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

[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

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

[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

[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}

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

[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

[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]

[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

[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

[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

[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.

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:

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]

[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

[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

[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

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)	Construc-tion Period (years)	Netfishing Direct Contact Baseline = 16 10^{-6} RBTC = 3.7 PRG = Background = 7.0									
			Time from Beginning of Construction (years)									
			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
Alternative 3C	58	3	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1
Alternative 4C	107	6	16	10	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.1
Alternative 5C	157	7	16	10	9.6	9.4	9.2	9.2	9.2	9.1	9.1	9.1
Alternative 6C	302	16	16	10	9.5	9.2	9.1	9.1	9.1	9.1	9.1	9.1
Alternative 2R	32	4	16	10	9.8	9.4	9.3	9.2	9.2	9.2	9.2	9.1
Alternative 3R	58	6	16	10	9.7	9.4	9.2	9.2	9.2	9.1	9.1	9.1
Alternative 4R	107	11	16	10	9.7	9.3	9.2	9.2	9.2	9.2	9.1	9.1
Alternative 5R	157	17	16	10	9.7	9.4	9.3	9.2	9.2	9.2	9.1	9.1
Alternative 6R	302	42	16	10	9.7	9.4	9.3	9.2	9.2	9.1	9.1	9.1

Alternative	Tribal Clamming Direct Contact Baseline = 13 10^{-6} RBTC = 1.3 PRG = Background = 7.0									
	Time from Beginning of Construction (years)									
	0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	13	11	11	11	11	11	11	10	10	10
Alternative 3C	13	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.1
Alternative 4C	13	9.5	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5C	13	9.6	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 6C	13	9.6	9.4	9.2	9.2	9.2	9.2	9.1	9.2	9.1
Alternative 2R	13	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.1
Alternative 3R	13	9.4	9.3	9.2	9.2	9.2	9.2	9.1	9.1	9.1
Alternative 4R	13	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5R	13	9.4	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 6R	13	9.4	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.1

Alternative	Beach Play Direct Contact Baseline = 9.1 10^{-6} RBTC = 2.8 PRG = Background = 7.0									
	Time from Beginning of Construction (years)									
	0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	9.1	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 3C	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 4C	9.1	9.4	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5C	9.1	9.6	9.4	9.3	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 6C	9.1	9.6	9.4	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 2R	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 3R	9.1	9.3	9.3	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 4R	9.1	9.3	9.4	9.2	9.2	9.2	9.2	9.2	9.2	9.2
Alternative 5R	9.1	9.3	9.4	9.4	9.3	9.2	9.2	9.2	9.2	9.2
Alternative 6R	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)	Construc-tion 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									
			Time from Beginning of Construction (years)									
			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
Alternative 3C	58	3	180	86	65	52	49	46	45	44	43	42
Alternative 4C	107	6	180	79	61	50	47	45	45	43	43	41
Alternative 5C	157	7	180	70	56	48	46	44	44	43	43	41
Alternative 6C	302	16	180	70	48	39	40	40	41	41	41	40
Alternative 2R	32	4	180	91	68	54	50	48	47	45	44	42
Alternative 3R	58	6	180	86	65	52	49	46	45	44	43	42
Alternative 4R	107	11	180	86	62	50	47	45	45	43	43	41
Alternative 5R	157	17	180	86	62	50	47	45	44	43	43	41
Alternative 6R	302	42	180	86	62	50	44	41	41	40	39	39

Alternative	Tribal Clamming Direct Contact Baseline = 540 10^{-6} RBTC = 500 PRG = 500									
	Time from Beginning of Construction (years)									
	0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	190	95	68	55	52	50	49	47	47	46
Alternative 3C	190	66	56	50	48	47	46	45	45	44
Alternative 4C	190	61	53	48	46	45	45	44	44	43
Alternative 5C	190	59	52	48	46	45	45	44	44	43
Alternative 6C	190	59	49	41	42	42	42	42	42	41
Alternative 2R	190	71	59	52	49	48	47	45	45	44
Alternative 3R	190	66	56	50	48	47	46	45	45	44
Alternative 4R	190	66	54	48	46	45	45	44	44	43
Alternative 5R	190	66	54	49	46	45	45	44	44	43
Alternative 6R	190	66	54	49	44	43	43	41	41	40

Alternative	Beach Play Direct Contact Baseline = 286 10^{-6} RBTC = 1,700 PRG = 1,700									
	Time from Beginning of Construction (years)									
	0[a]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	270	110	69	51	49	47	47	45	45	42
Alternative 3C	270	61	53	47	45	45	45	44	44	42
Alternative 4C	270	54	49	45	44	44	45	44	44	42
Alternative 5C	270	54	49	45	44	44	45	44	44	42
Alternative 6C	270	54	47	43	43	43	44	44	44	42
Alternative 2R	270	66	55	48	46	45	45	44	44	42
Alternative 3R	270	61	53	47	45	45	45	44	44	42
Alternative 4R	270	61	50	45	44	44	45	44	44	42
Alternative 5R	270	61	50	47	45	44	45	44	44	42
Alternative 6R	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 *Time from Beginning of Construction (years)*										Tribal Clamming Direct Contact Baseline = 380 10^{-6} RBTC = 150 PRG = 150 *Time from Beginning of Construction (years)*										Beach Play Direct Contact Baseline = 331 10^{-6} RBTC = 90 PRG = 90 *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 *Time from Beginning of Construction (years)*										Tribal Clamming Direct Contact Baseline = 32 10^{-6} RBTC = 13 PRG = 13 *Time from Beginning of Construction (years)*										Beach Play Direct Contact Baseline = 18 10^{-6} RBTC = 28 PRG = 28 *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:

(Shaded cells:) 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

			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					
Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	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

			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					
Alternative	Active Area in FS Study Area (acres)	Construction Period (years)	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%

[grey shading] = 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, *Time from Beginning of Construction (years)*										Beach 2, Baseline = 23, *Time from Beginning of Construction (years)*										Beach 3, Baseline = 30, *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, *Time from Beginning of Construction (years)*										Beach 5[b], Baseline = 5.8, *Time from Beginning of Construction (years)*										Beach 6, Baseline = 8.3, *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, *Time from Beginning of Construction (years)*										Beach 8, Baseline = 3.8, *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) – Time from Beginning of Construction (years)										Sensitivity (Low, Low, Low) – 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	360	220	160	130	120	110	110	107	107	99	350	190	120	85	73	66	64	59	57	54
Alternative 3C	58	3	360	180	140	120	109	105	106	104	104	97	350	150	101	73	65	60	59	55	54	51
Alternative 4C	107	6	360	170	140	110	106	104	106	103	103	96	350	130	90	68	62	58	57	54	54	51
Alternative 5C	157	7	360	160	130	110	105	103	105	103	103	96	350	110	81	64	60	56	56	54	53	51
Alternative 6C	302	16	360	160	130	103	101	100	103	102	102	95	350	110	76	55	53	52	53	52	52	50
Alternative 2R	32	4	360	200	150	120	110	107	108	105	105	98	350	170	110	79	69	62	61	57	55	53
Alternative 3R	58	6	360	180	140	120	109	105	106	104	104	97	350	150	101	73	65	60	59	55	54	51
Alternative 4R	107	11	360	180	140	110	107	104	106	103	103	96	350	150	91	68	62	58	57	54	54	51
Alternative 5R	157	17	360	180	140	110	107	104	106	103	103	96	350	150	91	66	61	57	57	54	53	51
Alternative 6R	302	42	360	180	140	110	107	103	105	103	102	96	350	150	91	66	59	55	55	53	52	50

Alternative	Sensitivity (High, High, High) – Time from Beginning of Construction (years)										Sensitivity (Mid (Bed), Mid (Up), High (Lat)) – 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	360	360	350	330	330	330	340	340	340	320	360	250	200	160	150	150	150	150	150	130
Alternative 3C	360	310	330	310	320	320	330	340	340	320	360	200	180	140	140	140	150	150	150	130
Alternative 4C	360	290	320	310	320	320	330	330	340	320	360	190	170	140	140	140	150	150	150	130
Alternative 5C	360	270	310	300	320	320	330	330	340	320	360	170	160	140	140	140	150	150	150	130
Alternative 6C	360	270	280	270	300	310	330	330	330	320	360	170	150	130	130	140	150	140	150	130
Alternative 2R	360	330	340	320	320	330	330	340	340	320	360	220	190	150	150	140	150	150	150	130
Alternative 3R	360	310	330	310	320	320	330	340	340	320	360	200	180	140	140	140	150	150	150	130
Alternative 4R	360	310	310	310	320	320	330	330	340	320	360	200	170	140	140	140	150	150	150	130
Alternative 5R	360	310	310	290	310	320	330	330	340	320	360	200	170	140	140	140	150	150	150	130
Alternative 6R	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) – Time from Beginning of Construction (years)										Sensitivity (Low, Low, Low) – 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	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
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
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
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
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
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
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
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
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
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

Alternative	Sensitivity (High, High, High) – Time from Beginning of Construction (years)										Sensitivity (Mid (Bed), Mid (Up), High (Lat)) – 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	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	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	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	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	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	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	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	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	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	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)

[Shaded cell] 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)

Alternative	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
	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)

Alternative	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
	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)

Alternative	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
	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)

Alternative	Time from Beginning of Construction (years)										Percent Reduction of Site-wide SWAC from Year 45 Alternative 6R SWAC[a]									
	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

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.

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

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)	Construction 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)	Construction 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 = 2×10^{-3}									
			Time from Beginning of Construction (years)[a]									
			0[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	29	0	5×10^{-4}	4×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 3C	58	3	5×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 4C	107	6	5×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 5C	157	7	5×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 6C	302	16	5×10^{-4}			2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 2R	32	4	5×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 3R	58	6	5×10^{-4}	3×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 4R	107	11	5×10^{-4}		2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 5R	157	17	5×10^{-4}			2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}	2×10^{-4}
Alternative 6R	302	42	5×10^{-4}								2×10^{-4}	2×10^{-4}

Alternative	Child Tribal RME (Tulalip data) Baseline HHRA = 3×10^{-4}									
	Time from Beginning of Construction (years)[a]									
	0[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	1×10^{-4}	7×10^{-5}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 3C	1×10^{-4}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 4C	1×10^{-4}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 5C	1×10^{-4}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 6C	1×10^{-4}			3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 2R	1×10^{-4}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 3R	1×10^{-4}	5×10^{-5}	4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 4R	1×10^{-4}		4×10^{-5}	4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 5R	1×10^{-4}			4×10^{-5}	4×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}	3×10^{-5}
Alternative 6R	1×10^{-4}								3×10^{-5}	3×10^{-5}

Alternative	Adult API RME Baseline HHRA Risk = 5×10^{-4}									
	Time from Beginning of Construction (years)[a]									
	0[b]	*5*	*10*	*15*	*20*	*25*	*30*	*35*	*40*	*45*
Alternative 1	2×10^{-4}	1×10^{-4}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}
Alternative 3C	2×10^{-4}	8×10^{-5}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 4C	2×10^{-4}	8×10^{-5}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 5C	2×10^{-4}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 6C	2×10^{-4}			5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 2R	2×10^{-4}	9×10^{-5}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 3R	2×10^{-4}	8×10^{-5}	7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 4R	2×10^{-4}		7×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 5R	2×10^{-4}			6×10^{-5}	6×10^{-5}	6×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}	5×10^{-5}
Alternative 6R	2×10^{-4}								5×10^{-5}	5×10^{-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}	Colored cells indicate residual excess cancer risk rounded to the nearest order of magnitude.
10^{-4}	
10^{-5}	
5×10^{-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 – Time from Beginning of Construction (years)[a]										Child Tribal RME (Tulalip data) Baseline HHRA HQ = 86 – Time from Beginning of Construction (years)[a]										Adult API RME Baseline HHRA HQ = 29 – 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 – Time from Beginning of Construction (years)[a]										Otter LOAEL-based HQ – without Juvenile Fish[c] – 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).

Legend	
HQ >1	Colored cells indicate residual non-cancer hazard quotient.
HQ ≤1	
0.4	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 (Time from Beginning of Construction (years))

Receptor Group	Baseline Risk[a]	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	3×10^{-5}	6×10^{-6}	4×10^{-6}	4×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	2×10^{-4}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}	9×10^{-6}	9×10^{-6}	9×10^{-6}
Beach 1	9×10^{-6}	9×10^{-6}	7×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	9×10^{-5}	1×10^{-5}	8×10^{-6}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	1×10^{-5}	6×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 4	6×10^{-4}	6×10^{-4}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	3×10^{-5}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	1×10^{-4}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Alternative 3 Combined (3 years[b]) (Time from Beginning of Construction (years))

Receptor Group	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Beach 1	9×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}
Beach 4	6×10^{-4}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Alternative 4 Combined (6 years[b]) (Time from Beginning of Construction (years))

Receptor Group	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Beach 1	9×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}
Beach 4	6×10^{-4}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Risk for Each Alternative — Alternative 5 Combined (7 years[b]) (Time from Beginning of Construction (years))

Receptor Group	Baseline Risk[a]	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	3×10^{-5}	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	2×10^{-4}	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Beach 1	9×10^{-6}	9×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	9×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	1×10^{-5}	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}
Beach 4	6×10^{-4}	6×10^{-4}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	3×10^{-5}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	1×10^{-4}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

Alternative 6 Combined (16 years[b]) (Time from Beginning of Construction (years))

Receptor Group	0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Beach 1	9×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	6×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}
Beach 4	6×10^{-4}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}

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

Removal Alternatives

Risk for Each Alternative

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

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

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

Risk for Each Alternative

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

Receptor Group	Alternative 6 Removal (42 years[b]) – Time from Beginning of Construction (years): 0[c]	5	10	15	20	25	30	35	40	45
Site-wide Netfishing	6×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}	3×10^{-6}
Tribal Clamming	1×10^{-5}	9×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}	8×10^{-6}
Beach 1	9×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 2	9×10^{-5}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 3	8×10^{-6}	7×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}	7×10^{-6}	6×10^{-6}	6×10^{-6}	6×10^{-6}
Beach 4	6×10^{-4}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}
Beach 5	3×10^{-5}	5×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 6	1×10^{-4}	5×10^{-6}	5×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}
Beach 7	4×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	4×10^{-6}	5×10^{-6}	5×10^{-6}	5×10^{-6}	4×10^{-6}
Beach 8	6×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-6}	4×10^{-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.

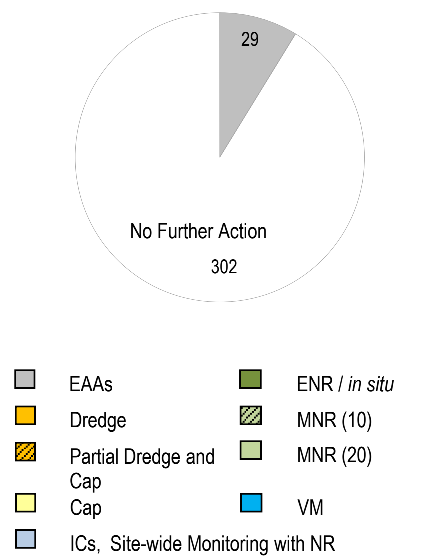
AOPC = area of potential concern; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; dw = dry weight; EAA = early action area; HHRA = human health risk assessment; kg = kilogram; LDW = Lower Duwamish Waterway; µg = microgram; mg = milligram; ng = nanogram; PCB = polychlorinated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

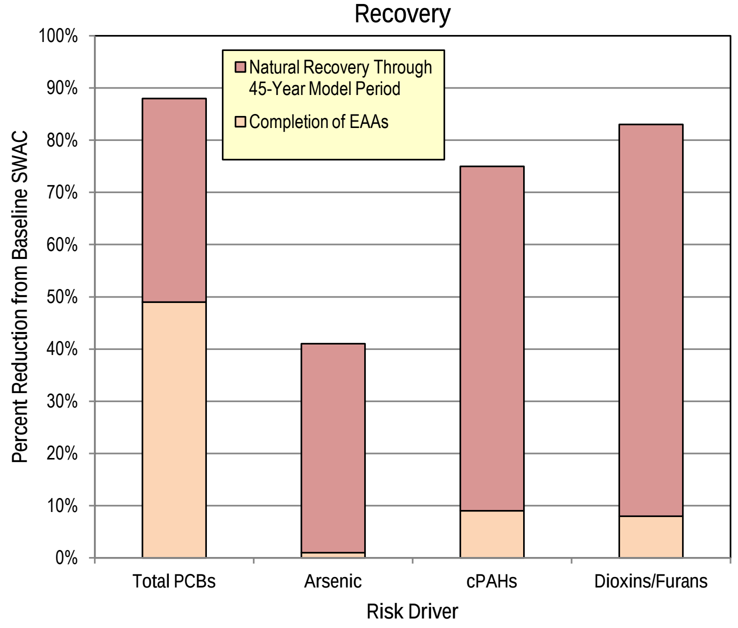
Cost Summary		
Costs ($)[a]	Completion of EAA Construction	95,000,000
	Alternative 1	9,000,000
	Total	104,000,000

Alternative 1



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 Completion of EAAs 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)[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.

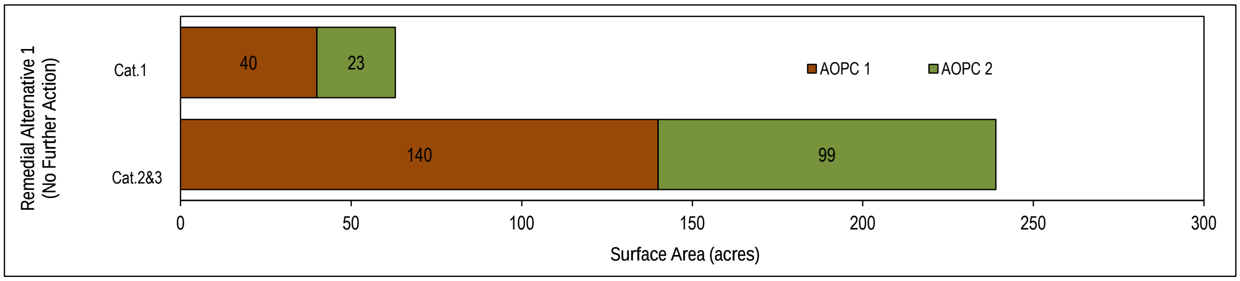
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yards; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; HHRA = human health risk assessment; 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

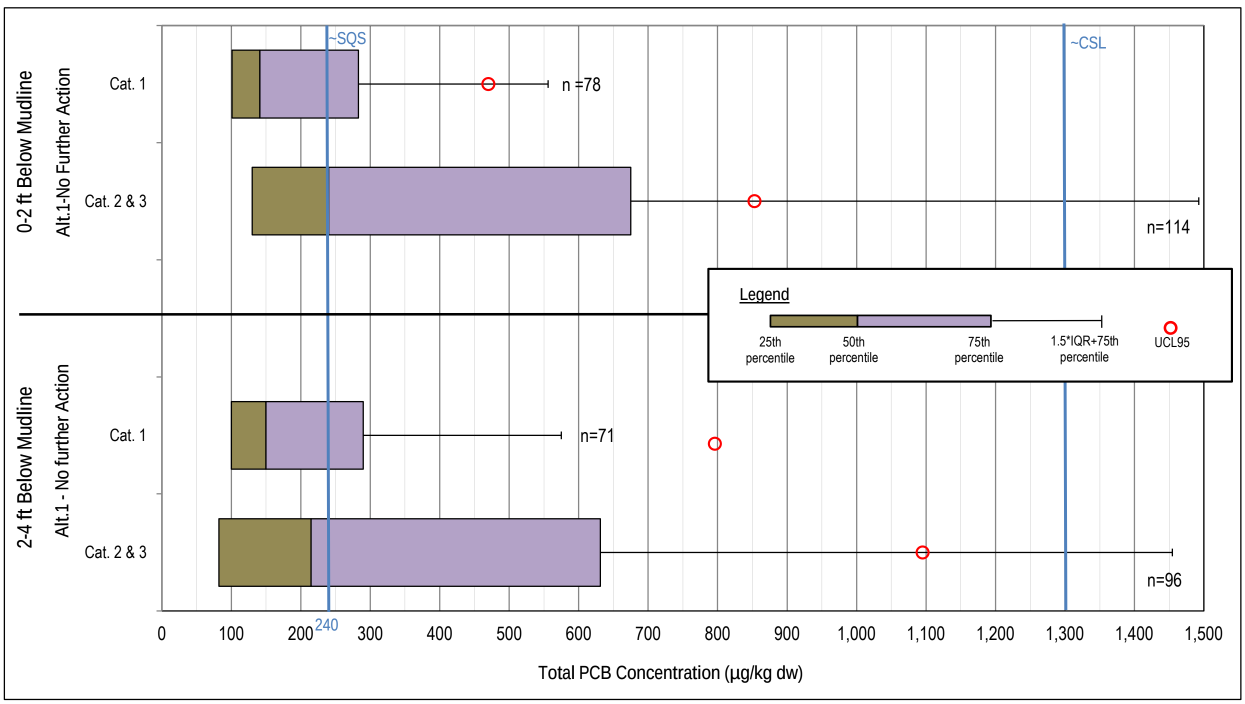
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA Footprint for Alternative 1

Remedial Alternative 1	Recovery Category	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		
		> 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).

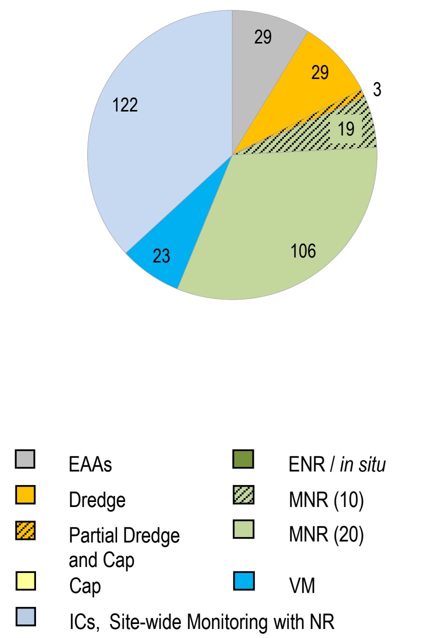
Alt. = alternative; AOPC = area of potential concern; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; n = number of cores; na = not available; PCB = polychlorinated 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

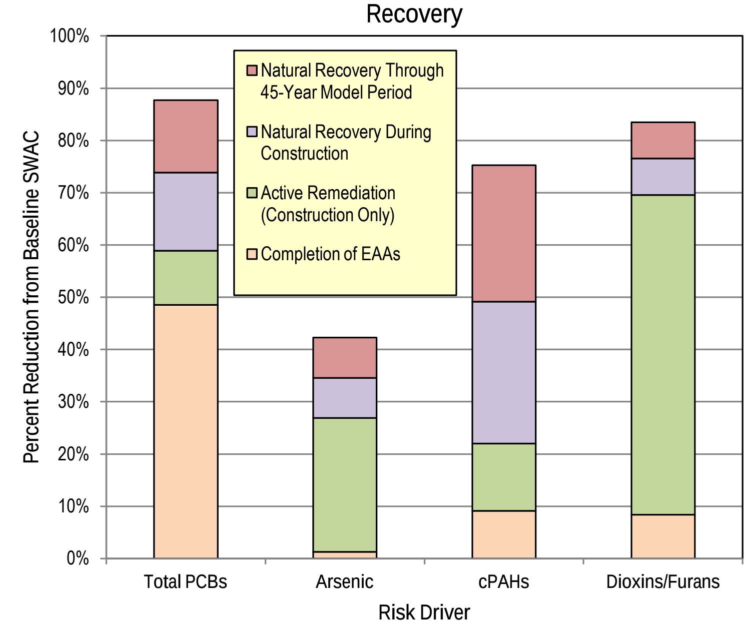
Cost Summary		
Costs ($)[g]	Capital (Alternative 2R/2R-CAD)	169,000,000/ 148,000,000
	OM&M (Alternative 2R/2R-CAD)	46,000,000/ 48,000,000
	Total (Alternative 2R/2R-CAD)	220,000,000/ 200,000,000

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

Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario

Remedial Action Objective	Risk Outcome and Exposure Scenario	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	Time to Achieve Individual Cleanup Objectives (years)
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	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas	■	■	■	■	■																						19
	≤ 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	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												14
RAO 4	River Otter LOAEL-based HQ <1[h]	■	■	■	■	■	▒	▒																				4

End of Construction (marked by a line at the end of year 4)

■ 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.

