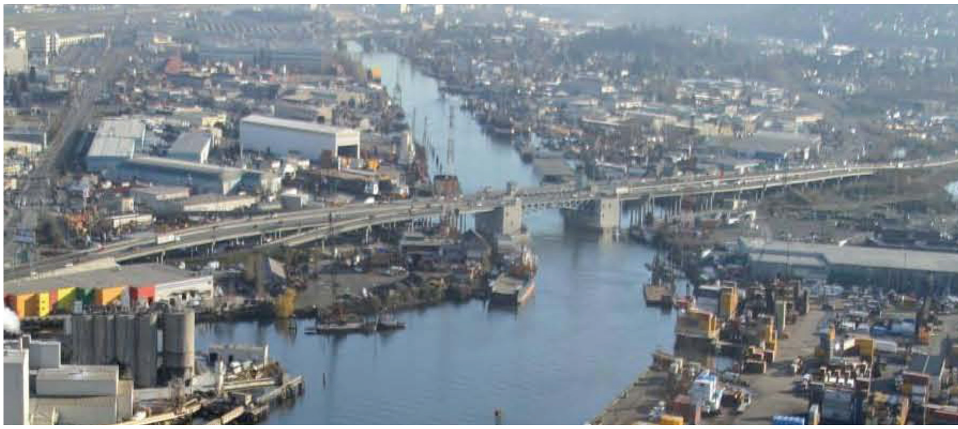
Lower Duwamish Waterway Group
Port of Seattle / City of Seattle / King County / The Boeing Company



Executive Summary

Final Feasibility Study

Lower Duwamish Waterway
Seattle, Washington

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FOR SUBMITTAL TO:

THE U.S. ENVIRONMENTAL PROTECTION AGENCY
REGION 10
SEATTLE, WA

THE WASHINGTON STATE DEPARTMENT OF ECOLOGY
NORTHWEST REGIONAL OFFICE
BELLEVUE, WA

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Acronyms Used in the Executive Summary

AOPC	area of potential concern
ARAR	applicable or relevant and appropriate requirement
CAD	contained aquatic disposal
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSO	combined sewer overflow
DCA	disproportionate cost analysis
EAA	early action area
Ecology	Washington State Department of Ecology
ENR	enhanced natural recovery
ENR/*in situ*	enhanced natural recovery/*in situ* treatment
EPA	U.S. Environmental Protection Agency
FS	feasibility study
LDW	Lower Duwamish Waterway
µg/kg dw	micrograms per kilogram dry weight
MLLW	mean lower low water
MNR	monitored natural recovery
MTCA	Model Toxics Control Act
NOAA	National Oceanic and Atmospheric Administration
PCB	polychlorinated biphenyl
PRG	preliminary remediation goal
RAL	remedial action level
RAO	remedial action objective
RME	reasonable maximum exposure
RI	remedial investigation
SMS	Sediment Management Standards
SQS	sediment quality standard
TOC	total organic carbon

Photo courtesy King County

On the Lower Duwamish Waterway, industrial and commercial facilities line the shoreline, and two long-established residential communities (Georgetown and South Park) are neighbors.

All elements of this Feasibility Study, including comments received on the Draft Feasibility Study, have been made available online at: www.ldwg.org.

Key Facts about the Lower Duwamish Waterway Feasibility Study

Site Description: The study area for the Lower Duwamish Waterway (LDW) Superfund Site is 441 acres, extending five miles up the waterway from the southern tip of Harbor Island. In the early 1900s, the U.S. Army Corps of Engineers modified the river into an engineered waterway for industrial development, resulting in the loss of much of its natural wetlands, marshlands, and mudflats over the years. Even with significant sediment contamination, the corridor is currently home to people, animals, and industries, and is used for navigation, recreation, and fishing. It is also home to low income and minority communities in the surrounding neighborhoods, and is used by Native American tribes as a resource and for cultural purposes. This feasibility study (FS) identifies and analyzes a wide range of alternatives for cleaning up the LDW.

Contaminants of Concern: Contaminants include polychlorinated biphenyls (PCBs), arsenic, carcinogenic polycyclic aromatic hydrocarbons (cPAHs), dioxins/furans, phthalates, and other hazardous substances.

