objectives (years)***													
	RAO 1	10^{-4} magnitude PCB risk (Adult Tribal RME) [e]	5	4	4	3	6	6	11	7	17	17	16	42
		Predicted time for total PCBs and dioxins/furans to reach long-term model-predicted concentration range in surface sediment (in years) [e]	25	24	24	18	21	21	21	17	22	22	16	42
	RAO 2	Total direct contact excess cancer risk $\leq 1 \times 10^{-5}$ and all non-cancer HQs < 1 (All exposure scenarios) [f]	5	4	4	3	4	3	4	3	4	4	3	4
		Individual risk from cPAHs $\leq 1 \times 10^{-6}$ in all areas except Beach 3	25	19	19	3	6	3	6	3	6	6	3	6
	RAO 3	Ecological protection of benthic invertebrates (SQS) [g]	20	14	14	8	11	6	11	6	11	11	6	11
	RAO 4	Ecological protection for wildlife – river otter (HQ <1) [h]	<5	4	4	3	6	6	11	7	17	17	16	42
	Effects Due to Construction													
	Air Quality Impacts (CO_2/PM_{10}; metric tons)		n/c - n/c	20,000/17	17,000/18	19,000/15	27,000/23	27,000/22	42,000/35	30,000/25	60,000/50	51,000/44	64,000/53	139,000/118
	Truck and Train Transportation (miles) [i]		n/c	480,000	227,000	404,000	620,000	560,000	940,000	610,000	1,380,000	1,010,000	1,380,000	3,170,000
	Risk Reduction: Predicted % of PCB SWAC Reduction from Baseline Attributable to Construction Only (Active Remediation)		49%	59%	59%	62%	62%	67%	67%	72%	72%	72%	87%	87%
	Magnitude of Residual Risk													
	Post-construction number of core stations remaining >CSL in the FS dataset (under caps / all other locations) [j]		70 outside of EAAs [k]	0/37	0/37	15/32	1/24	18/26	1/14	20/22	1/5	1/5	27/8	1/0

Notes:

a. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting and do not include O&M. The cost of cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided for informational purposes and are not used in the comparison of alternatives.

b. The estimated ranges of costs are related only to the sediment cleanup actions; potential upland source control costs could be significant but are not included; EAA costs are also not included in Alternatives 2 through 6.

c. Alternative 2R-CAD includes the construction and use of CAD facilities within the LDW and encompasses an additional 23 acres of capped contaminated sediment.

d. Total active area excludes the 29 acres managed by the EAAs. The AOPC 1 and 2 footprints are approximately 180 and 122 acres, respectively.

e. No remedial alternative achieves RAO 1 PRGs without an ARAR waiver. All alternatives achieve protectiveness with some combination of active and passive remediation and ICs. Two time frames are provided for purposes of comparing the alternatives: 1) the point at which the alternatives reduce the Adult Tribal RME seafood consumption risk to 10^{-4}, and 2) the predicted time for risk-driver concentrations to achieve long-term model-predicted concentration ranges. The former is provided for information only. The latter are based on achieving a site-wide total PCB SWAC within 25% (≤ 49 µg/kg dw) of the 45-yr Alternative 6R total PCB SWAC of 39 µg/kg dw, and a site-wide dioxin/furan SWAC within 25% (≤ 5.4 ng TEQ/kg dw) of the 45-yr Alternative 6R dioxin/furan SWAC of 4.3 ng TEQ/kg dw. Resident fish and shellfish tissue concentrations are expected to remain elevated during construction and up to 2 years after construction as a result of resuspension and release of total PCBs into the water column.

f. See Figure 10-4 for times for individual risk drivers to achieve excess cancer risk thresholds. Alternatives 3C and 3R specifically address direct contact risks and achieve the total and individual direct contact risk metrics defined in Section 9.1.2.3 at the end of construction for all exposure scenarios. The FS assumes that the Alternative 3 actions occur at the beginning of Alternatives 4, 5, and 6; these alternatives are assumed to have the same times to achieve the other cleanup objective metrics for RAO 2 as described for Alternatives 3C and 3R. Alternative 2 does not actively remediate for all direct contact risks. However, surface sediments in clamming and beach play areas are $\leq 1 \times 10^{-5}$ following construction of the EAAs and are expected to continue recovering naturally over time.