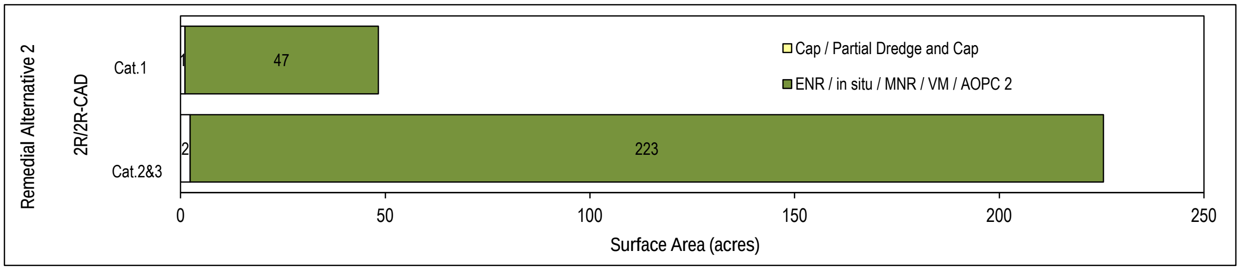
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; CAD = contained aquatic disposal; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; 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

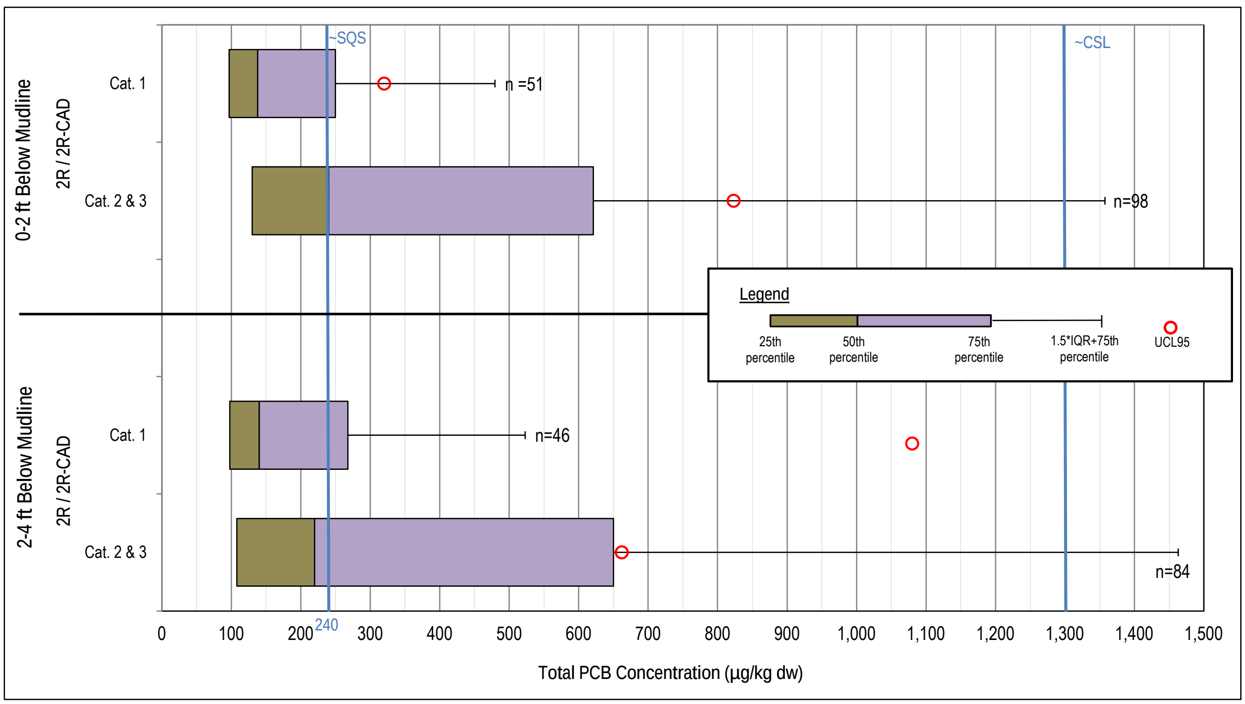
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 2

Remedial Alternative 2	Recovery Category	Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint: Core Station Counts: > CSL	Core Station Counts: < CSL, > SQS	Total PCB Concentration (µg/kg dw), 0 to 2 ft depth: n	0 to 2 ft depth: Mean	0 to 2 ft depth: UCL95	2 to 4 ft depth: n	2 to 4 ft depth: Mean	2 to 4 ft depth: UCL95	Cap / Partial Dredge and Cap: Core Station Counts: > CSL	Core Station Counts: < CSL, > SQS	Total PCB Concentration (µg/kg dw), 0 to 4 ft depth: n	0 to 4 ft depth: 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).

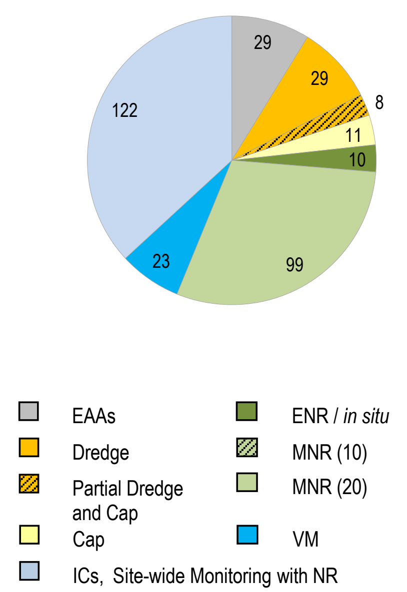
AOPC = area of potential concern; CAD = contained aquatic disposal; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per 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

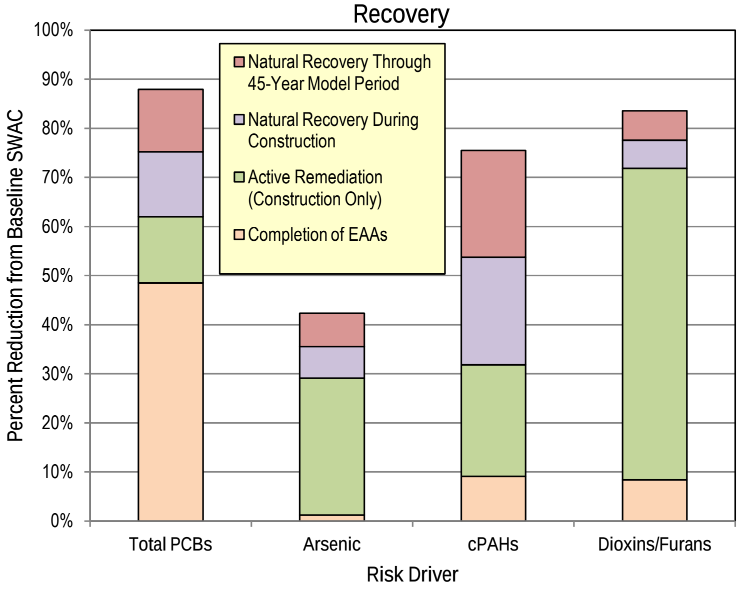
Cost Summary		
Costs ($)[g]	Capital	156,000,000
	OM&M	45,000,000
	Total	200,000,000

Alternative 3 Combined Technologies



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 (0–25)	Time to Achieve Individual Cleanup Objectives (years)
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	End of Construction	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

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.

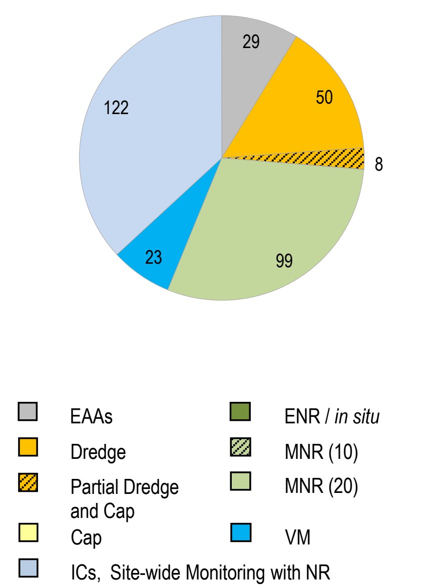
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = insitutional 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

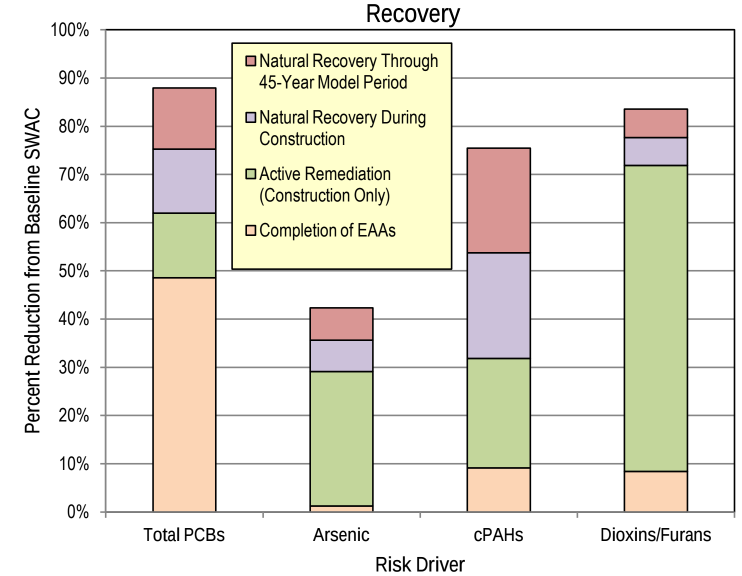
Cost Summary		
Costs ($)[g]	Capital	224,000,000
	OM&M	43,000,000
	Total	270,000,000

Alternative 3 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 (0–25)	Time to Achieve Individual Cleanup Objectives (years)
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.

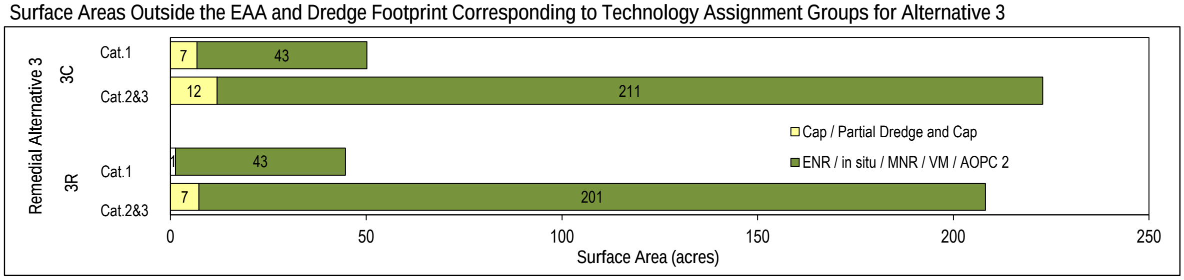
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; 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

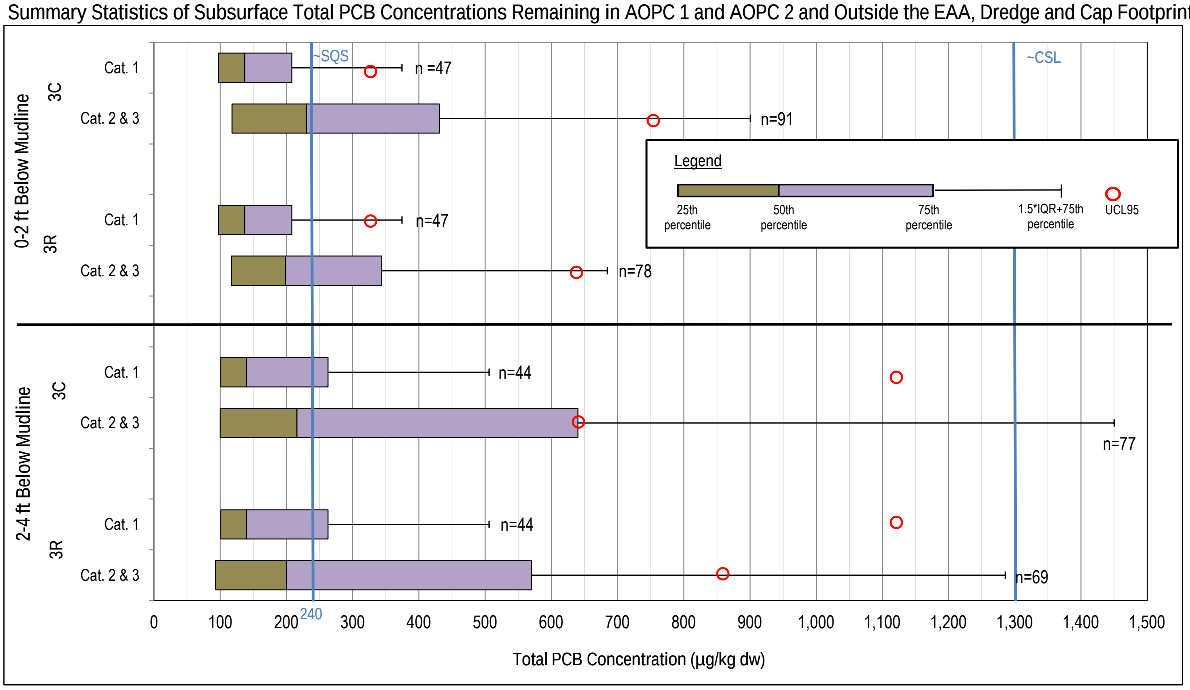
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 3

Remedial Alternative 3	Recovery Category	Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint: Core Station Counts		Total PCB Concentration (µg/kg dw): 0 to 2 ft depth			Total PCB Concentration (µg/kg dw): 2 to 4 ft depth			Cap / Partial Dredge and Cap: Core Station Counts		Total PCB Concentration (µg/kg dw): 0 to 4 ft depth	
		> 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).

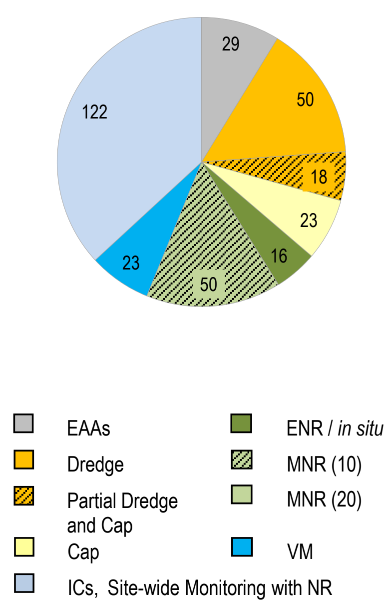
AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; 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

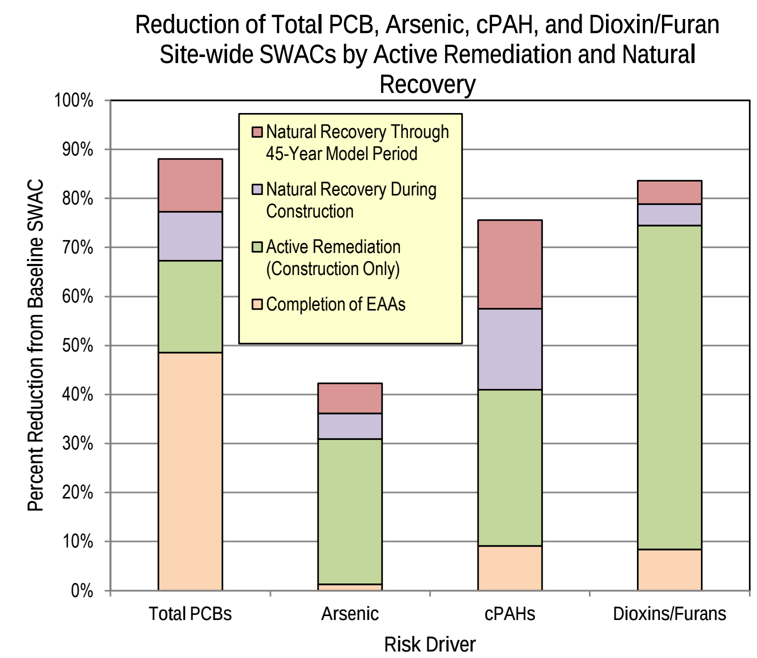
Technology Application Summary		
Actively Remediated Area (acres)	Dredge	50
	Partial Dredge and Cap	18
	Cap	23
	ENR / *in situ*	8 / 8
	Habitat Area[a]	42
Passively Remediated Area (acres)	MNR(10)[b]	50
	MNR(20)[c]	0
	Verification Monitoring	23
	Habitat Area[a]	32
Active/Passive/Total Managed Area (acres)[d]		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



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	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	Time to Achieve Individual Cleanup Objectives (years)
		Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario																										
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.

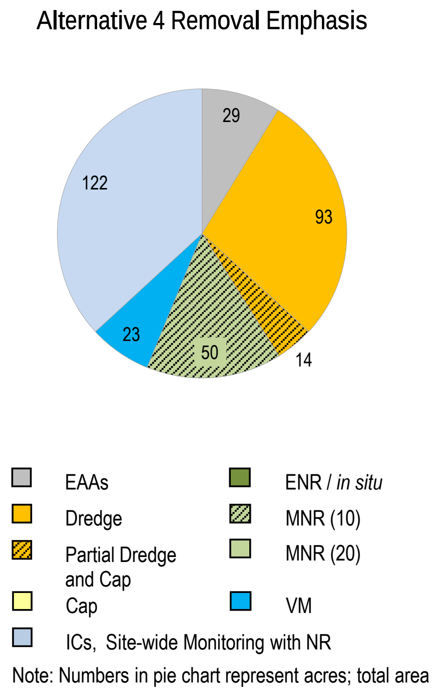
a. Habitat area is defined as all locations with mudline elevation above -10 ft MLLW. Actively remediated habitat acres represent the sum of all active technologies in habitat areas, and passively remediated habitat acres represent the sum of all passive technologies in habitat areas.
b. MNR(10) is the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

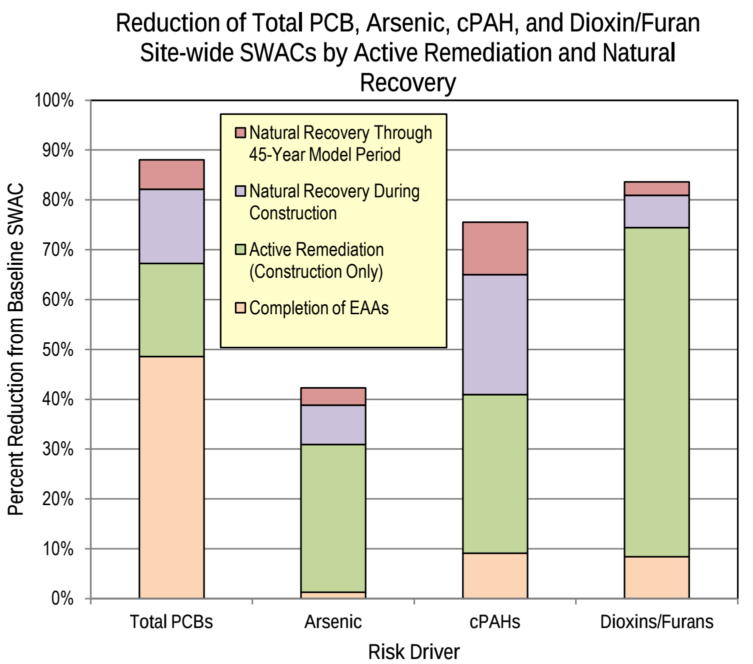
Table 9-17 Remedial Alternative 4R: Scope, Costs, and Risk Performance Summary

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



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 to Achieve Individual Cleanup Objectives (years)
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

Time (years) to Reach Model-predicted Risk Outcome or Exposure Scenario: 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

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.