Contaminant Risks: Human health and ecological risks exist at levels that warrant action under federal and state law. Risks to people are highest from eating fish that reside in the waterway for most or all of their life (but not salmon, which spend most of their lives outside the waterway), clams, and crabs. Lower, but still significant, health risks to people come from sediment contact while playing on the beach, clamming, and netfishing. Animals that live in the mud and in the water, and animals that feed in the waterway, including the river otter, are also at risk.

Early Action Areas (EAAs): The most contaminated areas of the waterway, considered hot spots and comprising 29 acres of contaminated sediment, were targeted for cleanup early in the investigation process. Cleanups have been conducted at three EAAs and two more will be cleaned up by the end of 2015. Total PCB concentrations in the surface sediments will be reduced by about half when the EAA cleanups are complete.

Source Control: Reducing contaminants entering the waterway is a priority to avoid recontamination following remediation. The Washington State Department of Ecology's (Ecology) source control strategy for the 32 square mile drainage basin is currently being implemented. Ecology formed the LDW Source Control Work Group, whose primary members include the U.S. Environmental Protection Agency (EPA), Seattle Public Utilities, King County, and the Port of Seattle. Investigations and cleanups of facilities, storm drains, and combined sewer overflows (CSOs) within the LDW drainage basin are being conducted to address ongoing sources of contamination to the LDW. Ecology has issued several reports to document the source control strategy (Ecology 2004) for the LDW site and the progress to date in addressing ongoing sources of contamination, which are available on their website at http://www.ecy.wa.gov/programs/tcp/sites. These activities are also briefly summarized in the remedial investigation (RI; Windward 2010) and this FS. Numerous activities are in progress, and further upland cleanup is anticipated that will help control sources of contaminants.

Cleanup Alternatives for the Rest of the Waterway: This FS describes options for cleaning up contaminated sediments in the rest of the LDW after EAA cleanups are complete, using combinations of dredging, capping, natural recovery, enhanced natural recovery, and treatment, along with institutional controls and monitoring. Federal and state criteria were used to develop and evaluate cleanup alternatives. These alternatives form the basis for selecting a final cleanup plan.

Cleanup Process and Status: Public review of the FS occurred from October 18, 2010 through January 14, 2011. EPA and Ecology used the public input to finalize the FS and develop a Proposed Plan for remediating the site. The Proposed Plan is scheduled to be issued for public review and comment in early 2013. Public comments on the Proposed Plan will be used by EPA to develop its Record of Decision for the final cleanup plan. EPA anticipates issuing the Record of Decision in early 2014, after seeking concurrence from the State of Washington in consultation with the Muckleshoot and Suquamish Tribes.