g. The time to achieve cleanup objectives for RAO 3 was assumed for purposes of the FS to be when at least 98% of FS surface sediment dataset stations are predicted to comply with the SMS and more than 98% of the LDW surface area is predicted to comply with the SMS. This is not intended as a compliance metric. EPA and Ecology will determine the appropriate metric for SMS compliance.

h. The time to achieve the cleanup objective for RAO 4 is when wildlife seafood consumption HQ <1 is achieved based on the site-wide total PCB SWAC at the end of construction.

i. Short-term impacts to workers, the community, and the environment are assumed to be proportional to the volume of material managed and the length of construction. Transportation (truck and train miles) is a surrogate for total volume managed. It is one particular metric that affects the community. See Table 10-3 for other short-term metrics.

j. Remaining cores grouped by those located under caps and those located anywhere else within the LDW after construction.

k. Alternative 1 has 25 core stations remaining in Category 1.

AOPC = area of potential concern; ARAR = applicable or relevant and appropriate requirement; BCM = bed composition model; C = combined technology; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CO_2 = carbon dioxide; CSL = cleanup screening level; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; EPA = U.S. Environmental Protection Agency; FS = feasibility study; HQ = hazard quotient; ICs = institutional controls; kg = kilograms; LDW = Lower Duwamish Waterway; µg = micrograms; MNR = monitored natural recovery; n/a = not applicable; n/c = not calculated; ng = nanograms; O&M = operation and maintenance; PCB = polychlorinated biphenyl; PM_{10} = particulate matter with a diameter of 10 micrometers or less; PRG = preliminary remediation goal; RAO = remedial action objective; RME = reasonable maximum exposure; R = removal emphasis; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; T = treatment; TEQ = toxic equivalent

Figure 12-1 Comparative Analysis of Remedial Alternatives

		CERCLA Evaluation of Alternatives [a]					
Remedial Alternative	Cost (Net Present Value)	Achieve Threshold Requirements[b]	Reduction in Toxicity, Mobility or Volume through Treatment [c]	Long-term Effectiveness and Permanence	Short-term Effectiveness	Implementability	Cost [d]
1	$9 MM [e]	No	●	●	●	◓	◉
2R	$220 MM	Yes	●	◒	◒	○	◓
2R-CAD	$200 MM	Yes	●	●	◒	◒	◓
3C	$200 MM	Yes	◒	○	◓	○	◓
3R	$270 MM	Yes	●	○	○	○	○
4C	$260 MM	Yes	◒	◓	◓	◓	○
4R	$360 MM	Yes	●	◓	○	◓	◒
5C	$290 MM	Yes	○	◓	◓	◓	○
5R	$470 MM	Yes	●	◉	◒	◒	◒
5R-Treatment	$510 MM	Yes	◓	◉	◒	●	◒
6C	$530 MM	Yes	○	◓	◒	◒	◒
6R	$810 MM	Yes	●	◉	●	●	●