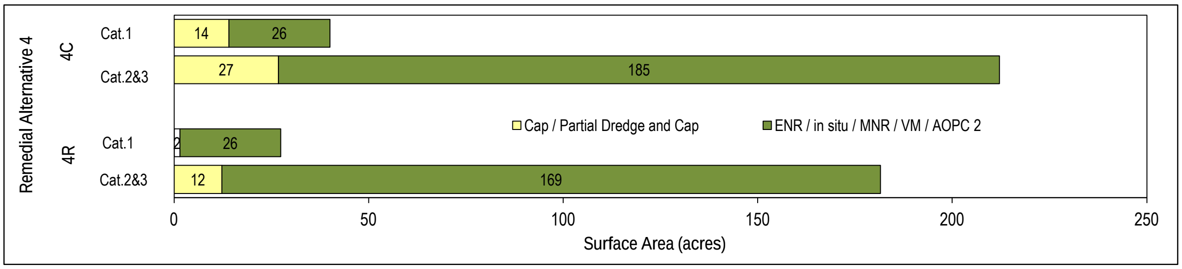
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; 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

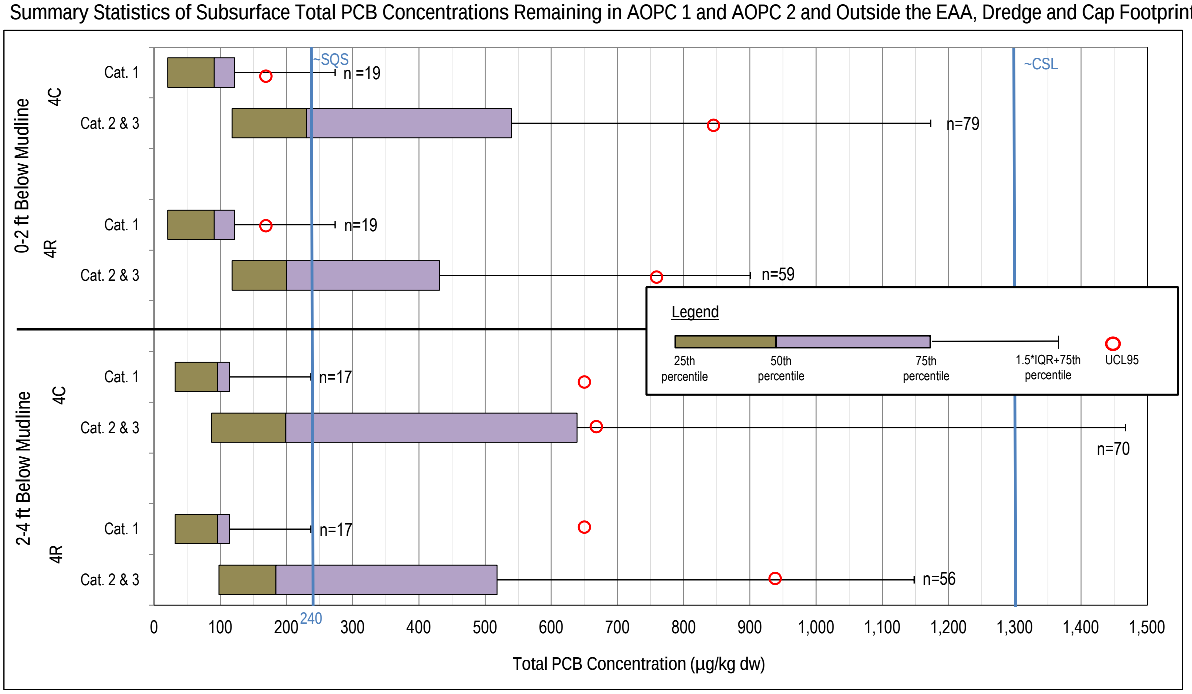
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 4

Remedial Alternative 4	Recovery Category	Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint: Core Station Counts > CSL	Core Station Counts < CSL, > SQS	Total PCB Concentration (µg/kg dw) 0 to 2 ft depth: n	0 to 2 ft depth: Mean	0 to 2 ft depth: UCL95	2 to 4 ft depth: n	2 to 4 ft depth: Mean	2 to 4 ft depth: UCL95	Cap / Partial Dredge and Cap: Core Station Counts > CSL	Core Station Counts < CSL, > SQS	Total PCB Concentration (µg/kg dw) 0 to 4 ft depth: n	0 to 4 ft depth: 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).

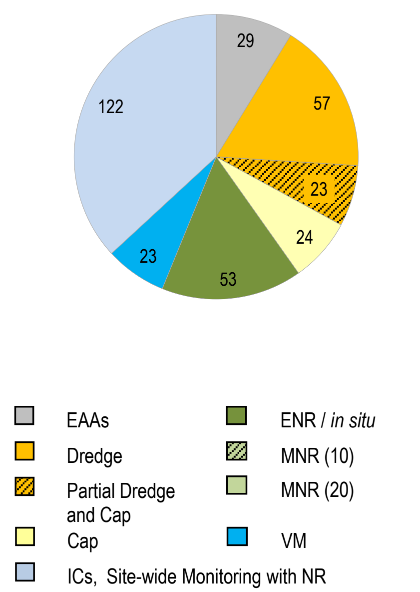
AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; 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

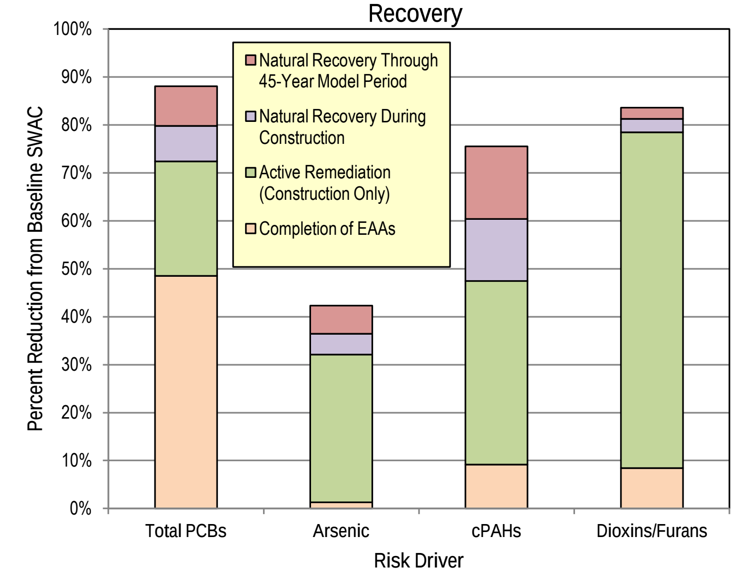
Cost Summary		
Costs ($)[g]	Capital	250,000,000
	OM&M	41,000,000
	Total	290,000,000

Alternative 5 Combined Technologies



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: 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	Time to Achieve Individual Cleanup Objectives (years)
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	≤ 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]																											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.

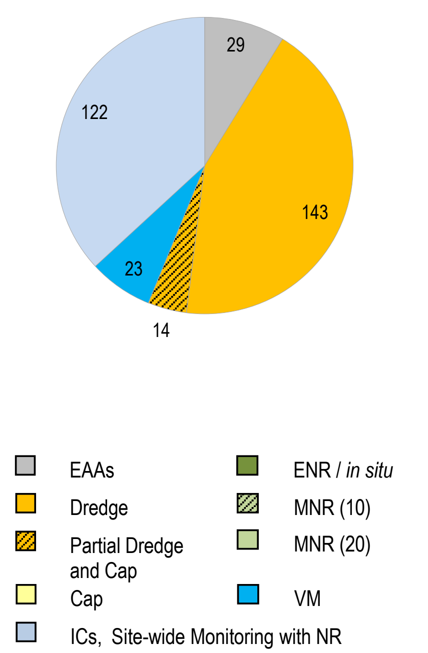
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; C = combined; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional 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

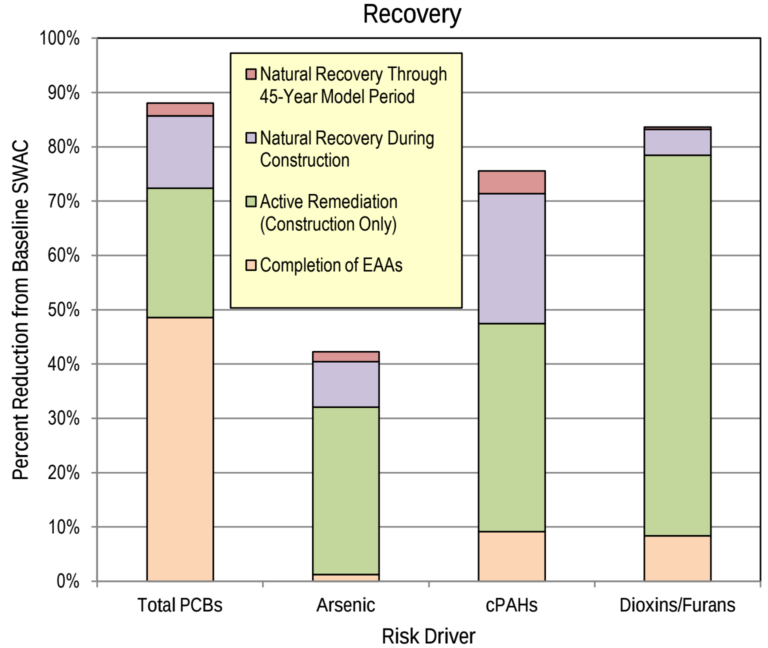
Cost Summary		
Costs ($)[g]	Capital (Alternative 5R/5R-T)	430,000,000/ 474,000,000
	OM&M	36,000,000
	Total (Alternative 5R/5R-T)	470,000,000/ 510,000,000

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	≤ 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]																											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.

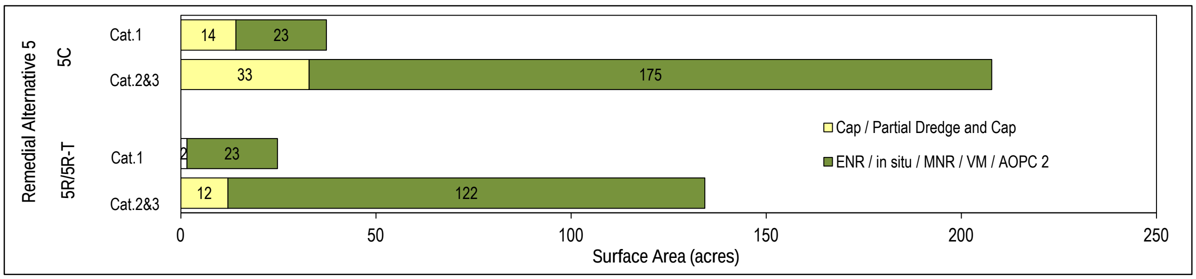
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; 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

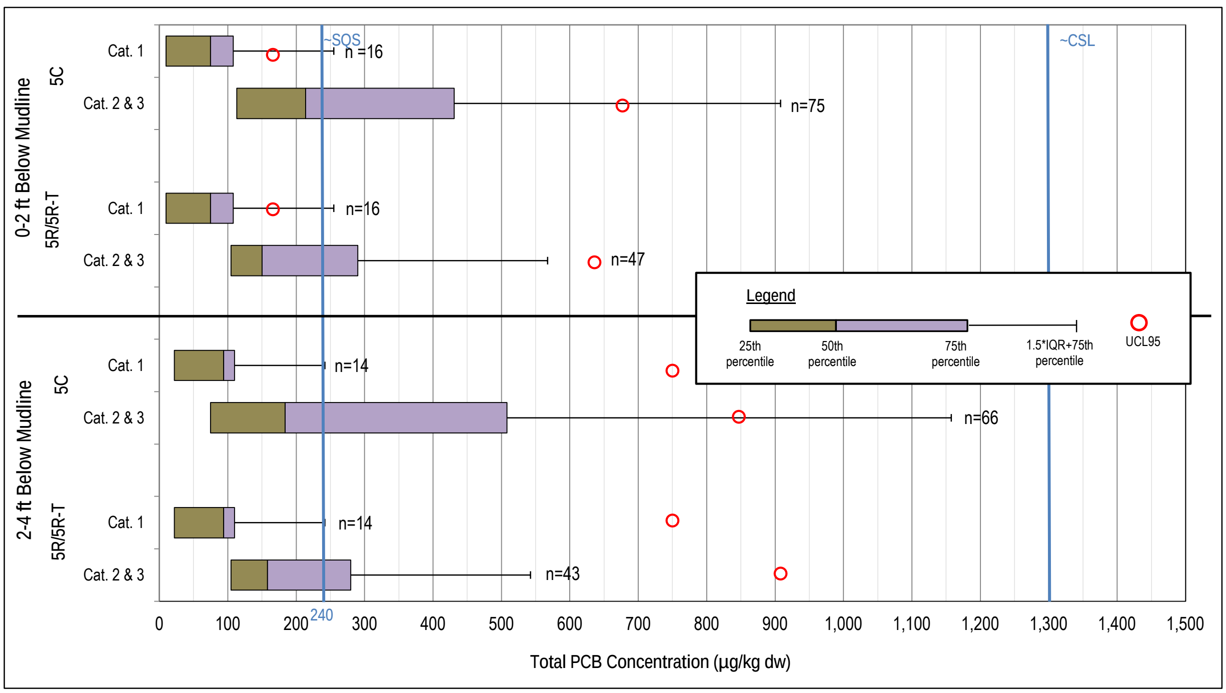
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 5

Remedial Alternative 5	Recovery Category	Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint: Core Station Counts		Total PCB Concentration (µg/kg dw): 0 to 2 ft depth			2 to 4 ft depth			Cap / Partial Dredge and Cap: Core Station Counts		Total PCB Concentration (µg/kg dw): 0 to 4 ft depth	
		> 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).

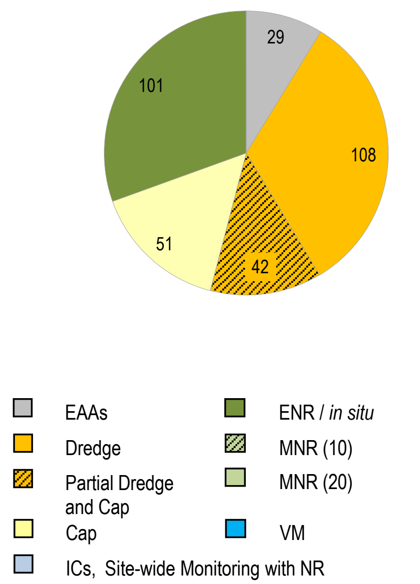
AOPC = area of potential concern; C = combined; Cat. = recovery category; CSL = cleanup screening level; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ft = foot; IQR = interquartile range; LDW = Lower Duwamish Waterway; µg/kg dw = microgram per kilogram dry weight; 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

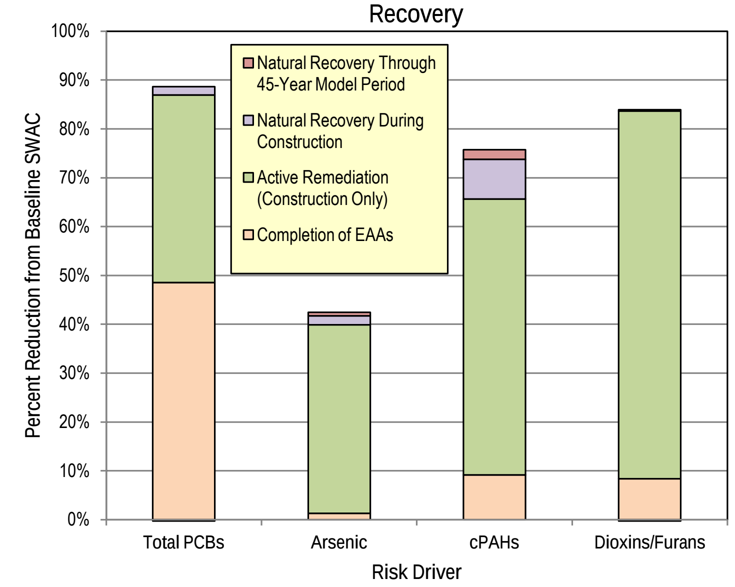
Cost Summary		
Costs ($)[g]	Capital	476,000,000
	OM&M	51,000,000
	Total	530,000,000

Alternative 6 Combined Technologies



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



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.

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 (after year 16)

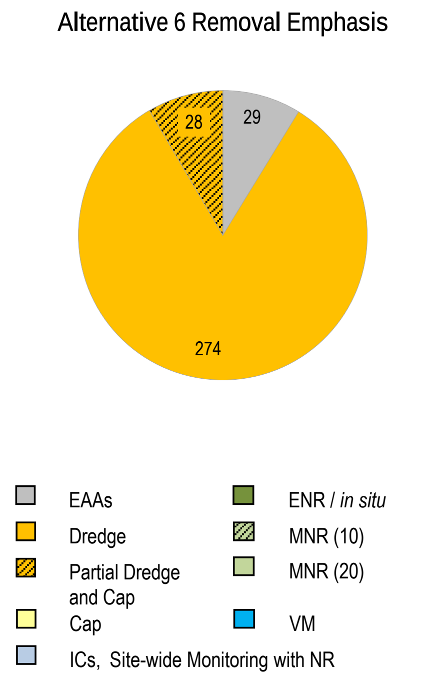
■ Estimated period of time to reach indicated risk outcome.

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

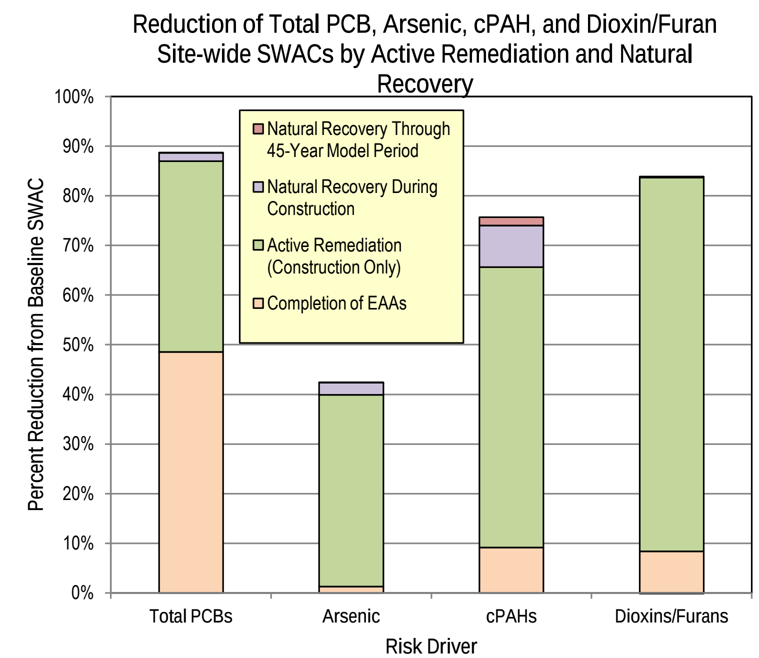
Table 9-23 Remedial Alternative 6R: Scope, Costs, and Risk Performance Summary

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.

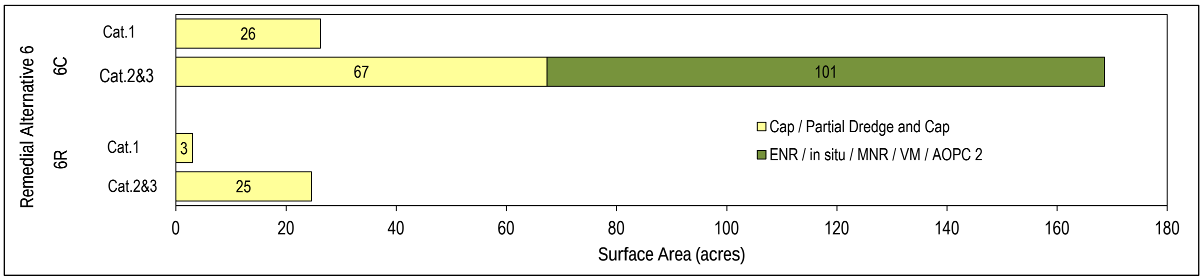
AOPC = area of potential concern; API = Asian and Pacific Islander; BCM = bed composition model; cPAH = carcinogenic polycyclic aromatic hydrocarbon; cy = cubic yard; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; ft = feet; HQ = hazard quotient; ICs = institutional controls; 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

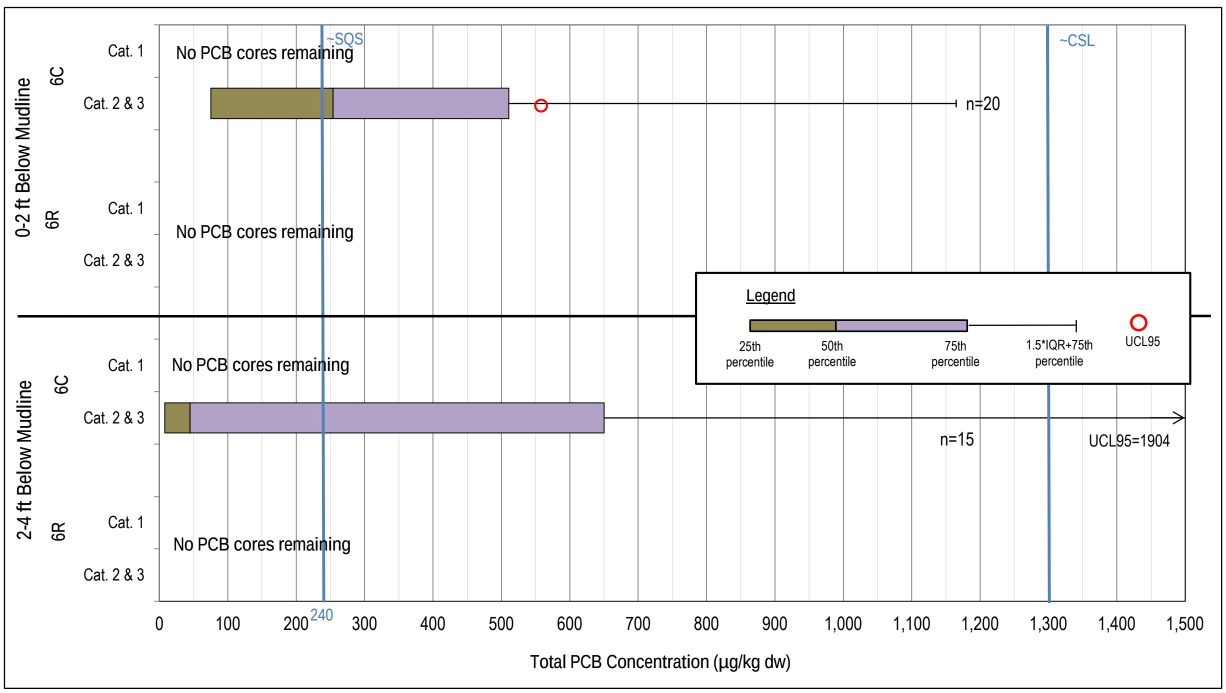
Number of Core Stations with SMS Exceedances and Total PCB Concentration in Areas Outside the EAA and Dredge Footprint for Alternative 6

Remedial Alternative 6	Recovery Category	Located within AOPC 1 and AOPC 2 Outside Dredge and Cap Footprint: Core Station Counts > CSL	Core Station Counts < CSL, > SQS	Total PCB Concentration (µg/kg dw) 0 to 2 ft depth n	0 to 2 ft Mean	0 to 2 ft UCL95	2 to 4 ft depth n	2 to 4 ft Mean	2 to 4 ft UCL95	Cap / Partial Dredge and Cap: Core Station Counts > CSL	Core Station Counts < CSL, > SQS	Total PCB Concentration (µg/kg dw) 0 to 4 ft depth n	0 to 4 ft 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

Remedial Alternative [b]	Construction Period	Remedial Action Levels	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]
			10^{-4} total PCB risk for Adult Tribal, Child Tribal and Adult API	10^{-5} total PCB risk for Child Tribal[g]	Total PCBs and dioxins/furans reach LTMPC ranges site-wide: Total PCBs	Total PCBs and dioxins/furans reach LTMPC ranges site-wide: 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. ≤1 × 10^{-5} total excess cancer risk and HQ <1 for netfishing (site-wide), clamming, and beach play areas (each beach). ≤1 × 10^{-5} and >1 × 10^{-6} arsenic in all areas. ≤1 × 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 ≤1 × 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.
	Pentachloro-phenol	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.