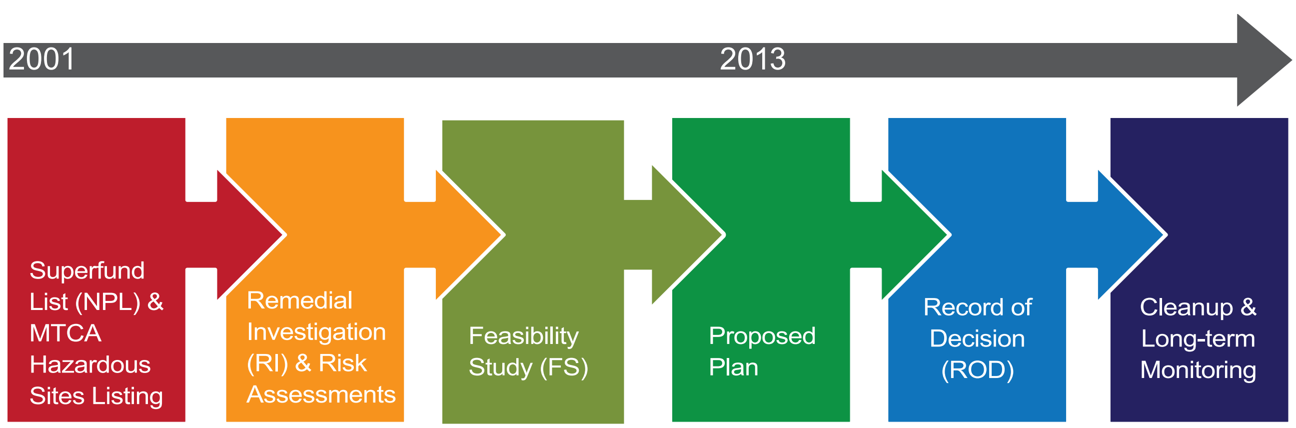
Executive Summary

The FS for the LDW Superfund Site in Seattle, Washington (Figure ES-1) was prepared by the Lower Duwamish Waterway Group (LDWG). This group consists of the City of Seattle, King County, the Port of Seattle, and The Boeing Company. LDWG was issued an Administrative Order on Consent in December 2000 jointly by EPA and Ecology under both federal and state law to conduct a remedial investigation/feasibility study (RI/FS) for the LDW (EPA, Ecology, and LDWG 2000). The LDW was added to EPA's National Priorities List on September 13, 2001 and later to Ecology's Hazardous Sites List on February 26, 2002. Both EPA and Ecology provided oversight for this FS.

The FS evaluates a range of remedial alternatives to clean up the LDW, extending just south of Harbor Island (river mile 0 [RM 0] to just beyond the Upper Turning Basin [RM 5]). The remedial alternatives are evaluated according to the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) and the Washington State Model Toxics Control Act (MTCA). These acts establish standards and procedures for evaluating remedial alternatives, selecting a remedy, and performing cleanup. In October 2010, the Draft Final FS was submitted for public input and agency review. Input received from the agencies and the public was used to finalize the FS. Following publication of the Final FS, EPA will issue the Proposed Plan identifying the preferred remedial alternative for the LDW. Formal public comment will be requested on the Proposed Plan. After public comments on the Proposed Plan are received and evaluated, EPA will select the final remedial alternative, seeking Ecology's concurrence, and will issue the Record of Decision.

The FS builds on a series of studies completed over nine years that are documented in the Final RI (Windward 2010). The RI describes:

- A conceptual site model for the LDW
- Physical and biological interactions of the waterway system, including transport of sediments into, within, and out of the LDW
- The nature and extent of contamination in the LDW
- The risks that contamination presents to people and animals that use the LDW.



This FS identifies alternatives for cleanup and compares these alternatives. EPA, Ecology, and LDWG made the draft FS widely available for public input, which has been considered in finalizing the FS. Another opportunity for formal public comment will occur after EPA issues the Proposed Plan. Following the comment period, EPA will issue the Record of Decision.

Scope of this FS in the Context of Other LDW Cleanup Activities

The Superfund and MTCA cleanup of the LDW includes three components: early cleanup actions, source control, and cleanup of the remainder of the LDW. The first two components are described below; this FS addresses the third component.

Early Action Areas

Cleanups at five Early Action Areas (EAAs) either have been completed or are under way. Cleanup was conducted by King County in the vicinity of the Norfolk combined sewer overflow/storm drain (CSO/SD) (RM 5) in 1999 and in the vicinity of the Duwamish/Diagonal CSO/SD (RM 0.5) in 2004/2005. A much smaller sediment cleanup was conducted at the Norfolk EAA in 2003 by The Boeing Company in the vicinity of the Boeing Developmental Center south storm drain. In 2012, cleanup was conducted in Slip 4 by the City of Seattle. Remedy decisions have been issued by EPA for Terminal 117 and Boeing Plant 2/Jorgensen Forge EAAs and cleanups are scheduled to be completed by 2015. Together, these five EAAs cover 29 acres, representing some of the highest levels of sediment contamination in the LDW. This FS evaluates options for cleanup outside of the EAAs. It is anticipated that cleanup of the EAAs will be completed prior to initiating any of the alternatives presented in the FS, and will reduce average total PCB concentrations in the LDW by approximately 50 percent.

Source Control

Ongoing sources of contamination to the LDW need to be controlled to the extent practicable to minimize the potential for recontamination of the site after cleanup. Ecology is the lead agency for managing activities that identify and address sources of contamination to the LDW. Ecology developed a source control strategy (Ecology 2004) to identify and manage sources of contaminants to LDW sediments in coordination with sediment cleanups. Ecology works in cooperation with other members of the Source Control Work Group (i.e., EPA, Seattle Public Utilities, King County, and the Port of Seattle) to create source control action plans that inform and prioritize upland cleanup efforts in the LDW. Ecology's first priority is to address sources contributing to contamination in the EAAs. The strategy and associated source control action plans for 24 individual drainage basins around the LDW provide a framework and process for identifying source control issues and implementing practical controls.