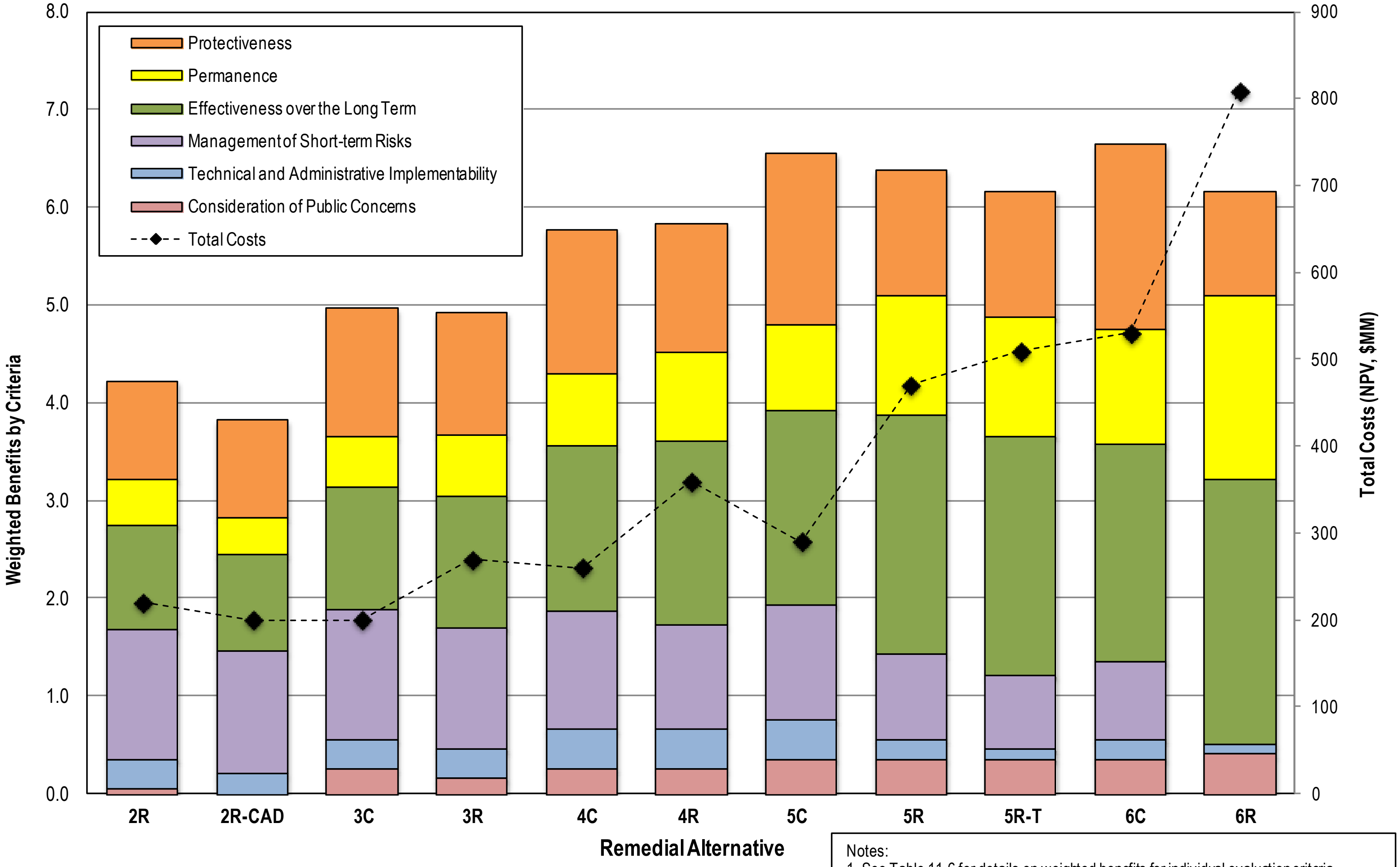
Notes:

1. State, tribal, and community acceptance will be evaluated following formal public comment on EPA's Proposed Plan.
a. Ratings based on rankings shown in Table 10-1.
b. Threshold requirements are: 1) Overall Protection of Human Health and the Environment and 2) Comply with or waive ARARs.
c. *Ex situ* treatment (soil washing) is a component of only Alternative 5R-Treatment. *In situ* treatment is a component of the combined-technology alternatives.
d. Low costs are given a high rank and high costs are given a low rank.
e. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting. The cost of cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided for informational purposes and are not used in the comparison of alternatives.

◉ - Ranks very high compared to other alternatives
◓ - Ranks relatively high compared to other alternatives
○ - Ranks moderate compared to other alternatives
◒ - Ranks low-moderate compared to other alternatives
● - Ranks low compared to other alternatives