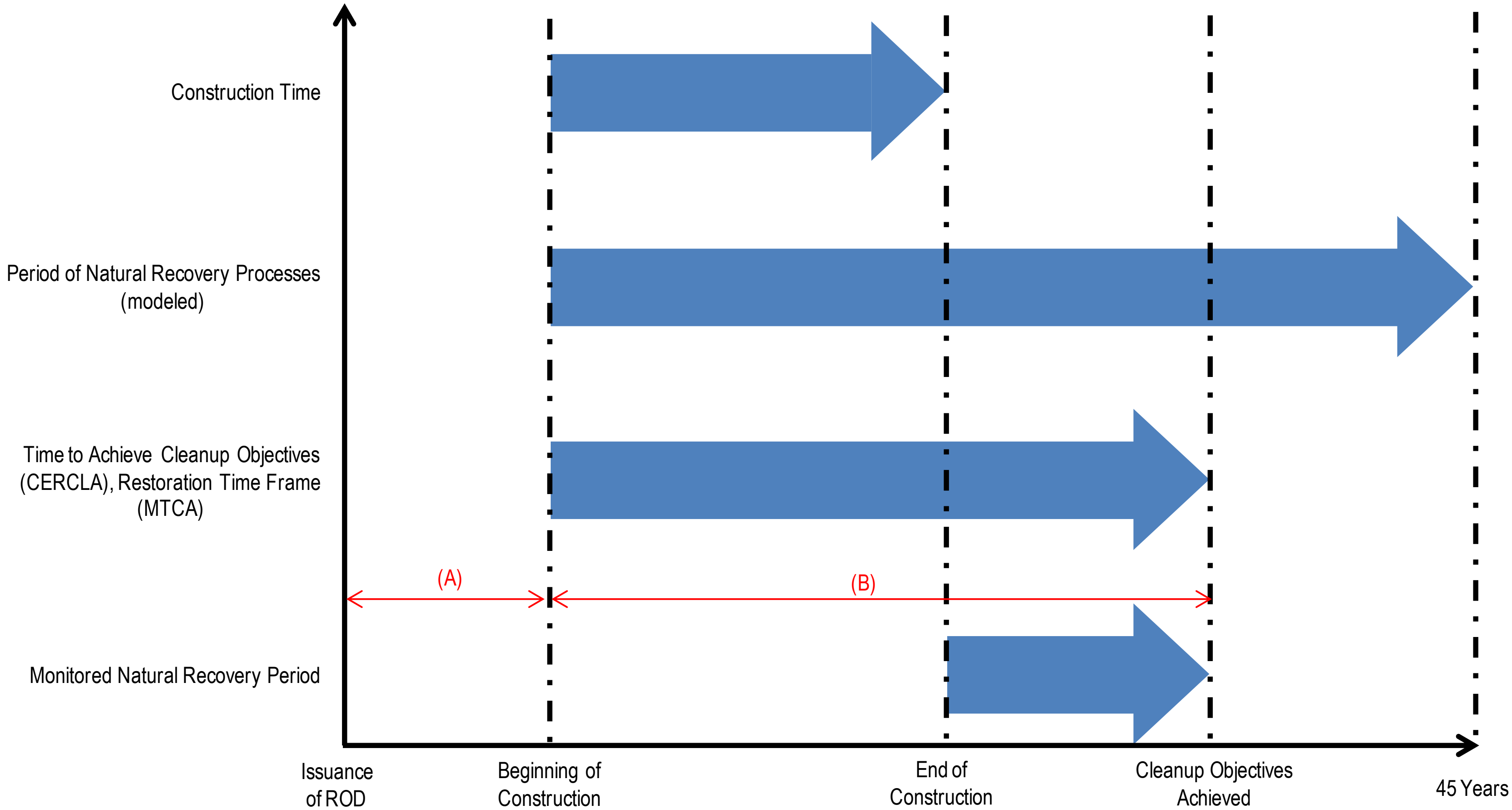
b. Concentrations in surface sediment are based on the RI baseline dataset. Comments regarding the HQs are based on the ERA baseline dataset; these comments would not change if the RI baseline dataset had been used.

c. Both high and poor quality foraging habitat.

d. Only high quality foraging habitat.

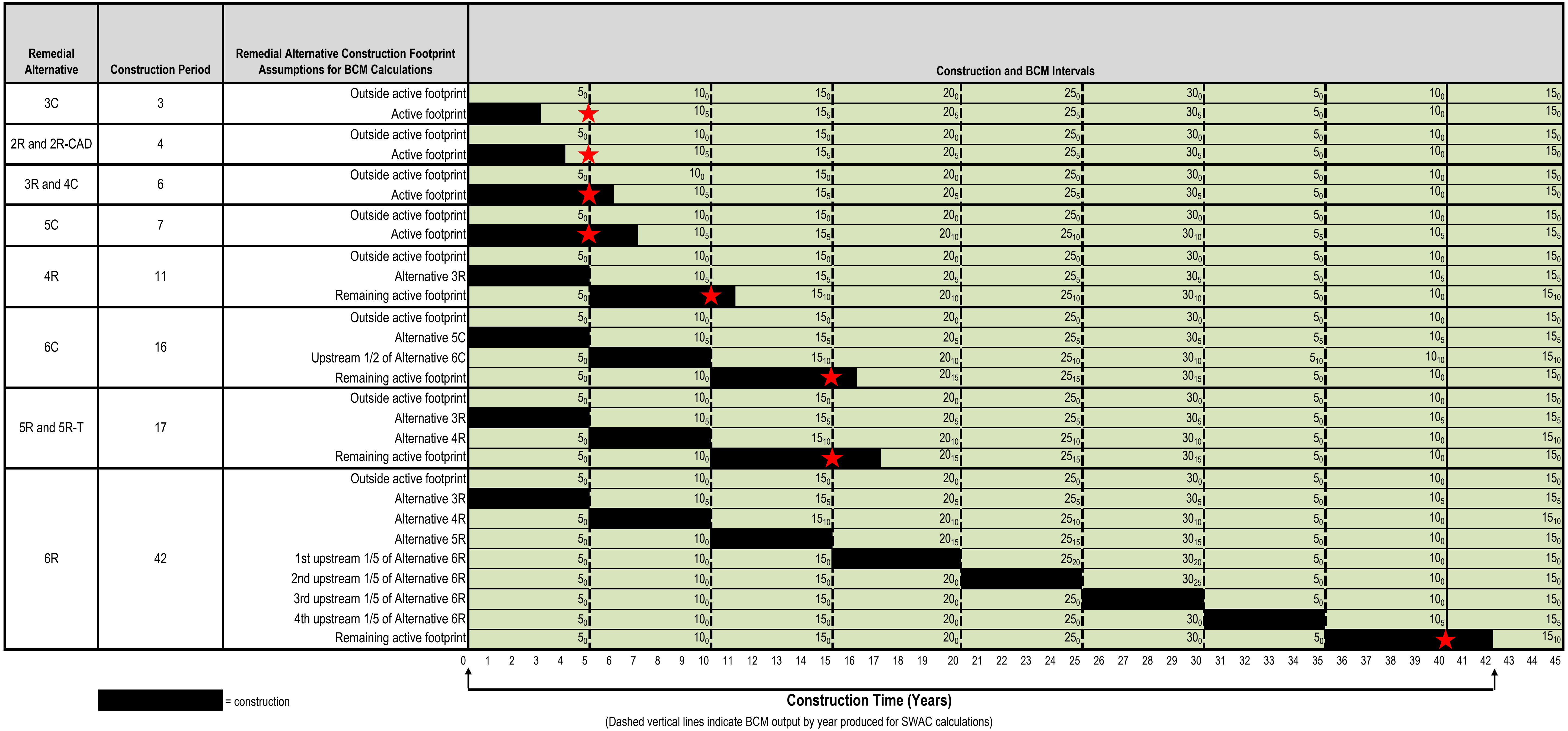
DDT = dichlorodiphenyltrichloroethane; dw = dry weight; EAA = early action area; ERA = Ecological Risk Assessment; FS = feasibility study; HQ = hazard quotient; kg = kilogram; LDW = Lower Duwamish Waterway; LOAEL = lowest-observed-adverse-effect level; µg = microgram; mg = milligram; NOAEL = no observed 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



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.

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AECOM

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

Lower Duwamish Waterway Final Feasibility Study 60150279-14.42			Temporal Sequencing of Actively Remediated Areas for BCM Calculations: Alternative 6 Combined
DATE: 10/31/12	DWRN:MVI/sea	Revision: 1	FIGURE 9-3

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 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

Feet: 0 200 400 800

AECOM

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

Lower Duwamish Waterway
Final Feasibility Study
60150279-14.42

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

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

FIGURE 9-4

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Figure 9-5a Site-wide Total PCB SWAC Versus Time – Removal Alternatives