Source tracing and control efforts include:

- Mapping storm drain systems and analyzing samples collected therein.
- Managing discharges from storm drains and CSOs.
- Inspecting local businesses that discharge or otherwise contribute to storm drains, CSOs, or directly to the LDW, and implementing best management practices.
- Conducting upland cleanups, including remediating contaminated soils, groundwater, and storm drain solids.

These efforts have progressed in parallel with the RI and FS and will continue throughout and after implementation of the cleanup alternatives discussed in this FS.

The success of source control depends on cooperation of all the Source Control Work Group members and active participation of local businesses that must make changes to accomplish source control goals, with enforcement by Ecology or EPA to the extent necessary. It is important to note that, in some localized areas, recontamination may occur even with aggressive source control because of the difficulty in identifying and completely controlling all potential sources of contaminants released by urban activities. Because of the dynamic nature of source control, it is essential to maintain flexibility. A flexible and adaptive strategy for prioritizing and conducting source control work will continue throughout selection, design, and implementation of the long-term remedy for the LDW.

Site Description

The northernmost portion of the Duwamish River, just south of Harbor Island and the confluence with Elliott Bay, makes up the LDW. The U.S. Army Corps of Engineers modified the river into an engineered waterway in the early 1900s to serve developing industries in Seattle. The LDW is a saltwater wedge-type estuary influenced by river flow and tidally-influenced saltwater inflow from Puget Sound, both of which fluctuate seasonally. The 5-mile study area (see Figure ES-1) encompasses approximately 441 acres, with an average width of 440 feet (ft) and supports various uses as described briefly below:

Habitat: Most of the natural wetlands, marshlands, and mudflats of the Duwamish River estuary were lost during construction in the early 1900s and in subsequent land development. Much of the present shoreline consists of riprap, pier aprons, and sheet pile walls. Despite significant alterations in habitat, the LDW contains diverse aquatic and wildlife communities and a robust food web that includes top predators. Some intertidal habitat remains in small isolated patches, with the area around Kellogg Island being the largest contiguous area. Remaining habitat is important to various species, including two threatened species, Puget Sound chinook salmon and bull trout, and other salmon species that use the LDW as a migration corridor. A number of habitat restoration and planning efforts are ongoing within the LDW.

Navigation: The LDW includes a federally-maintained navigation channel and numerous privately maintained berthing areas that support vessel traffic and waterway use. Many berthing areas and the upper reach of the navigation channel are periodically dredged to remove deposited sediments and maintain navigable depths. Authorized water depths in the navigation channel vary from approximately -30 ft mean lower low water (MLLW) elevation near the mouth of the LDW to -15 ft MLLW near the Upper Turning Basin (NOAA 2009).