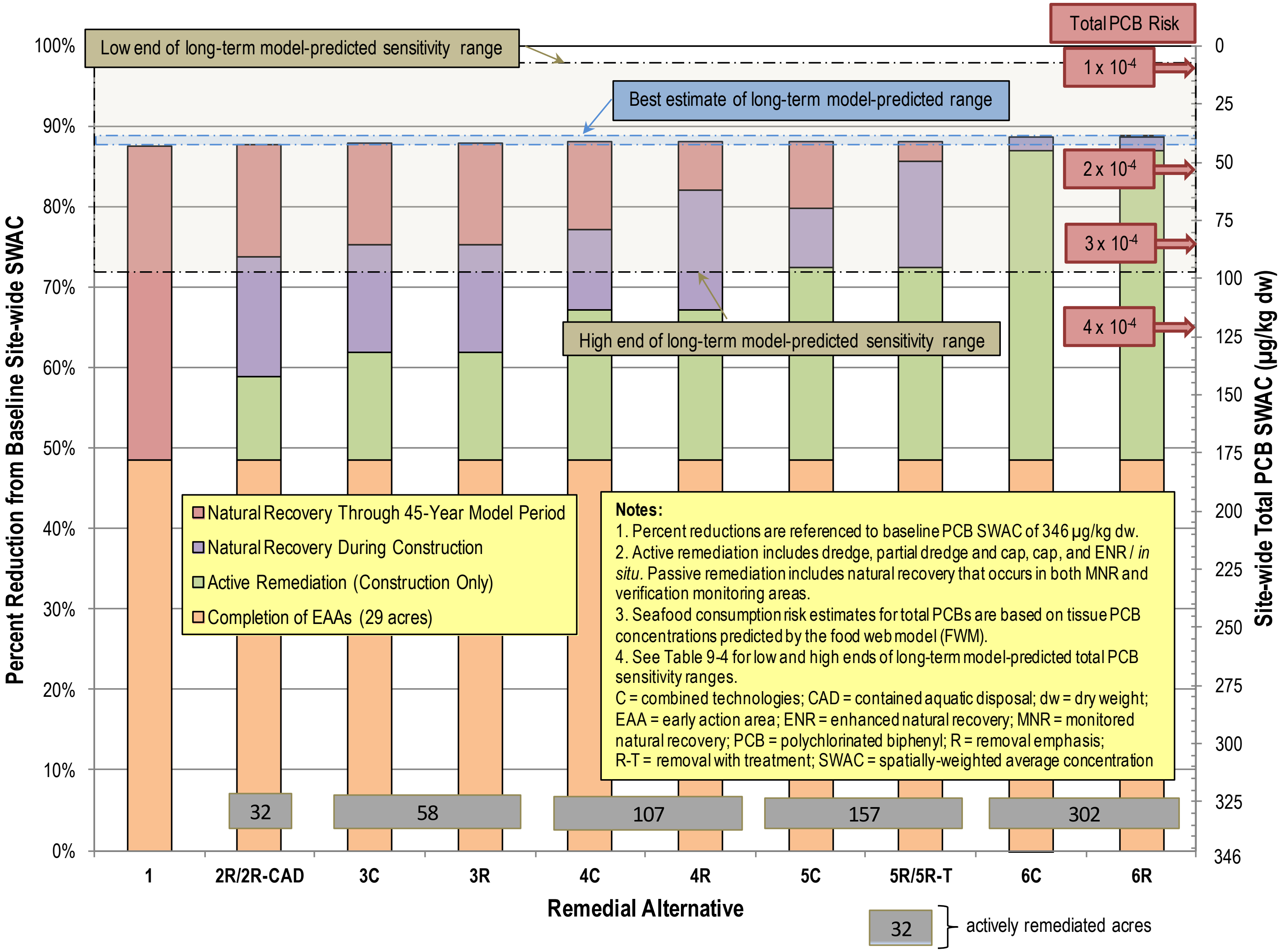
ARAR = applicable or relevant and appropriate requirement; C = combined technologies; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; EAA = early action area; EPA = U.S. Environmental Protection Agency; FS = feasibility study; LDW = Lower Duwamish Waterway; MM = million; R = removal emphasis

Figure 12-2 MTCA DCA Weighted Benefits by Criteria and Associated Costs for the Remedial Alternatives



Notes:
1. See Table 11-6 for details on weighted benefits for individual evaluation criteria.
2. Total weighted benefit represents rounded values and weighted benefits by criteria represent unrounded values.
C = combined-technology alternative; CAD = contained aquatic disposal;
DCA = disproportionate cost analysis; MM = million; MTCA = Model Toxics Control Act;
NPV = net present value; R = removal-emphasis alternative; R-T = removal with treatment

Figure 12-3 Reduction of Total PCB SWAC by Active Remediation and Natural Recovery



Notes:

1. Percent reductions are referenced to baseline PCB SWAC of 346 µg/kg dw.
2. Active remediation includes dredge, partial dredge and cap, cap, and ENR / *in situ*. Passive remediation includes natural recovery that occurs in both MNR and verification monitoring areas.
3. Seafood consumption risk estimates for total PCBs are based on tissue PCB concentrations predicted by the food web model (FWM).
4. See Table 9-4 for low and high ends of long-term model-predicted total PCB sensitivity ranges.

C = combined technologies; CAD = contained aquatic disposal; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; MNR = monitored natural recovery; PCB = polychlorinated biphenyl; R = removal emphasis; R-T = removal with treatment; SWAC = spatially-weighted average concentration

Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

Section 13
References

Final Feasibility Study

Lower Duwamish Waterway
Seattle, Washington

FOR SUBMITTAL TO:

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

October 31, 2012 (revised November 5, 2012)

Prepared by: AECOM

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