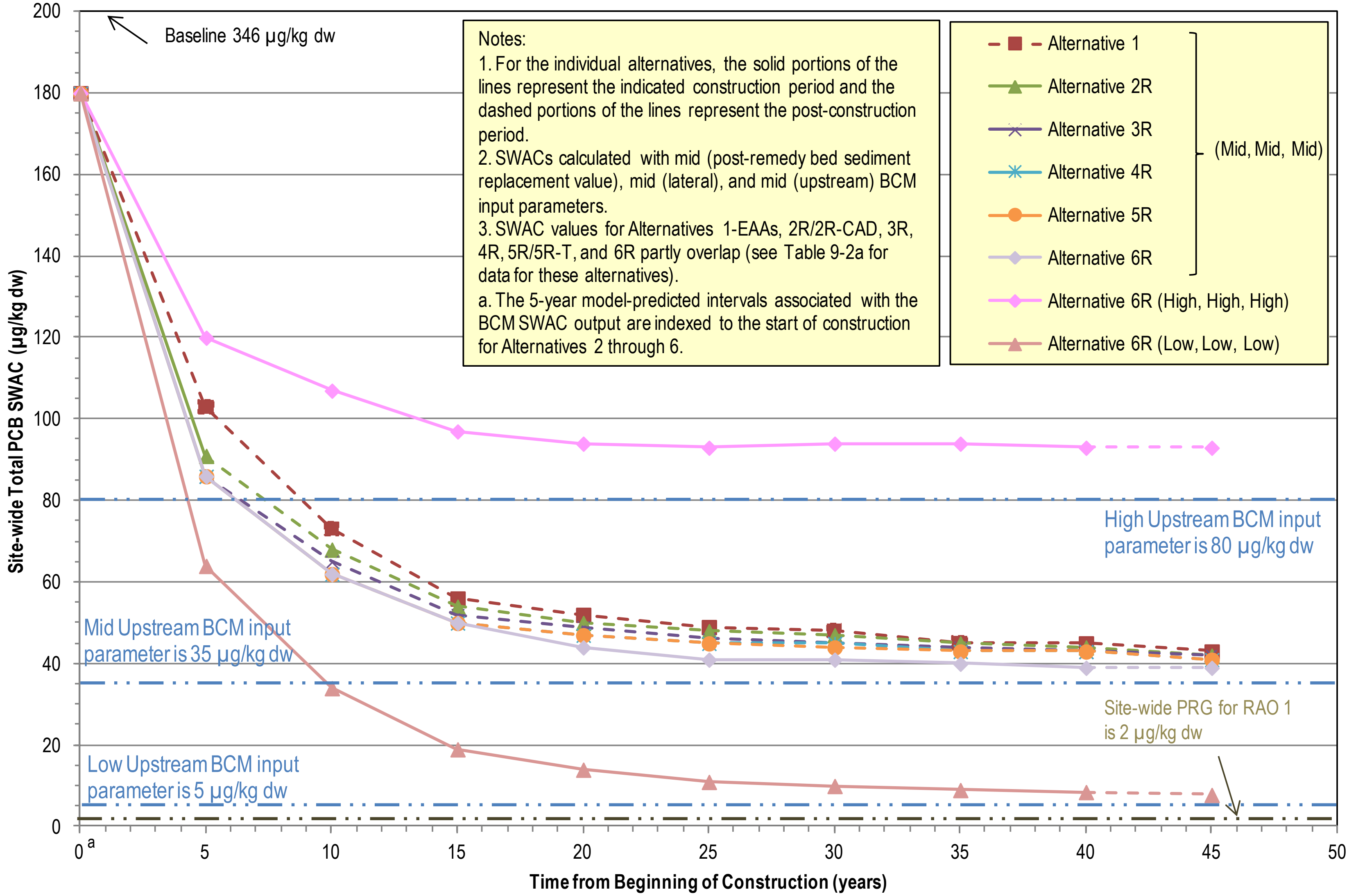


Figure 9-5b Site-wide Total PCB SWAC Versus Time – Combined Alternatives

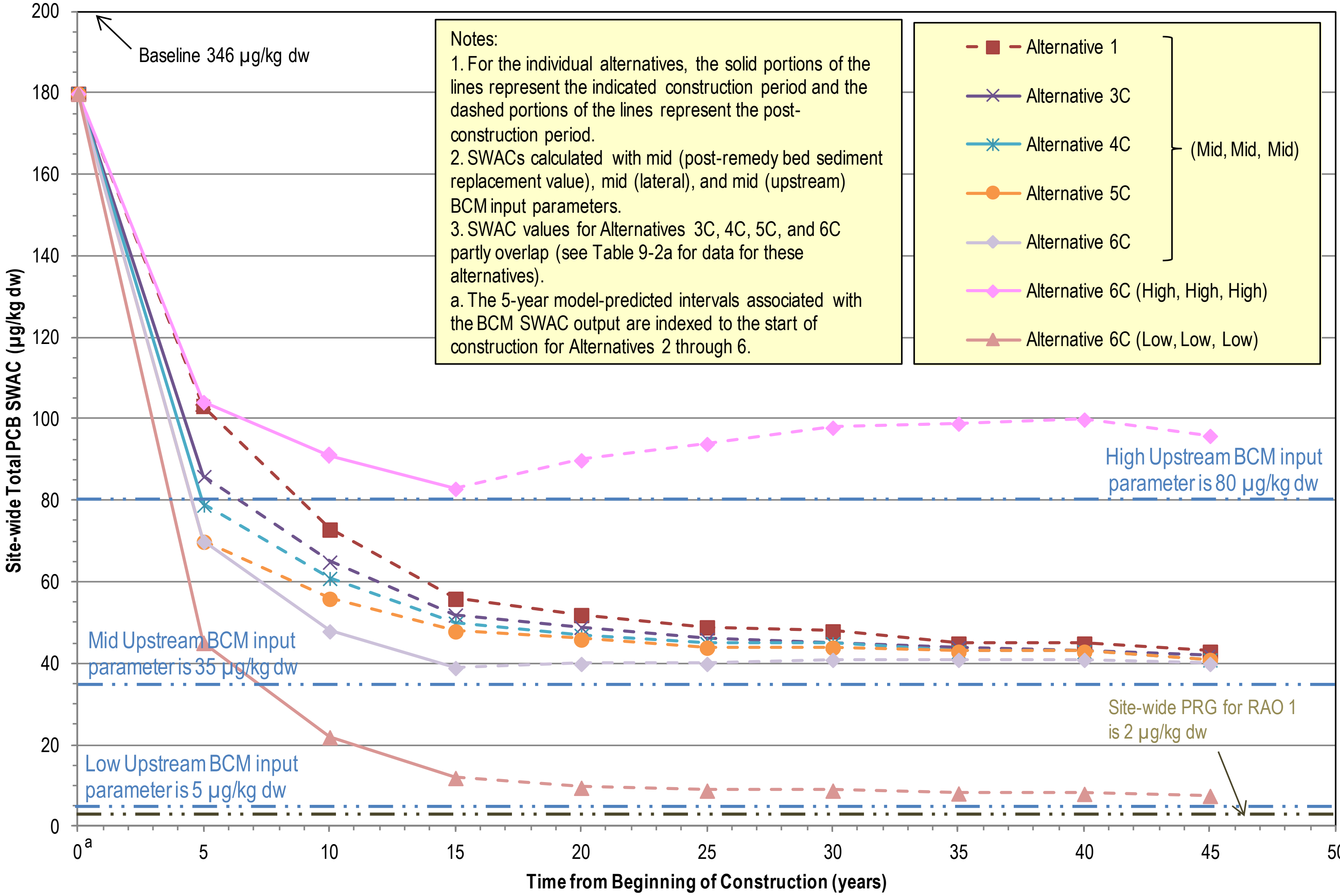


Figure 9-5c Site-wide Arsenic SWAC Versus Time – Removal Alternatives

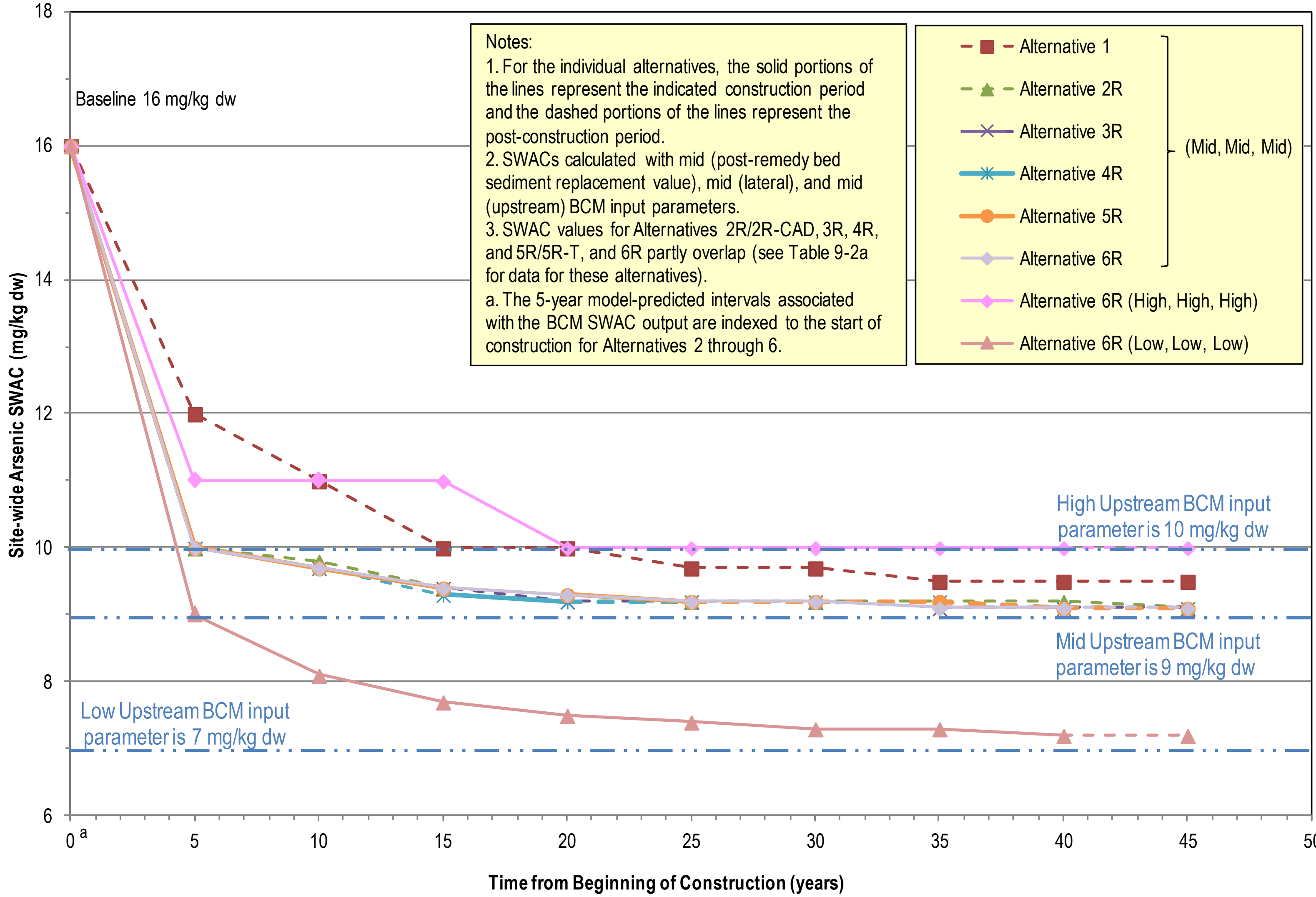


Figure 9-5d Site-wide Arsenic SWAC Versus Time – Combined Alternatives

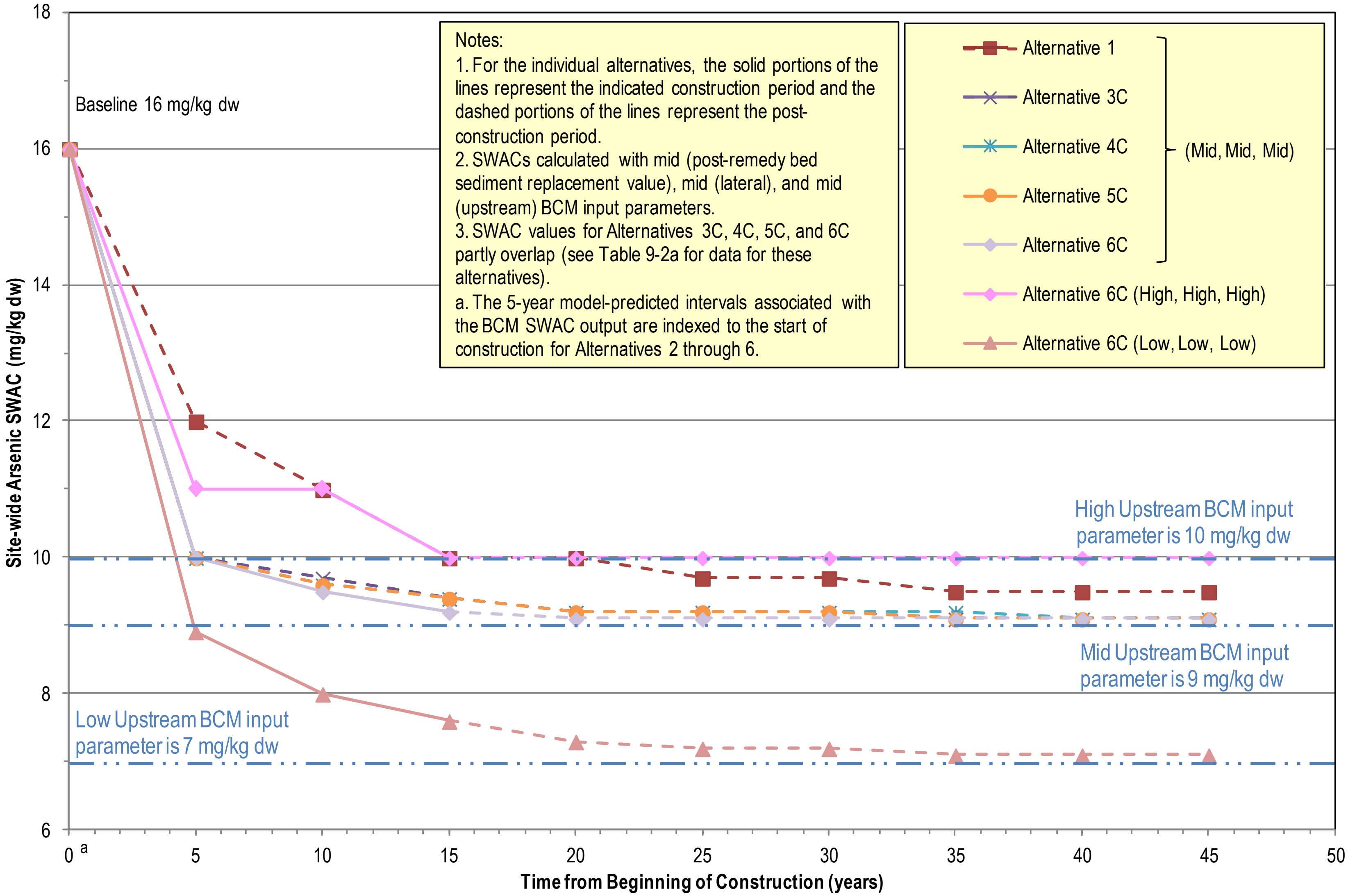


Figure 9-5e Site-wide cPAH SWAC Versus Time – Removal Alternatives

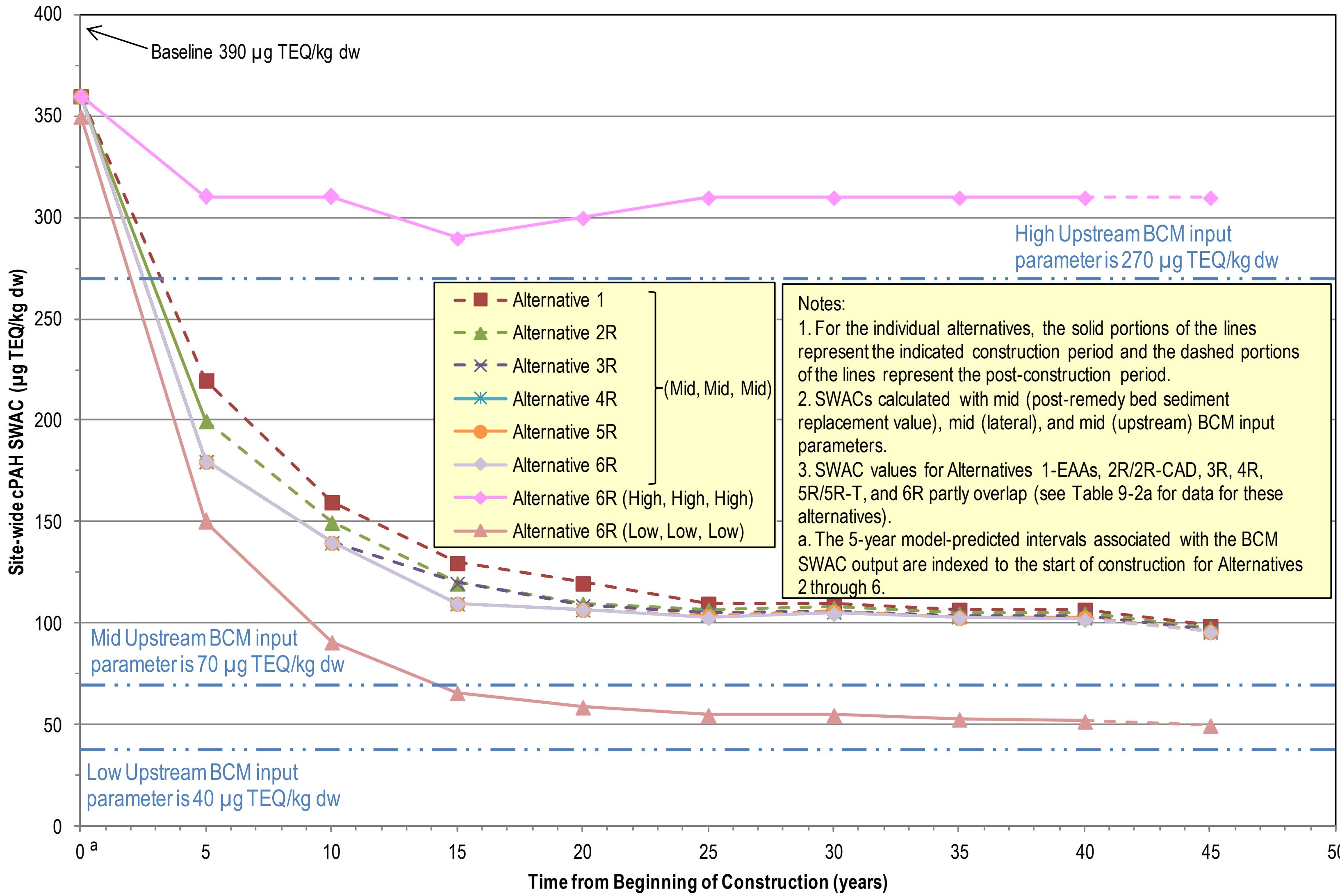


Figure 9-5f Site-wide cPAH SWAC Versus Time – Combined Alternatives

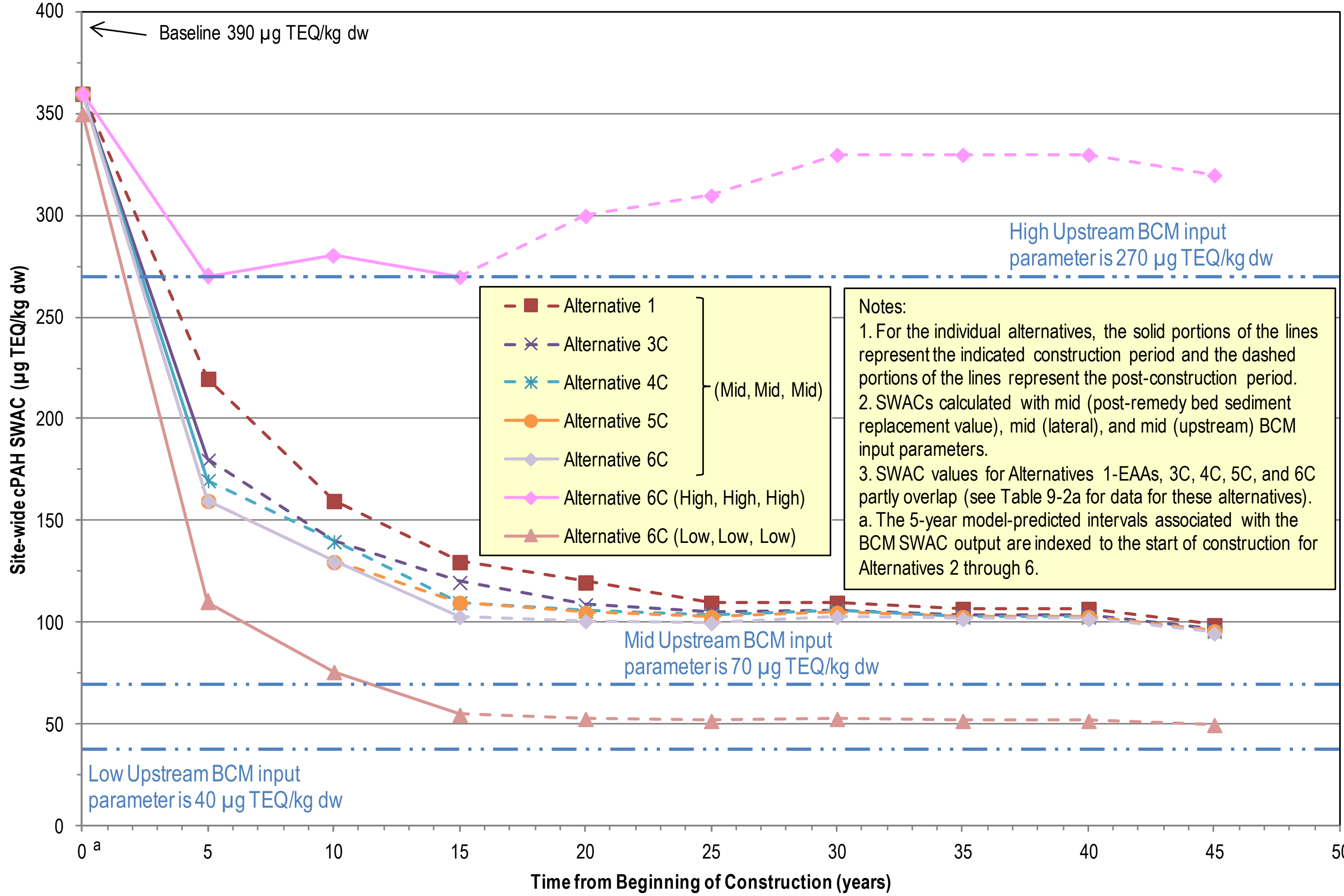


Figure 9-5g Site-wide Dioxin/Furan SWAC Versus Time – Removal Alternatives

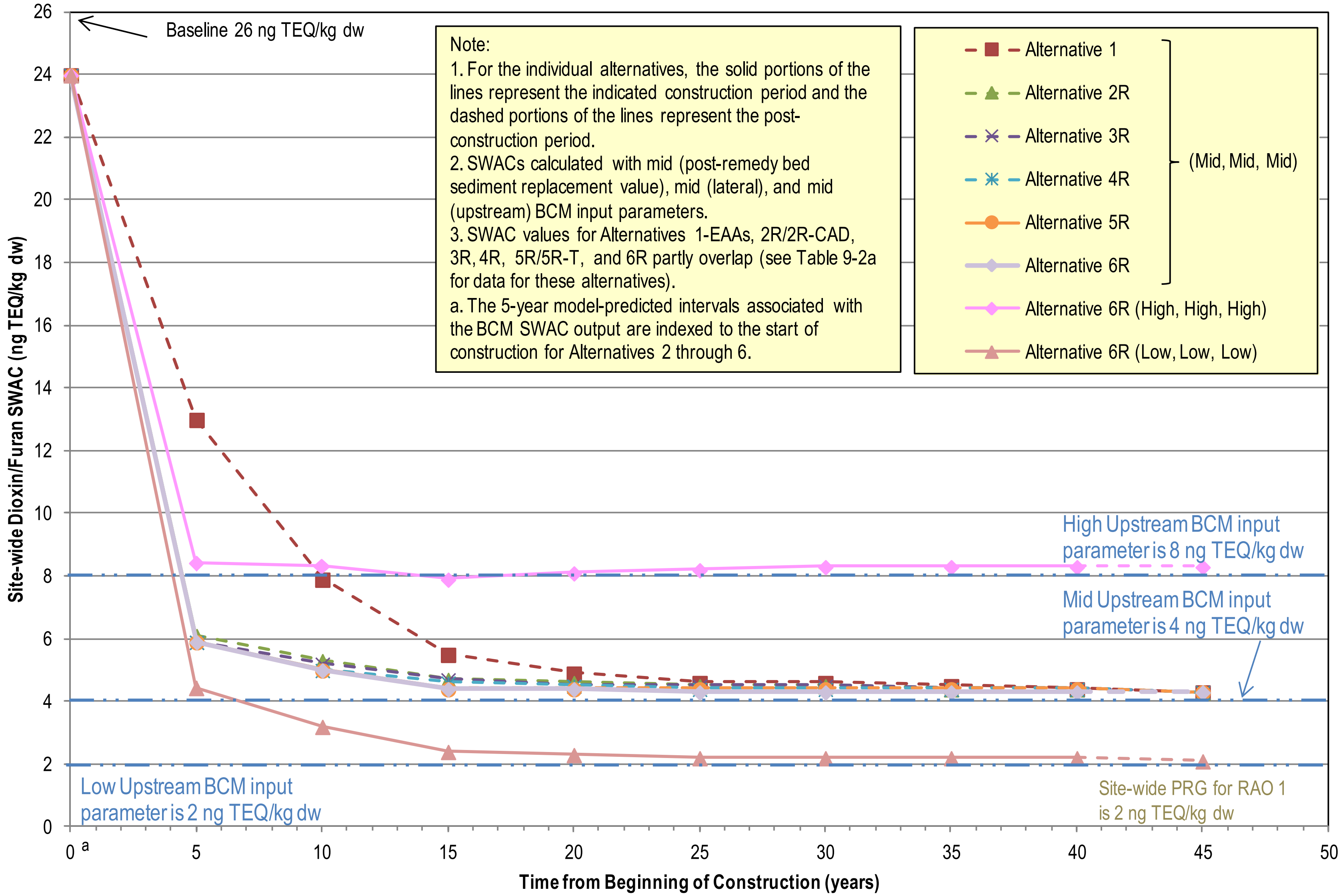


Figure 9-5h Site-wide Dioxin/Furan SWAC Versus Time – Combined Alternatives

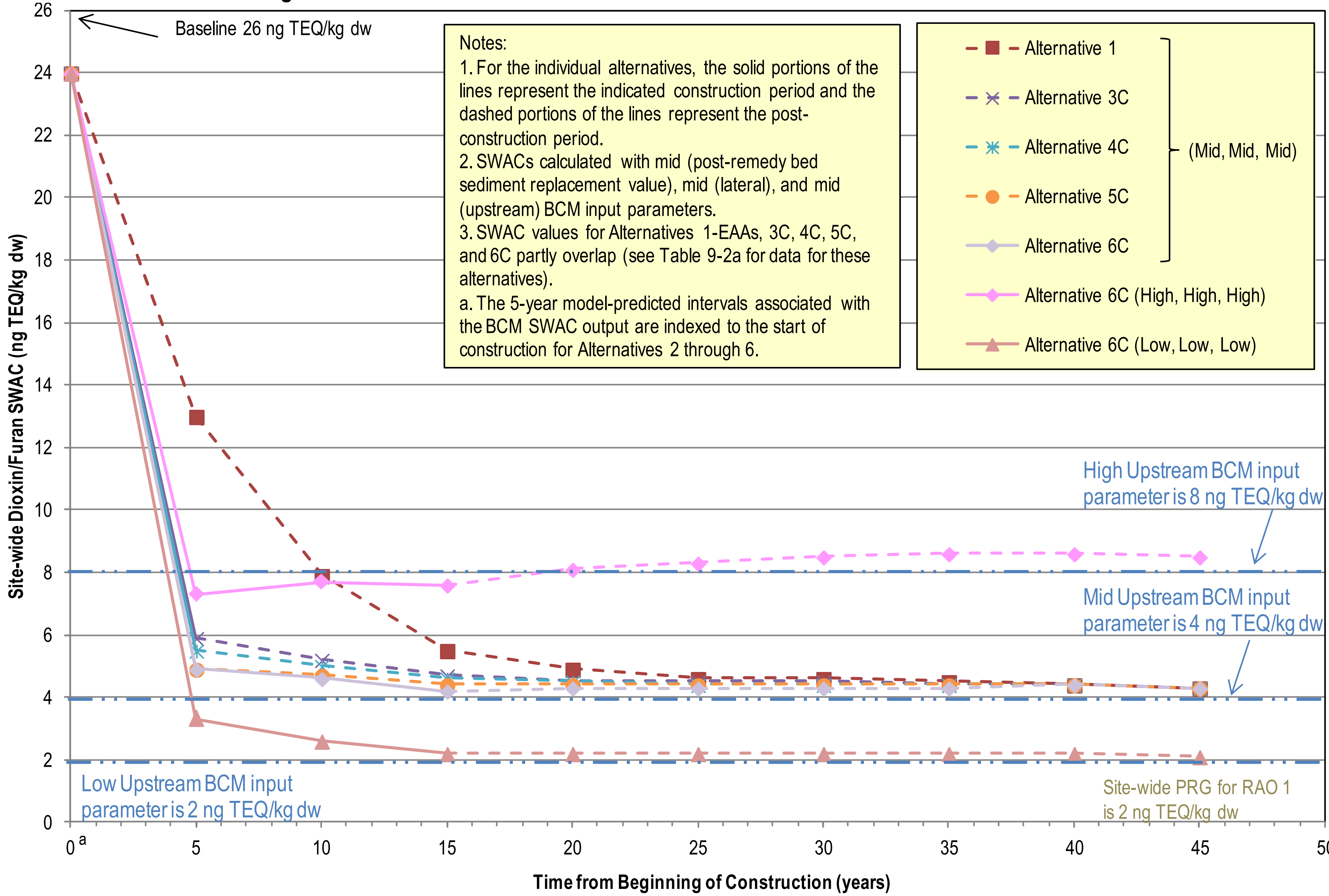


Figure 9-6a Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of Baseline Stations in Compliance with CSL Concentrations after Remediation

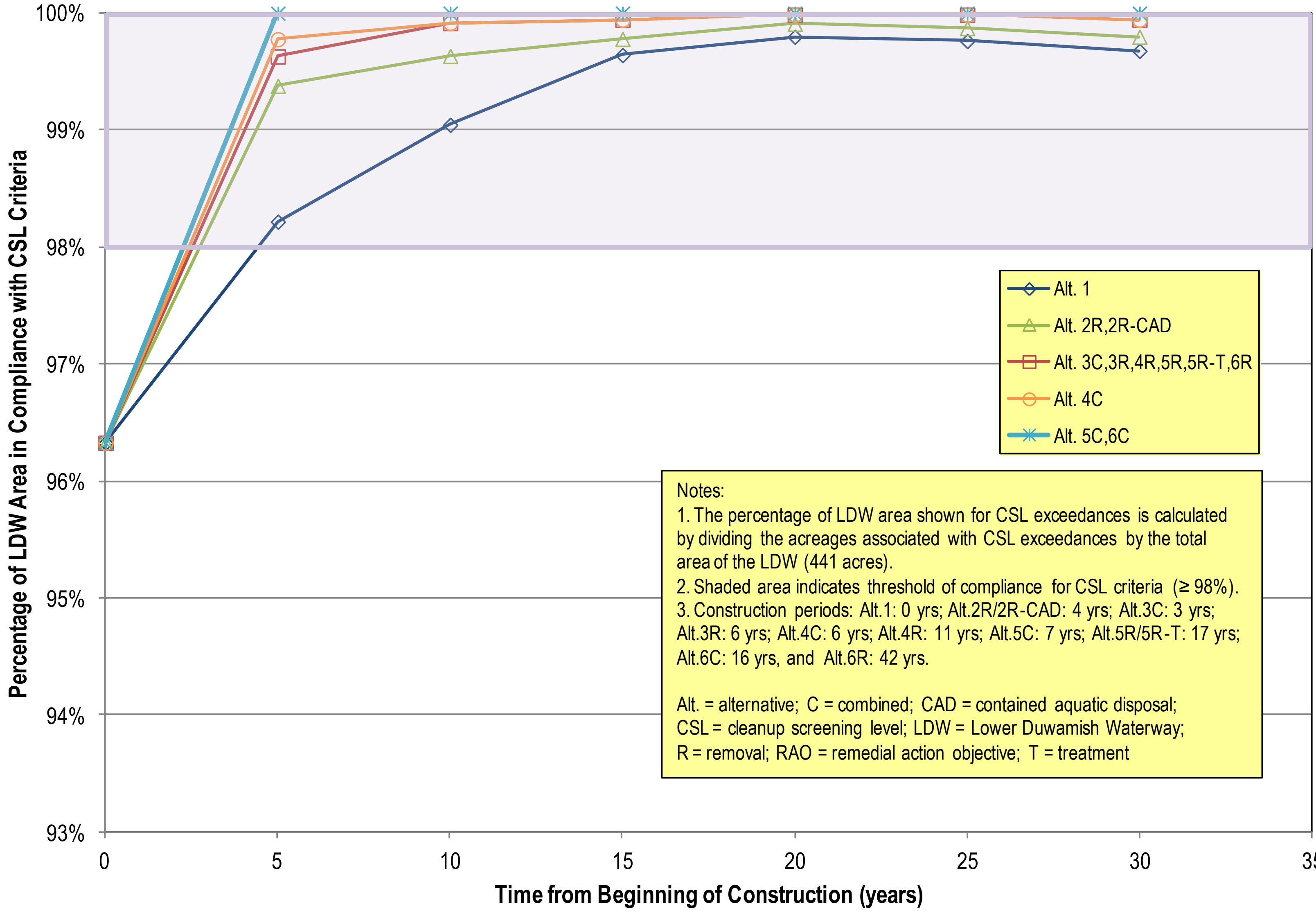


Figure 9-6b Comparative Evaluation of Residual Benthic Risk (RAO 3) for Remedial Alternatives – Predicted Percentage of LDW Area in Compliance with SQS after Remediation