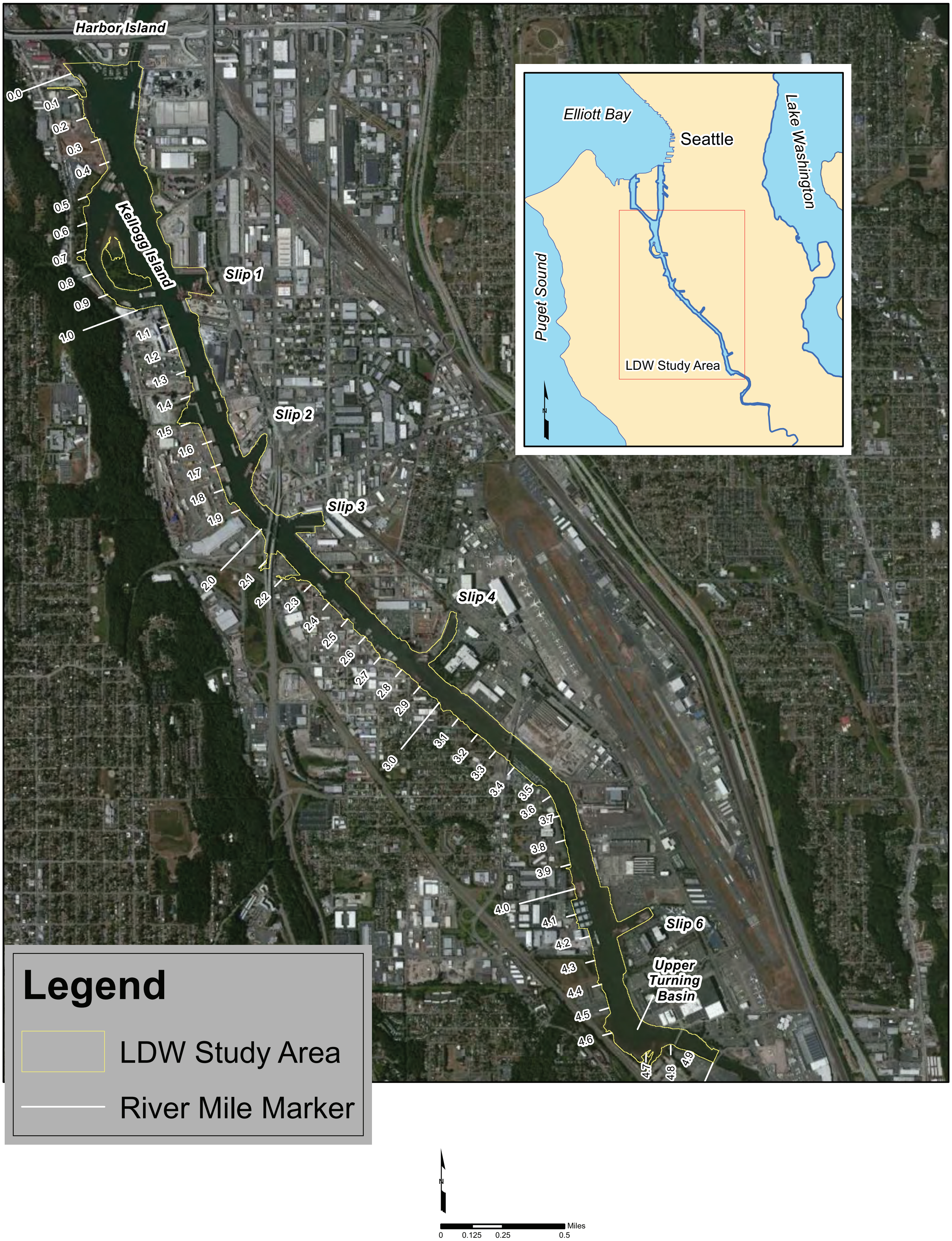
Other Uses: The LDW corridor is the City of Seattle's primary industrial area. Current land use, zoning requirements, and land ownership within most of this corridor are characteristic of an active industrial waterway. Two neighborhoods, South Park and Georgetown, are located to the west and east, respectively, of the LDW. These neighborhoods support a mix of residential, recreational, commercial, and industrial uses. EPA and Ecology believe there to be potential environmental justice concerns in accordance with Executive Order 12898 *(Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations)* for those affected by the LDW site and cleanup. In response, EPA is developing an Environmental Justice Analysis for the LDW Superfund Cleanup, to be published as an appendix to the Proposed Plan.

The LDW is the receiving water body for stormwater discharged from approximately 200 public and private storm drains, CSOs, ditches, and streams. The LDW supports considerable commercial navigation as well as various recreational activities such as boating, kayaking, fishing, and beach play. Several public parks and publicly accessible shoreline areas exist, with plans to create additional recreational and habitat opportunities in the LDW corridor. The LDW is part of the Muckleshoot Tribe's treaty-protected fishery, and includes a commercial fishery for salmon as well as ceremonial and subsistence uses by the tribe. The Suquamish Tribe actively manages aquatic resources north of the Spokane Street Bridge, just north of the LDW study area. The Duwamish Tribe uses Herring's House Park and other parks along the Duwamish for cultural gatherings.

Photo courtesy King County

The LDW serves primarily as an industrial and navigational corridor with some recreational uses. It is a migration corridor for salmon and supports a treaty-protected fishery for the Muckleshoot Tribe. The LDW area will continue to support diverse uses into the future as the heart of a still growing urban area.