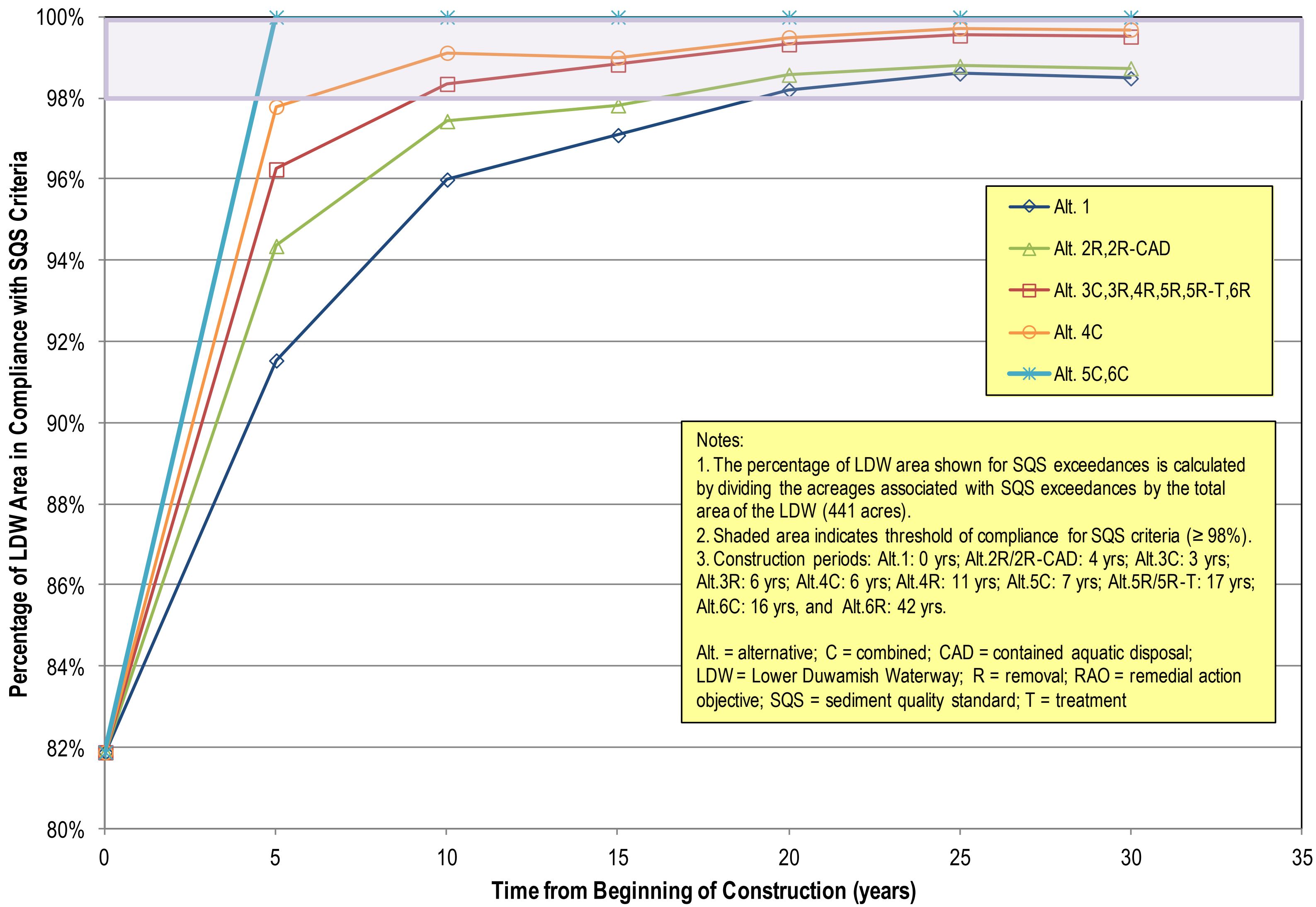
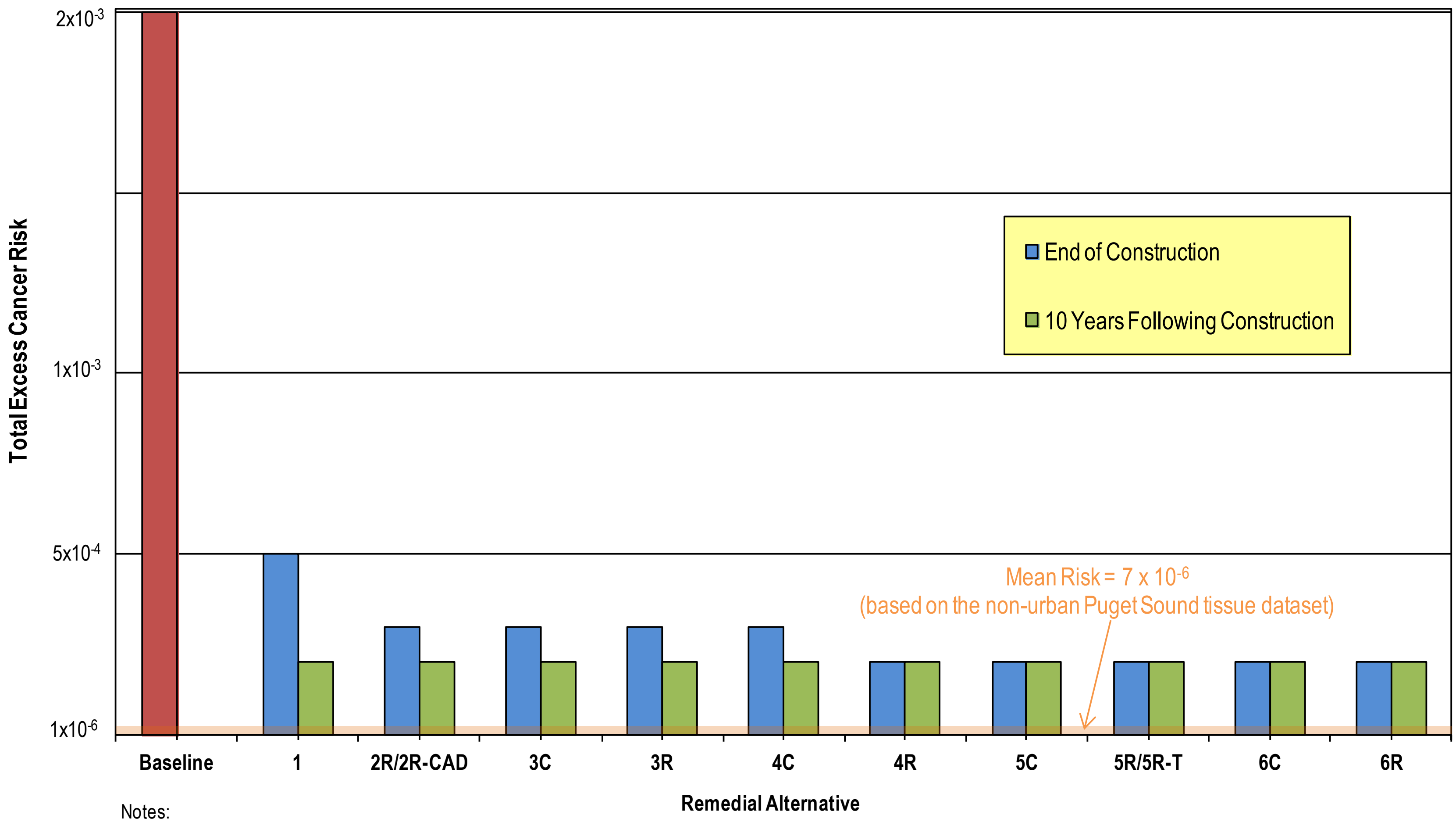
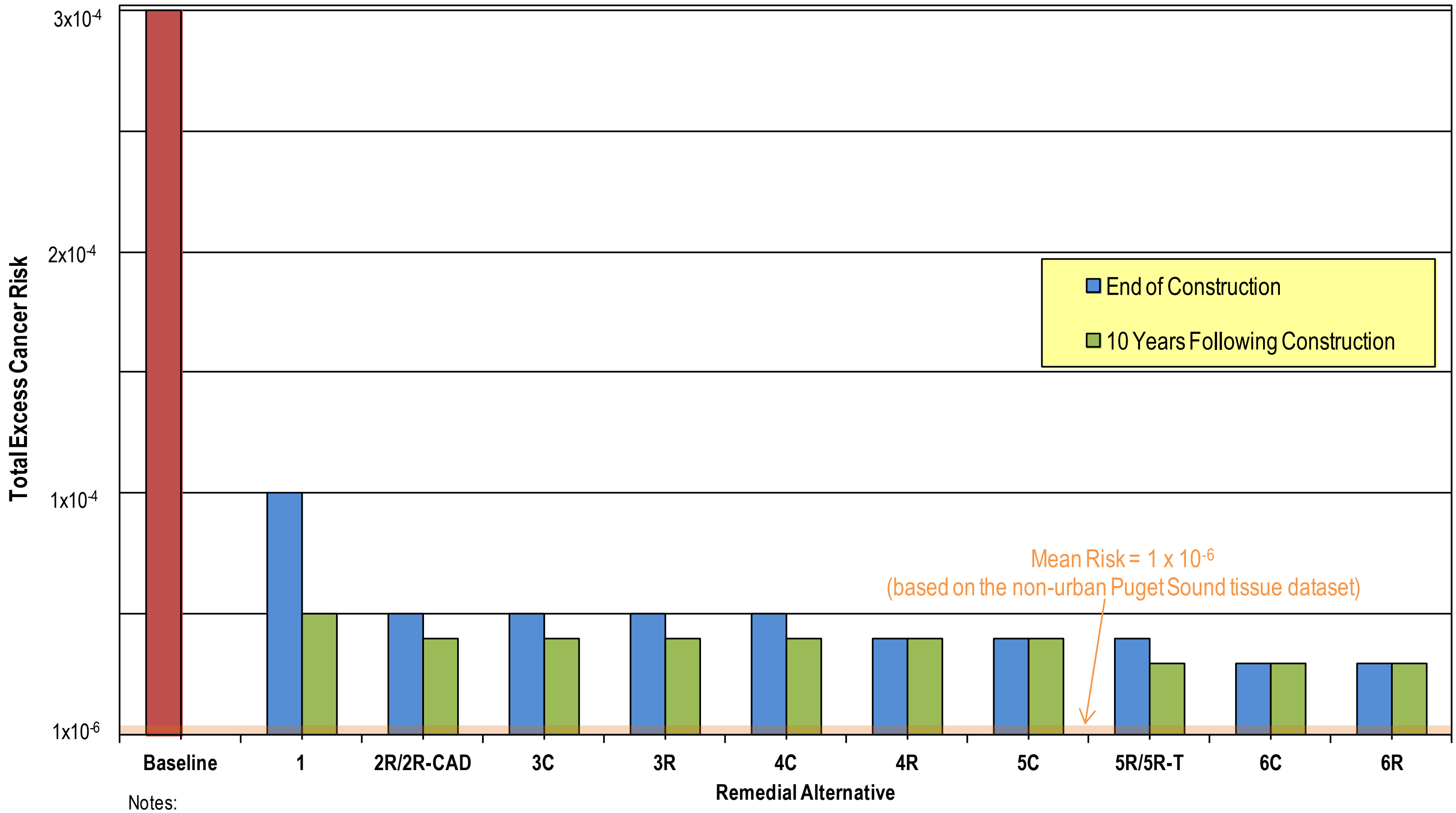


Figure 9-7a Residual Adult Tribal Reasonable Maximum Exposure Seafood Consumption Risk (RAO 1) for Total PCBs after Remediation



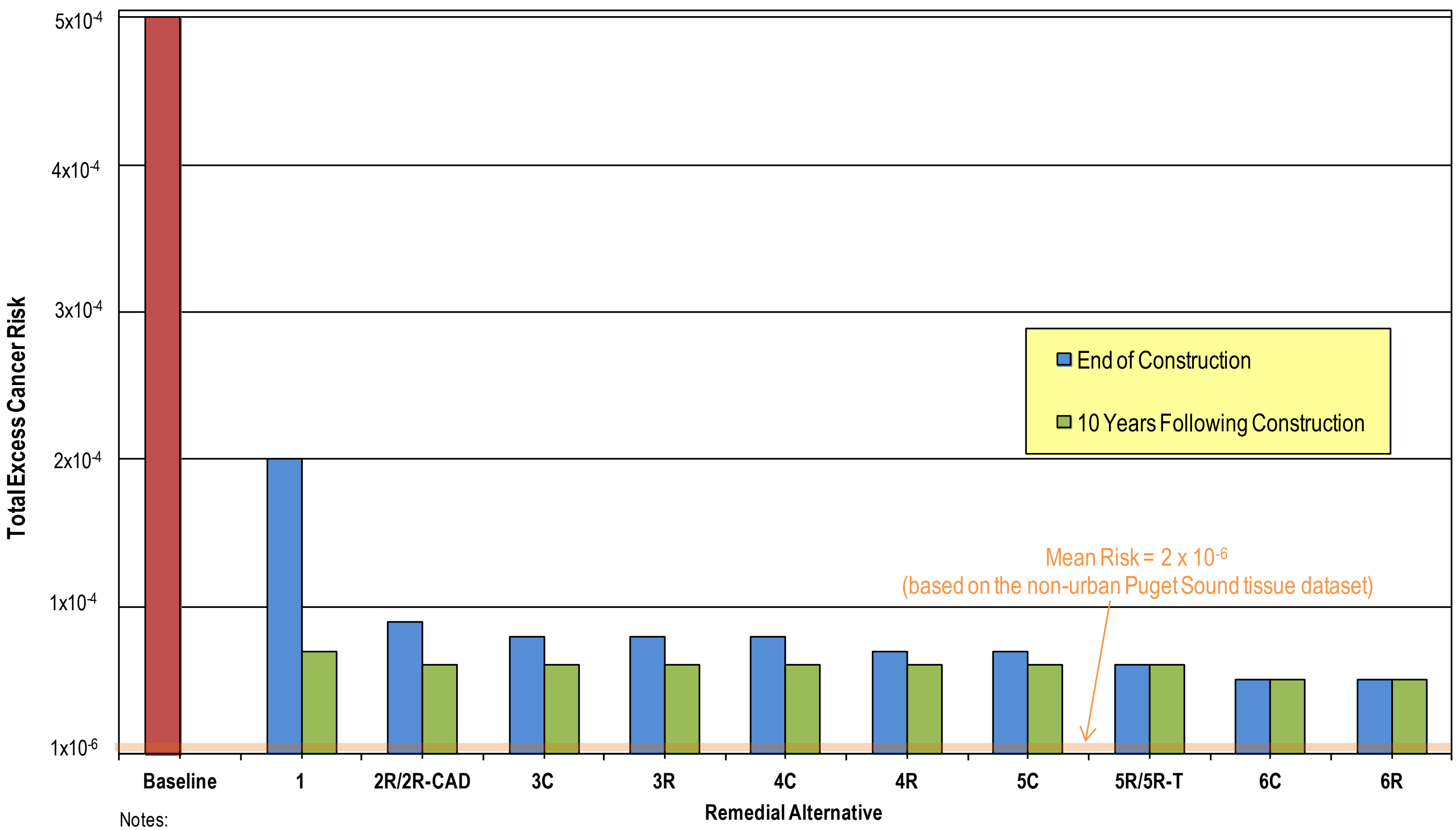
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Adult 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



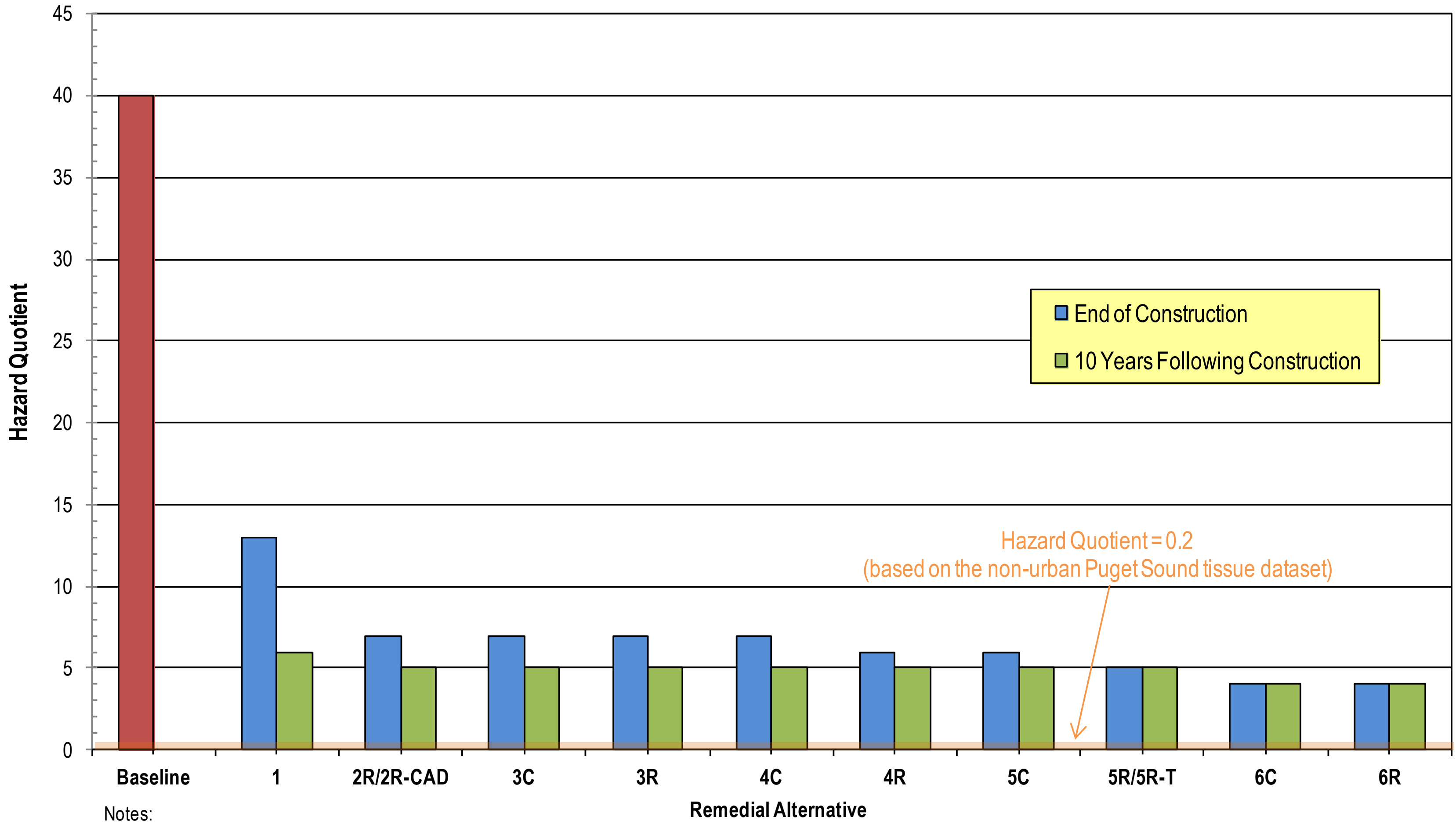
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Child 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



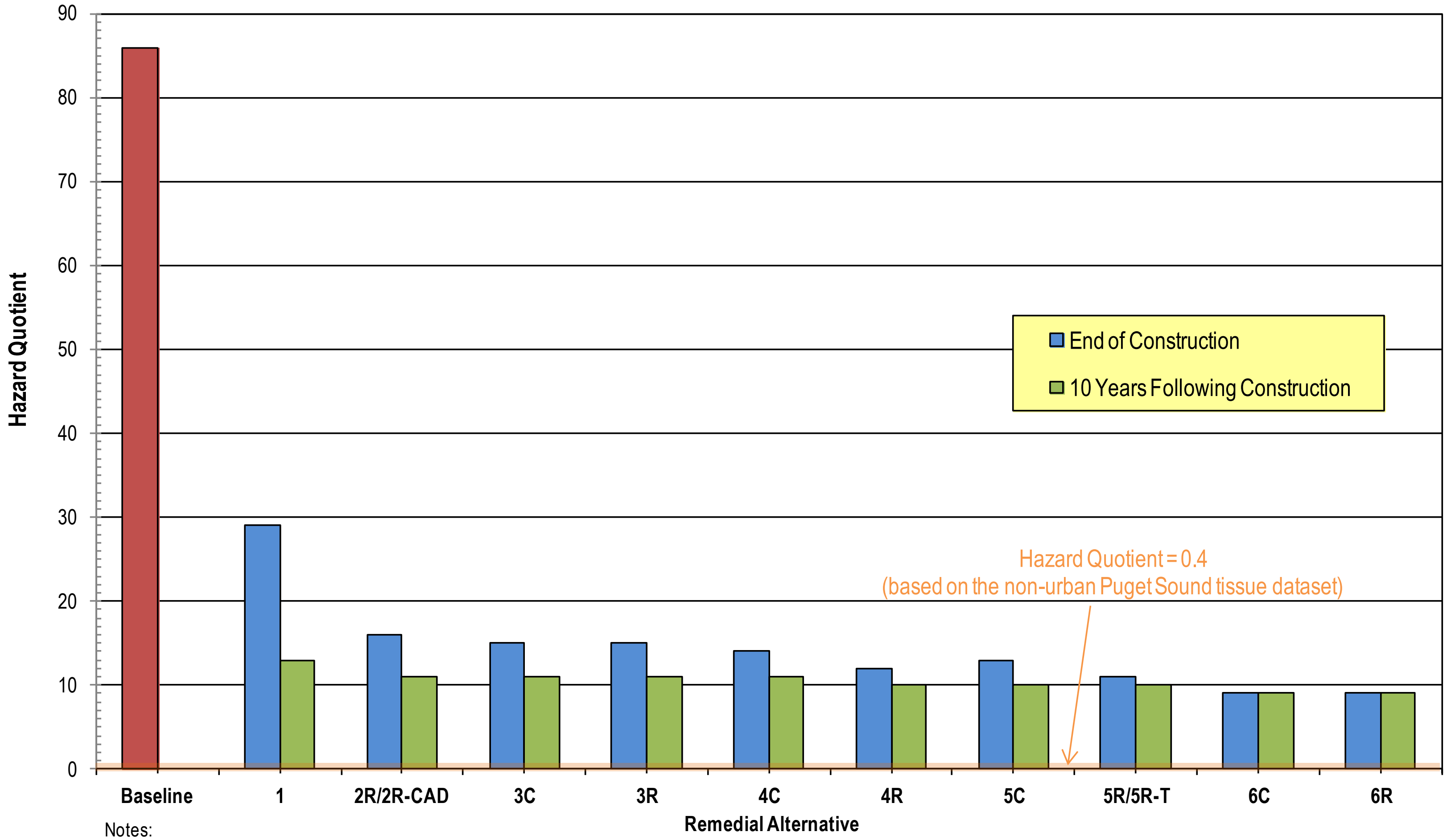
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7a.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean risk estimate for the Adult 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



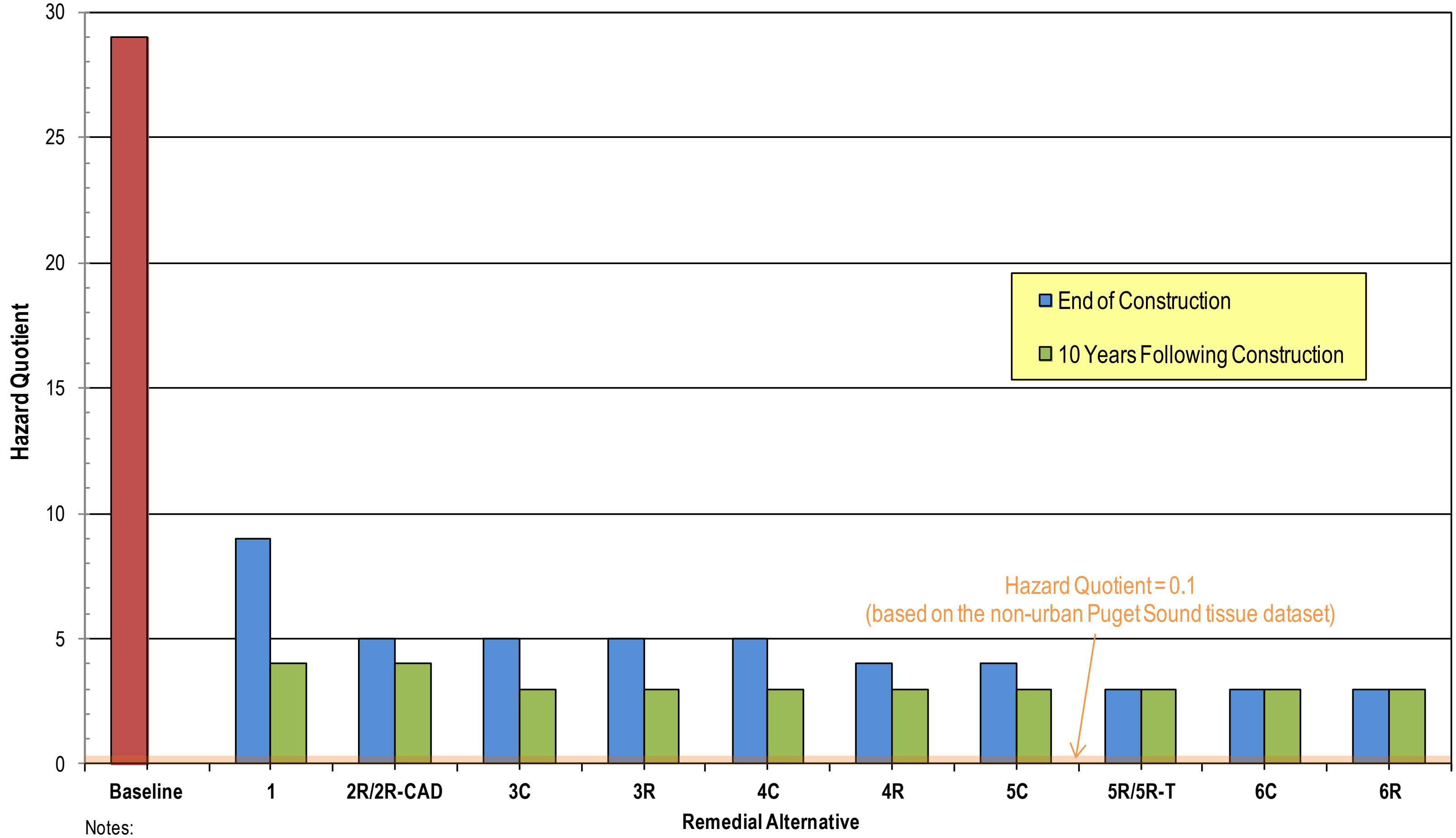
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate 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