Figure ES-1: Lower Duwamish Waterway Study Area



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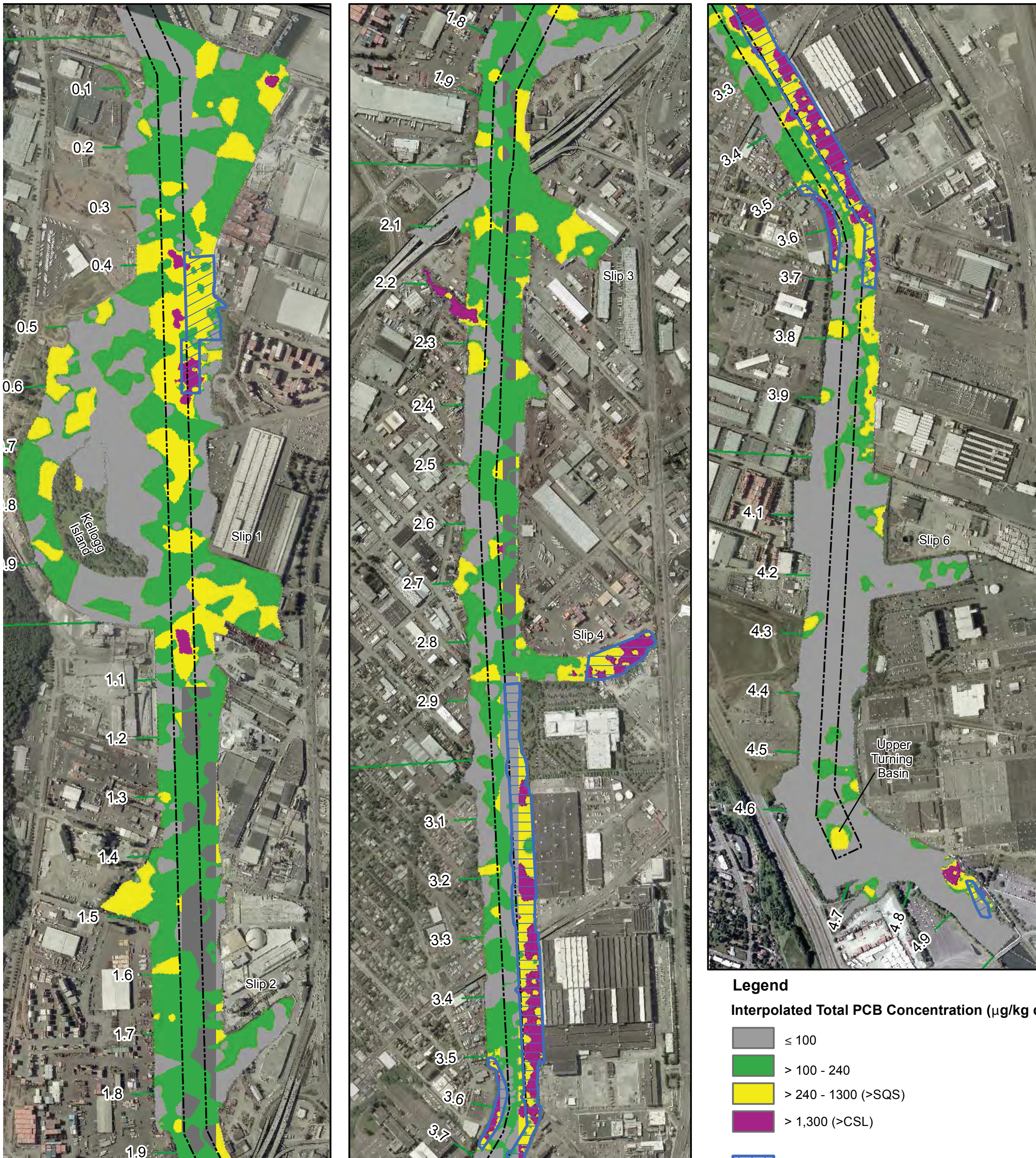
Nature and Extent of Contamination

The RI (Windward 2010) collected and analyzed information about the nature and extent of contamination, evaluated sediment transport processes, and assessed current conditions within the LDW, including risks to people and animals that use the LDW. The RI findings included:

- Contaminants in sediments were found at concentrations that could have adverse effects on the benthic community (worms, clams, and other organisms that live in the sediments). Several contaminants were found in resident fish and shellfish tissue at concentrations that could result in increased cancer risks and non-cancer hazards to people who rely on the LDW as a source of seafood as well as wildlife such as river otter.
- In general, higher concentrations of contaminants were detected in localized, fairly well defined areas separated by larger areas of the LDW with relatively low concentrations. Despite the widespread distribution of common contaminants, such as PCBs, the locations where elevated concentrations of total PCBs and arsenic were detected were generally not in the same areas, indicating that sources of these two contaminants are likely different. In general, elevated cPAH concentrations were more dispersed than those for PCBs and arsenic, suggesting more widespread sources for cPAHs. Except for a few areas with substantially higher concentrations, dioxins/furans were generally uniformly distributed in the LDW. Figure ES-2 shows the distribution of total PCBs within the LDW study area as an example of its uneven distribution pattern.

The remedial investigation included extensive sampling of sediments, fish, and shellfish.

Figure ES-2: Interpolated Total PCB Concentrations in Surface Sediments



Notes:

1. SQS values of 240 µg/kg dw based on conversion of 12 mg/kg oc to a dry weight value using 2% TOC.
2. Interpolation is defined as the estimation of surface sediment concentrations at unsampled points based on known surface sediment concentrations of surrounding points.

Risk Assessment

The baseline risk assessments conducted as part of the RI estimated risks to people (human health) and benthic invertebrates, fish, and wildlife (ecological receptors), resulting from exposure to contaminants in the absence of any cleanup measures. The risk assessments found the risks in the LDW to be high enough to warrant cleanup under both CERCLA and MTCA; these findings are summarized as follows:

- Contaminants contributing the most to human health risks include PCBs, arsenic, cPAHs, and dioxins/furans. These four are referred to as risk-driver contaminants for human health (Windward 2007b), based on the magnitude of their risk estimates and the relative percentage of their contributions to total human health risks.
- Risks to people are primarily associated with eating resident fish,[1] crabs, and clams. Reasonable maximum exposure (RME) seafood consumption rates (based on Tulalip Tribal and Asian and Pacific Islander seafood consumption rates) of resident fish, crabs, and clams result in a lifetime excess cancer risk that exceeds the CERCLA target excess cancer risk range of 10^{-4} to 10^{-6} and the MTCA lifetime excess cancer risk thresholds of one in one million (1×10^{-6}) for individual contaminants and one in one hundred thousand (1×10^{-5}) for all carcinogenic hazardous substances combined. Non-cancer hazards (the potential for adverse effects other than cancer, such as damage to the immune system) above the CERCLA and MTCA risk thresholds were also associated with eating resident seafood.
- Lower risks to people are associated with activities that involve direct contact with sediment, such as tribal netfishing, tribal clamming, and beach play. The risks for these activities are sometimes above the MTCA risk threshold for individual contaminants.
- Forty-one contaminants were identified in the ecological risk assessment (Windward 2007a) as presenting a risk (e.g., reduced survival, growth, or reproduction) to benthic invertebrates because their concentrations in surface sediments at one or more locations exceeded the sediment quality standards (SQS) contained in Washington State's Sediment Management Standards (SMS). Contaminant concentrations in surface sediments exceeded numerical standards in the SMS, indicating a potential for harmful effects to the benthic community. The SQS were exceeded in approximately 25% (110 acres) of the LDW study area: about 7% of the LDW had a higher likelihood for adverse effects (exceeding the cleanup screening levels of the SMS), while 18% of the LDW had effects falling between the SQS and cleanup screening levels. The remaining 75% of the LDW is considered not likely to have adverse effects on the benthic community.
- Risks to crabs, fish, and most wildlife were relatively low, with the exception of river otters. River otters have a higher risk of adverse effects such as reduced reproductive success attributable to the presence of PCBs in their prey. PCBs were identified as a risk driver for river otters in the ecological risk assessment (Windward 2007a).

Photo courtesy Windward Environmental

Photo courtesy Don Wilson, Port of Seattle

The greatest risks to people come from eating resident fish, crabs, and clams. Activities involving direct contact with sediment, such as clamming, netfishing, and beach play, pose lower risks. Ecological receptors, such as benthic organisms and river otters, also face risks.

[1] The term resident fish does not include salmon. Salmon and other anadromous species use the LDW for only short periods during their life cycle

Remedial Action Objectives (RAOs) and Preliminary Remediation Goals (PRGs)

A substantial body of research and guidance has been developed on how to manage risks from contaminated sediment. The regulatory agencies recognize that sediment cleanups are complex, difficult to predict, and often require an integrated approach for success. In response to these challenges and to lessons learned from other projects, EPA developed 11 sediment risk management principles, which are discussed in detail in Section 12. This FS has been prepared to be consistent with those principles.