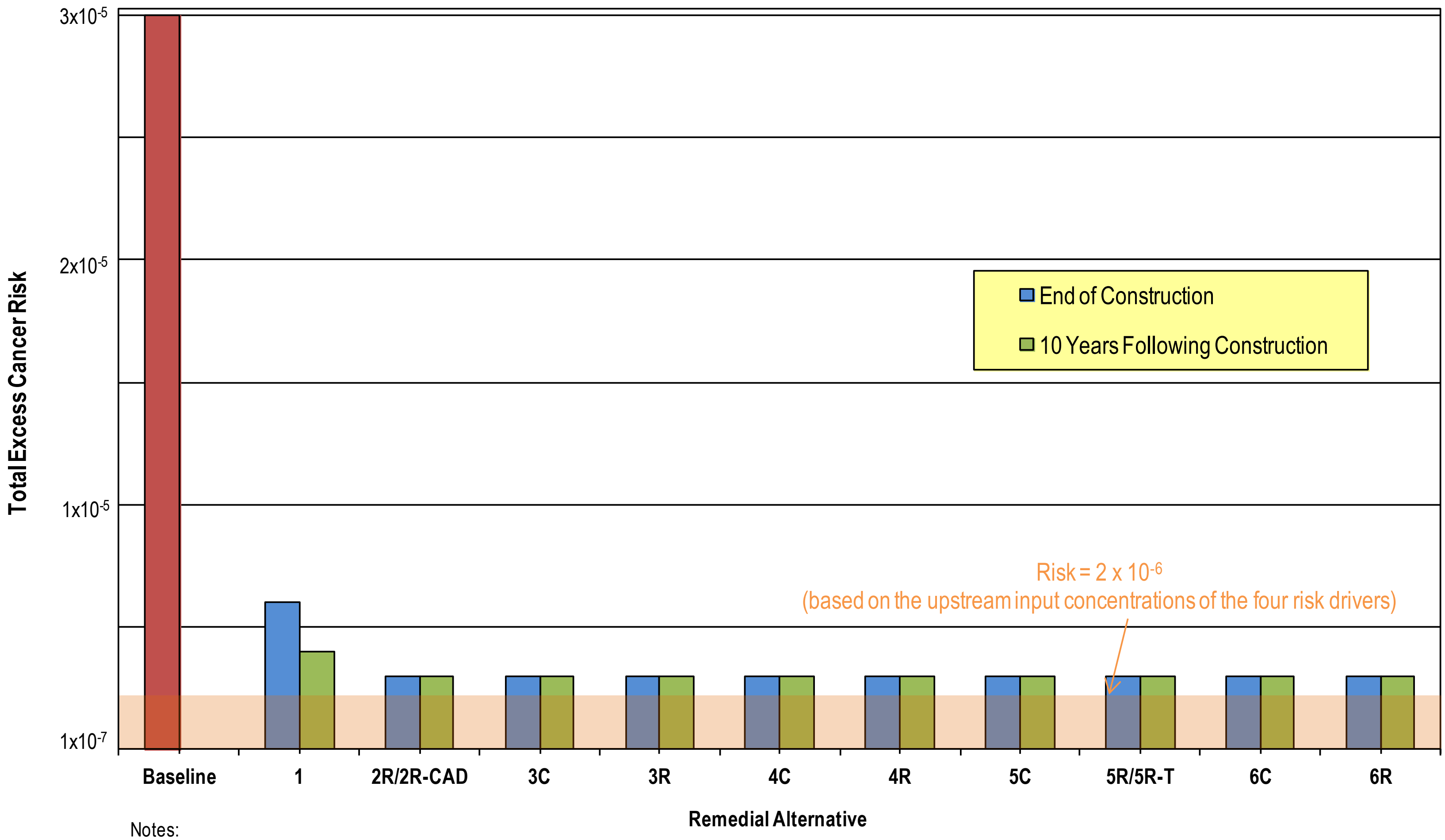
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate 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



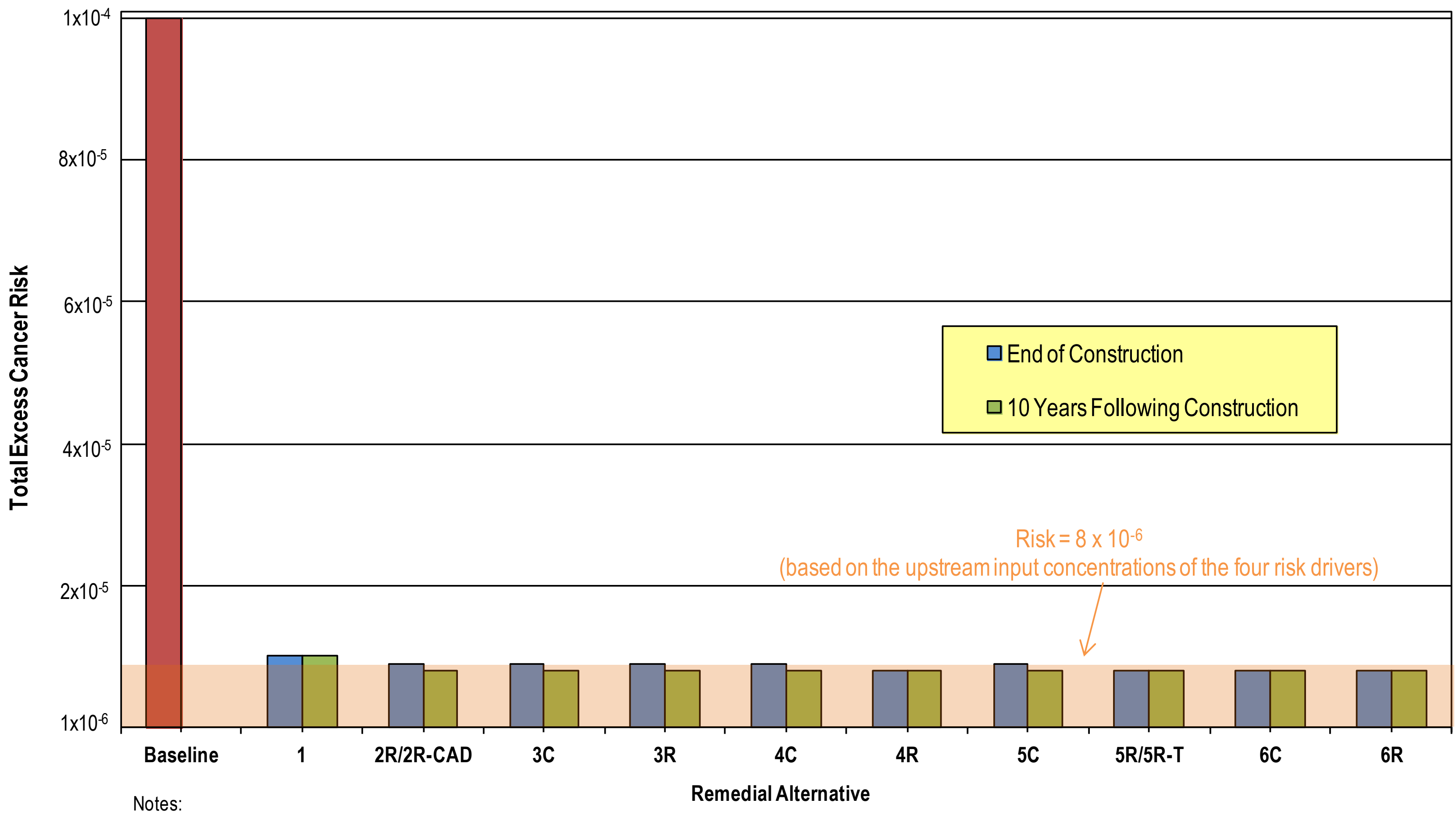
Notes:
1. Risk values shown for the alternatives are also presented in Table 9-7b.
2. Baseline risk (based on the HHRA) represents conditions before completion of EAAs. Blue bar for Alternative 1 represents the post-EAA conditions.
3. Shaded area in orange represents the mean hazard quotient estimate for the Adult Tribal RME seafood consumption scenario u sing 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.

[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

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

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.

[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

[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).

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).

[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]

[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

[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

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.

[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]

Evaluation Criteria				Remedial Alternative: 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.						
Comply with ARARs *(continued)*	Compliance with ARARs	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.											
Comply with ARARs *(continued)*	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
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	Total cap, partial dredge/cap	n/a	3	3 (+ 23 acres of CAD)	19	8	41	14	47	14	14	93	28
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	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
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	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
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	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
Long-term Effectiveness and Permanence	Magnitude of Residual Risk (Contaminated sediment remaining in the subsurface)	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.
Long-term Effectiveness and Permanence	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)
Long-term Effectiveness and Permanence	Adequacy and Reliability of Controls [h] – 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).										
Long-term Effectiveness and Permanence	Adequacy and Reliability of Controls [h] – Magnitude and Duration of Institutional Controls	Seafood consumption advisories, public outreach, and education	No outreach or education	Similar seafood consumption advisories, public outreach, and education are required for all alternatives.										
Long-term Effectiveness and Permanence	Adequacy and Reliability of Controls [h] – Magnitude and Duration of Institutional Controls	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.										
Long-term Effectiveness and Permanence	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.										
Long-term Effectiveness and Permanence	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 ≤1 × 10^{-5} (All exposure scenarios)[m]	5	4	4	3	4	3	4	3	4	4	3	4
		RAO 2: Individual risk from cPAHs ≤1 × 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

Alternative	Construction Time (years)	Site-wide SWAC				Clamming Area SWAC				Beach Play Area SWAC				SMS			
		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) 0	5	10	15	20	25	30	35	40	Model Year When Total PCB SWAC is between 40 and 50 µg/kg dw	Difference in Years (between sequencing assumptions)
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) 0	5	10	15	20	25	30	35	40	Model Year When Arsenic SWAC is between 9 and 11 mg/kg dw	Difference in Years (between sequencing assumptions)
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) 0	5	10	15	20	25	30	35	40	Model Year When cPAH SWAC is between 100 and 125 µg TEQ/kg dw	Difference in Years (between sequencing assumptions)
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) 0	5	10	15	20	25	30	35	40	Model Year When Dioxin/Furan SWAC is between 4.3 and 5.4 ng TEQ/kg dw	Difference in Years (between sequencing assumptions)
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	

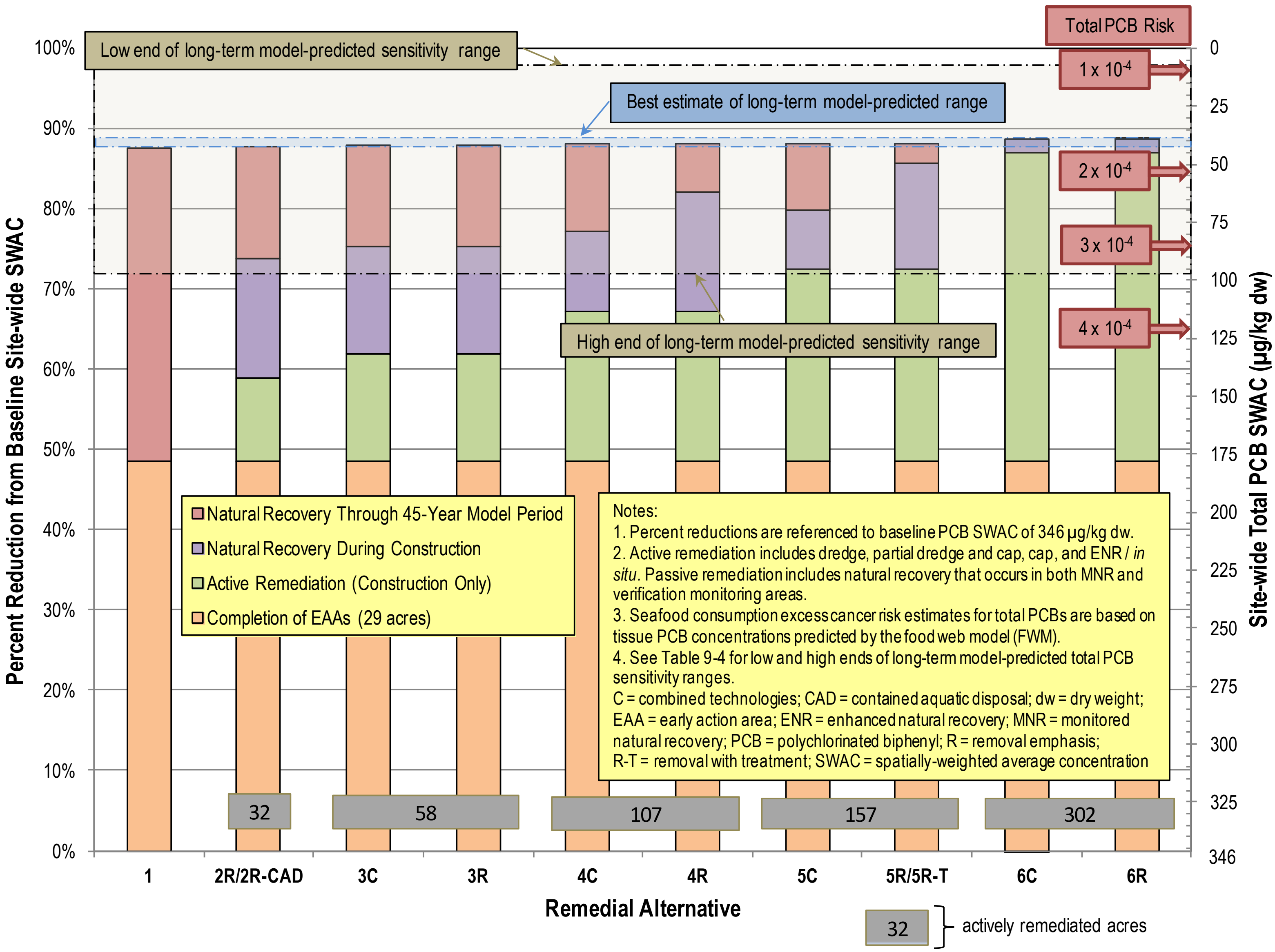
= Construction Time Frame

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



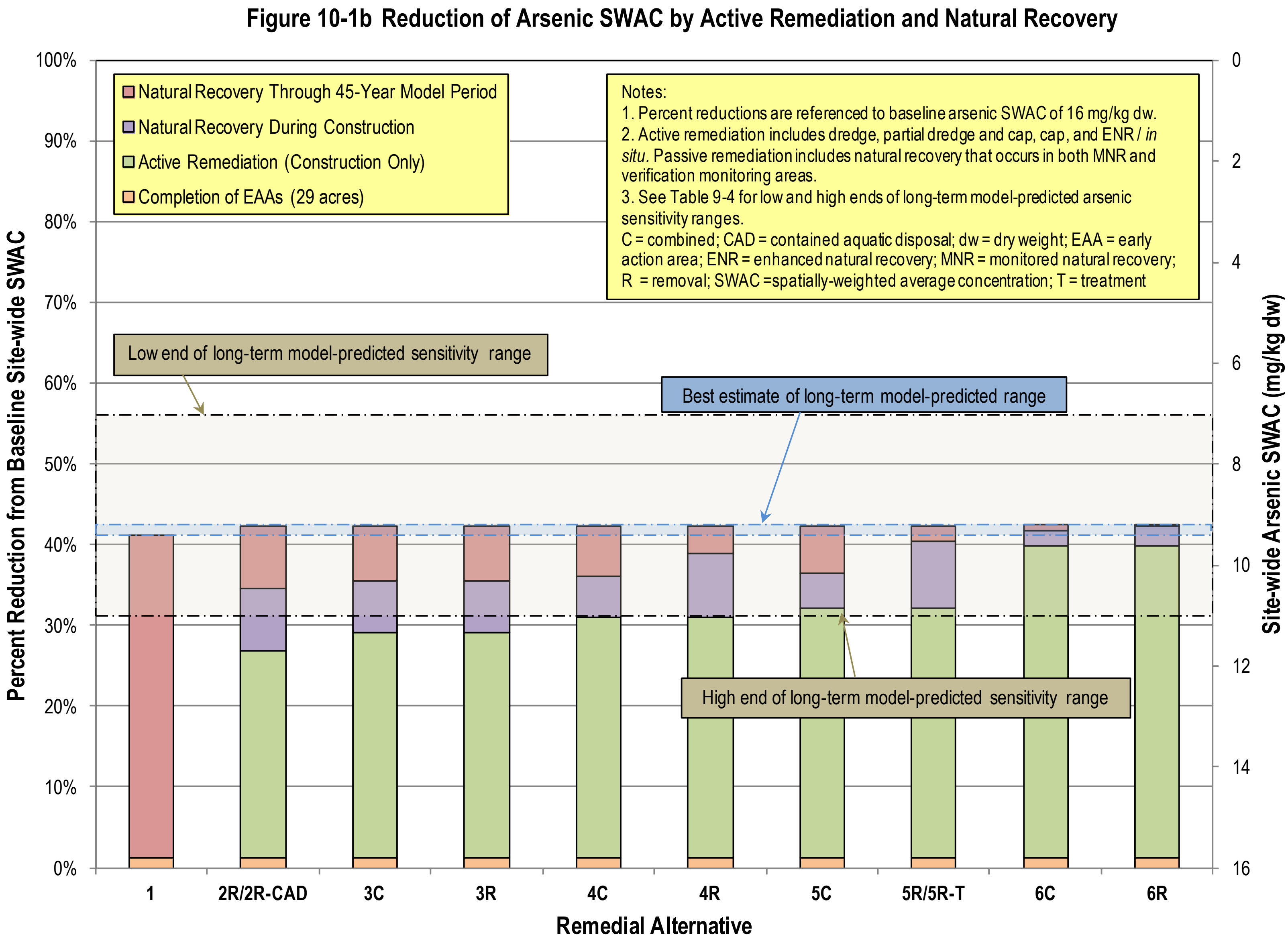


Figure 10-1b Reduction of Arsenic SWAC by Active Remediation and Natural Recovery
Natural Recovery Through 45-Year Model Period
Natural Recovery During Construction
Active Remediation (Construction Only)
Completion of EAAs (29 acres)
Notes:
1. Percent reductions are referenced to baseline arsenic SWAC 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
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
Percent Reduction from Baseline Site-wide SWAC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Site-wide Arsenic SWAC (mg/kg dw)
0
2
4
6
8
10
12
14
16
1
2R/2R-CAD
3C
3R
4C
4R
5C
5R/5R-T
6C
6R
Remedial Alternative

Figure 10-1c Reduction of cPAHs SWAC by Active Remediation and Natural Recovery

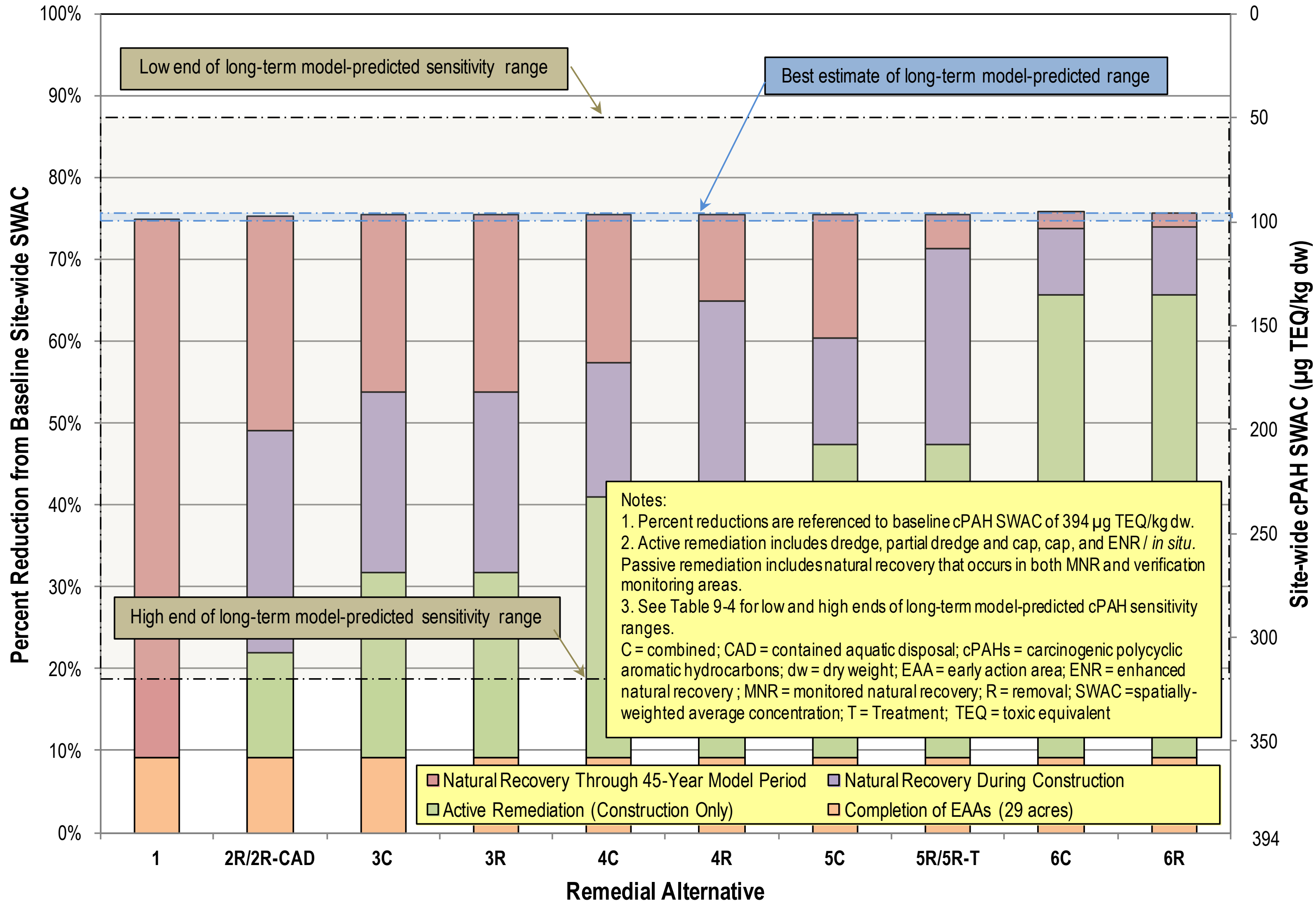


Figure 10-1d Reduction of Dioxin/Furan SWAC by Active Remediation and Natural Recovery

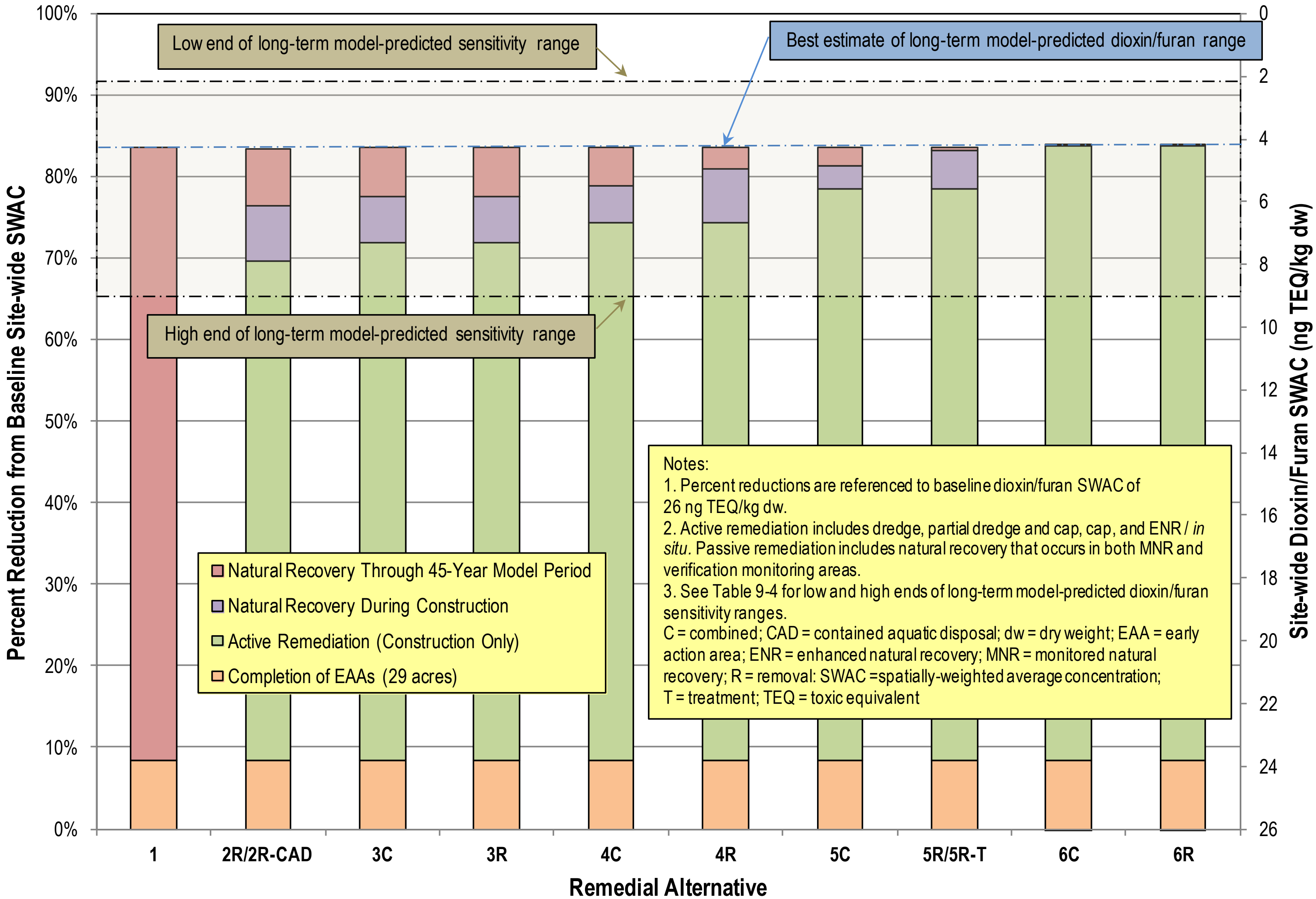


Figure 10-2 Contributions to Achievement of RAO 3 Cleanup Objective by Active Remediation and Natural Recovery

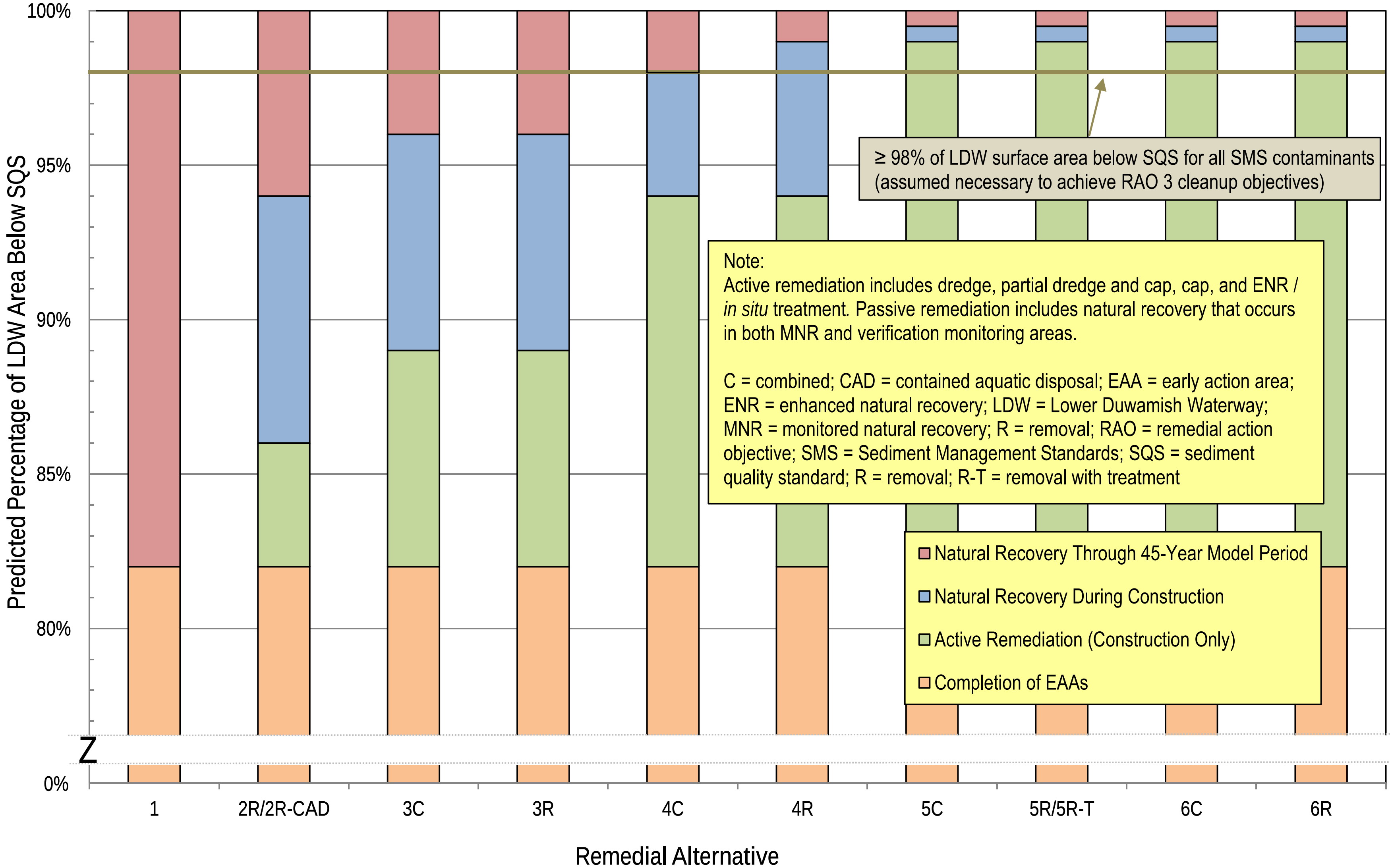


Figure 10-3 Areas that are not Dredged Corresponding to Technology Assignments for Each Recovery Category

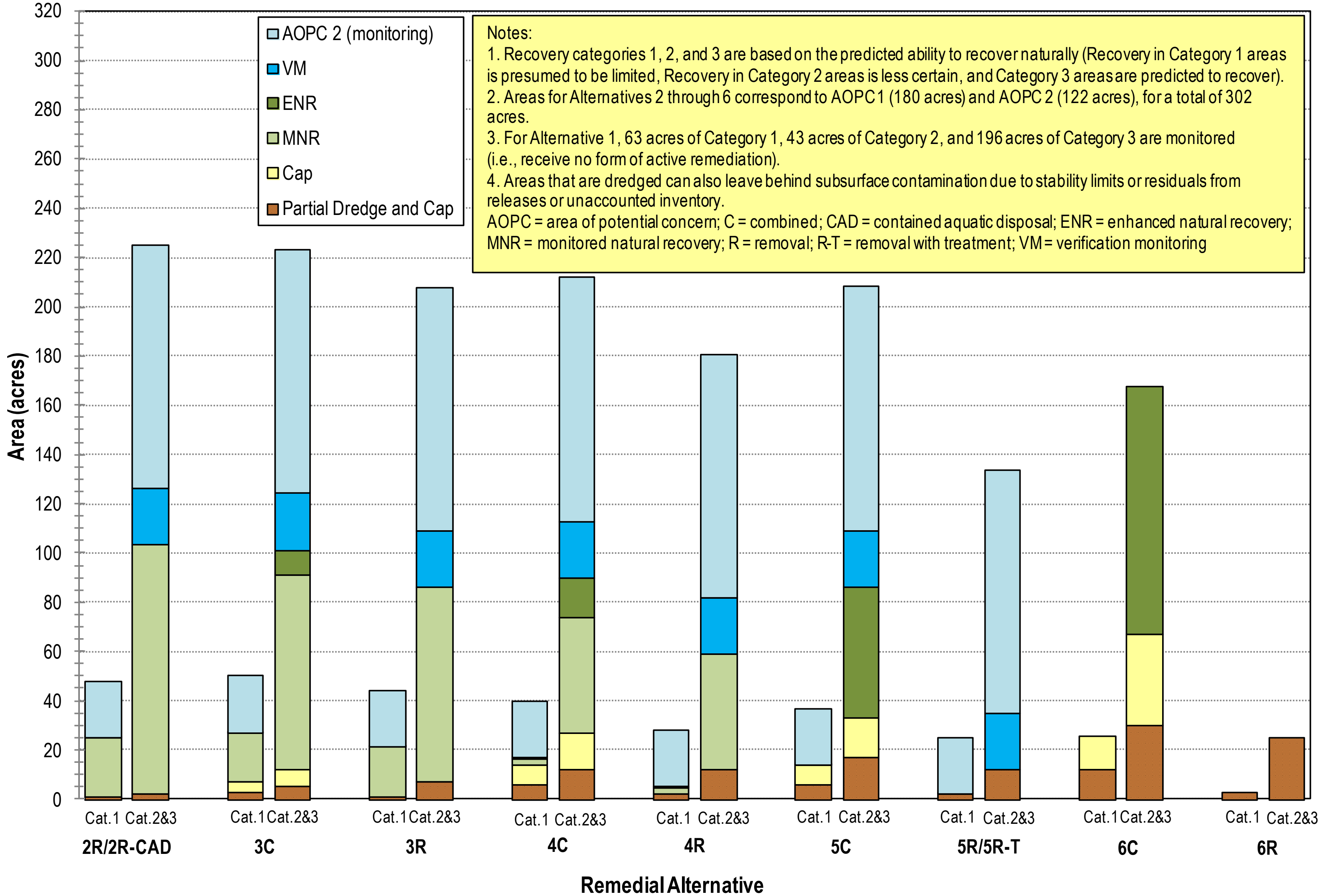
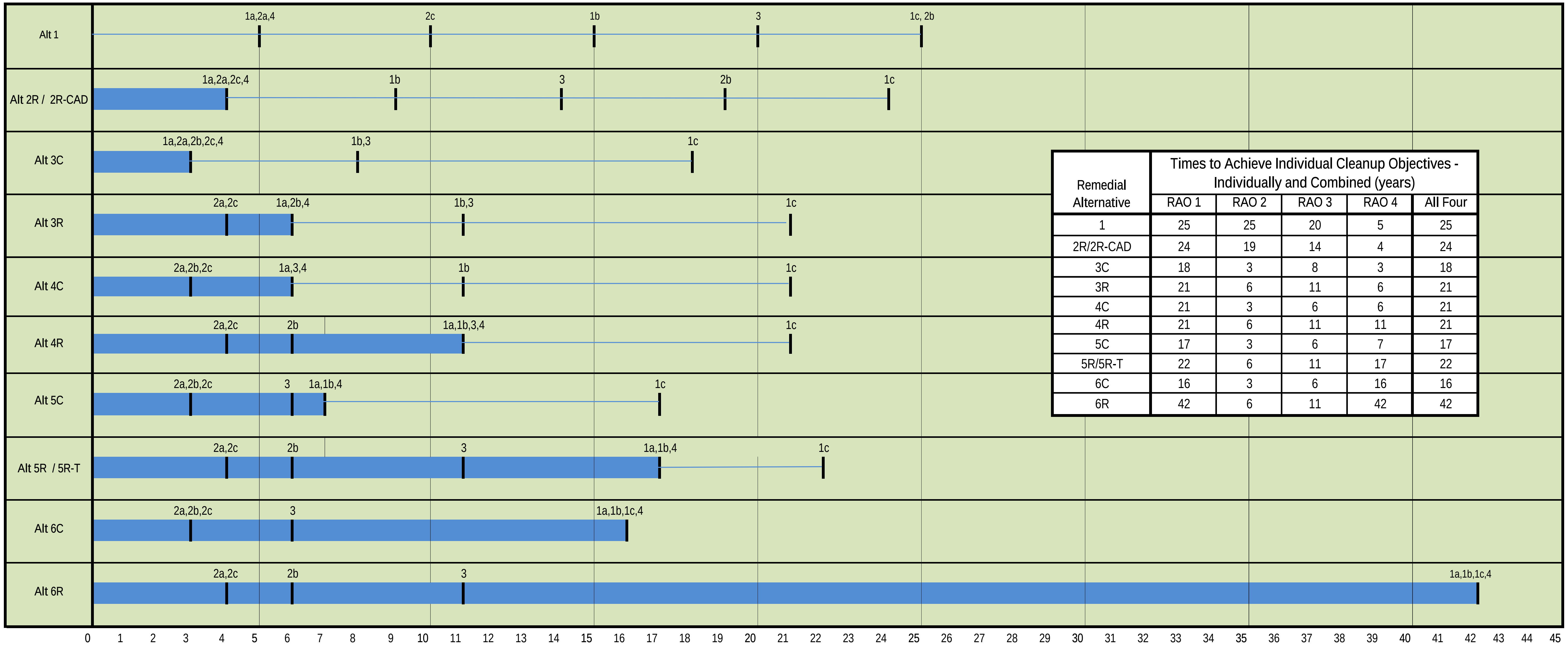


Figure 10-4 Time to Achieve Cleanup Objectives for RAOs for All Alternatives



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	≤ 1 x 10^{-5} total direct contact risk and HQ <1 in all exposure areas
		≤ 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
	2b	< 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
	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 ≤ 1 x 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

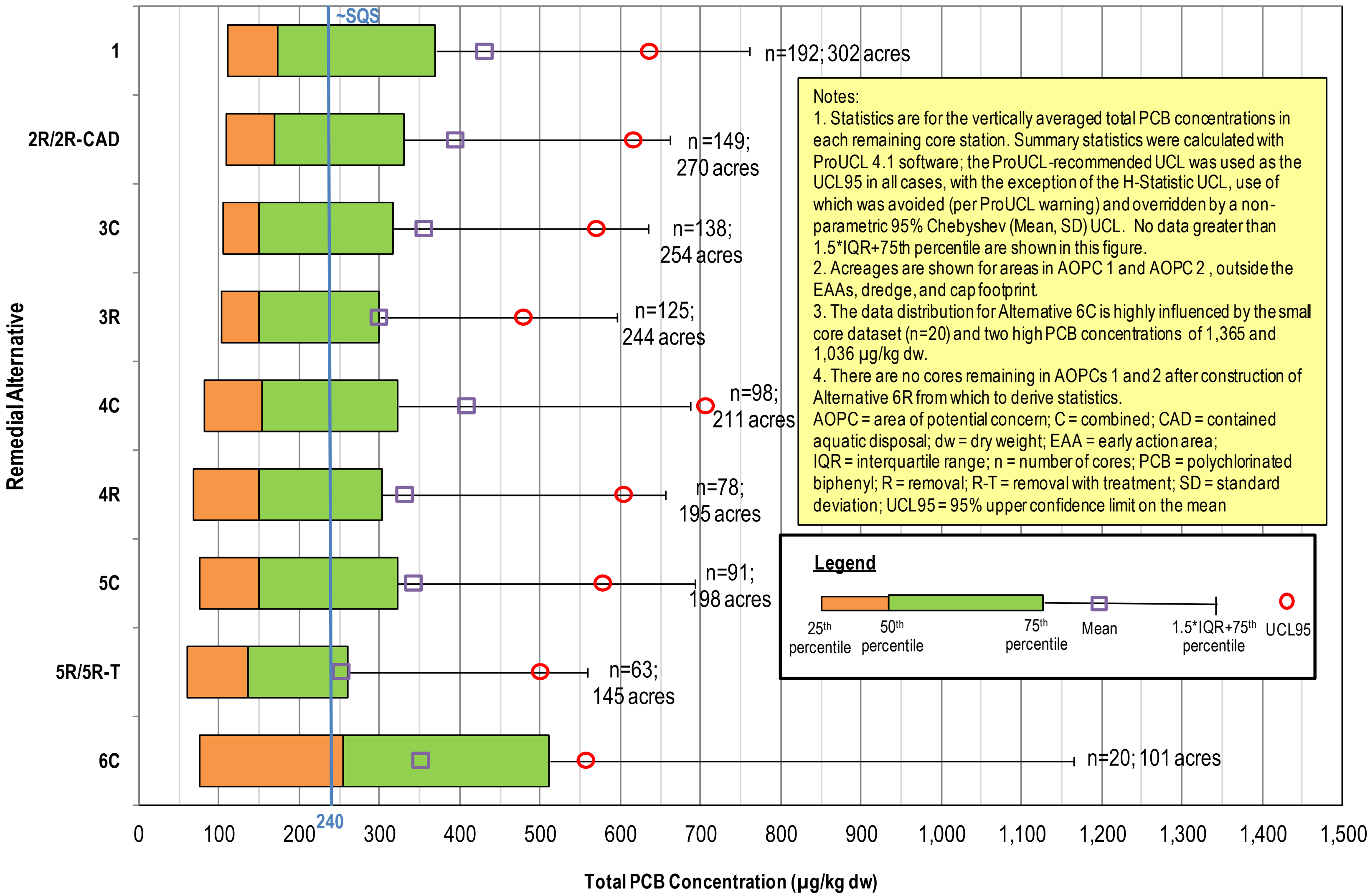
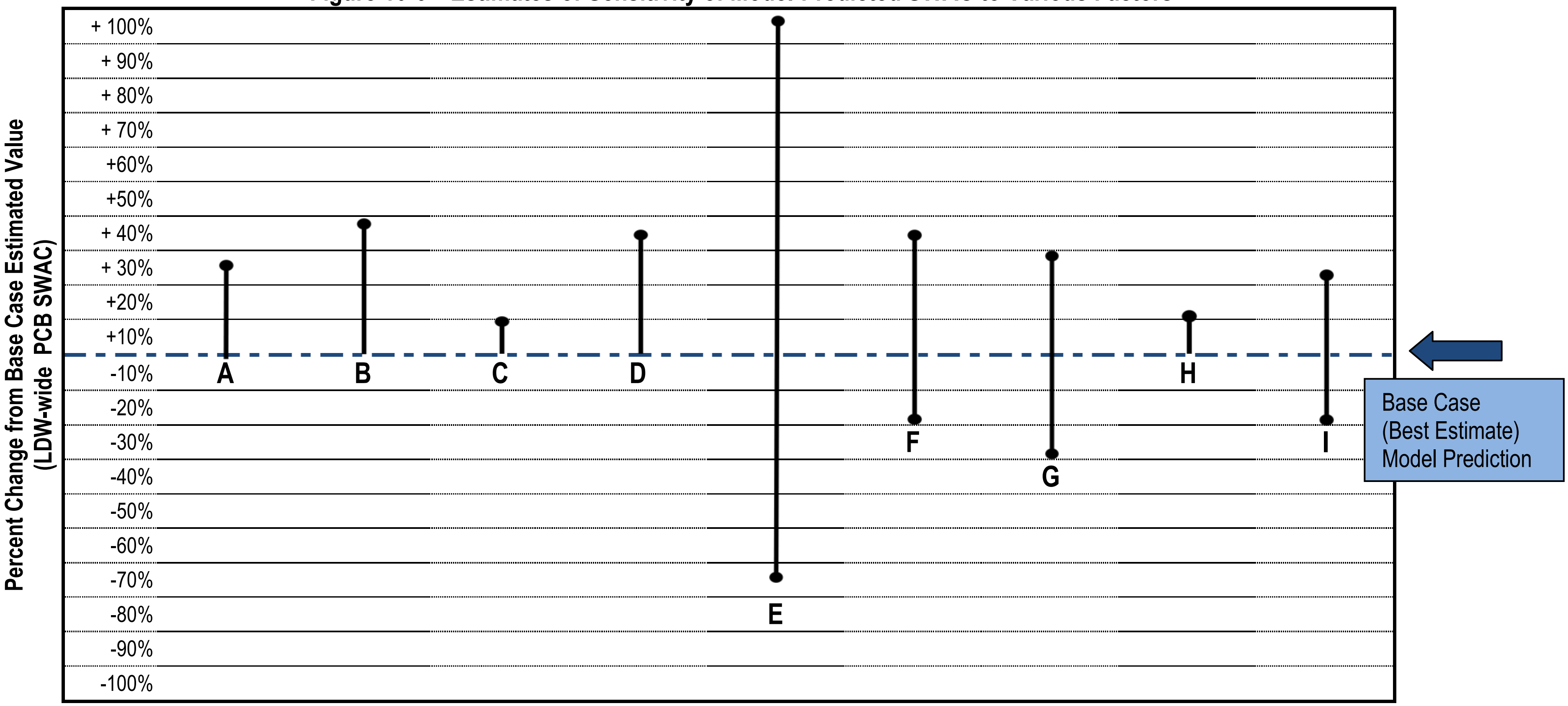


Figure 10-6 Estimates of Sensitivity of Model-Predicted SWAC to Various Factors



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