Controlling sources of contaminants early in the cleanup process will be especially critical to the long-term success of any remedial action taken in the LDW. Ecology published a source control strategy for the LDW (Ecology 2004) and is leading source control efforts to reduce pollution entering the LDW. Effectiveness of the source control efforts will be evaluated prior to sediment cleanup.

Four remedial action objectives (RAOs) have been identified based on the risk assessments. The RAOs describe what the cleanup actions should accomplish in the LDW to address the identified risks. The RAOs are:

- **RAO 1:** Reduce human health risks associated with the consumption of resident LDW fish and shellfish by reducing sediment and surface water concentrations of contaminants of concern to protective levels.
- **RAO 2:** Reduce human health risks associated with exposure to contaminants of concern through direct contact with sediments and incidental sediment ingestion by reducing sediment concentrations of contaminants of concern to protective levels.
- **RAO 3:** Reduce risks to benthic invertebrates by reducing sediment concentrations of contaminants of concern to comply with the Washington State SMS.
- **RAO 4:** Reduce risks to crabs, fish, birds, and mammals from exposure to contaminants of concern by reducing sediment and surface water concentrations of contaminants of concern to protective levels.

Preliminary remediation goals (PRGs) were developed for each RAO; they represent concentrations that are believed to provide adequate protection of human health and the environment. Depending on the cleanup objective, PRGs for a given contaminant may be applied to individual locations (i.e., point-based), or applied as an average across the entire LDW or over a specific exposure area. PRGs are not final cleanup levels. EPA will select cleanup levels in the Record of Decision. Table ES-1 summarizes the PRGs for the risk-driver contaminants.

Both CERCLA and MTCA consider background concentrations when formulating PRGs and cleanup levels. Final MTCA cleanup levels cannot be set at concentrations below natural background. For those contaminants with risk-based concentrations below natural background concentrations, both CERCLA and MTCA allow PRGs and cleanup levels to be set at natural background concentrations.

MTCA defines natural background as the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities. Thus, a natural background concentration can be defined for man-made compounds (e.g., PCBs deposited by atmospheric deposition into an alpine lake).

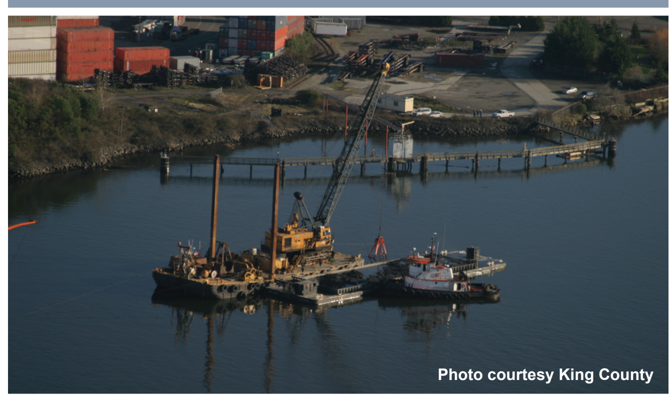
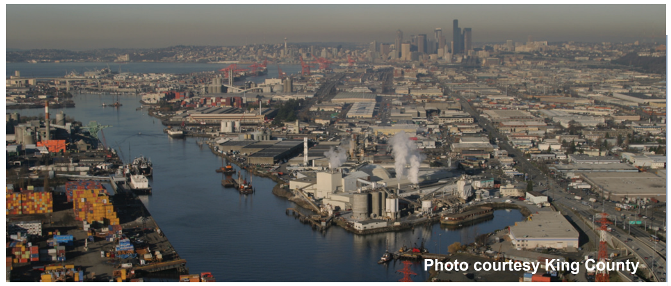


Photo courtesy King County

Cleanup activities have been conducted at the Duwamish/Diagonal, Norfolk, and Slip 4 EAAs and are in progress for the two other EAAs (T117 and Boeing Plant 2/Jorgensen Forge).

Three PRGs are set to natural background. Natural background PRG concentrations for PCBs, arsenic and dioxins/furans are unlikely to be achieved because long-term sediment concentrations will continue to be affected by input from the Green/Duwamish River and from lateral sources (e.g., storm drains and CSOs) depending on the degree to which these inputs can be reduced through ongoing source control actions.



Although the sediment concentrations of four contaminants that drive human health risks are elevated in the LDW, these contaminants are also commonly found in urban environments. It is not possible to entirely eliminate all risks associated with these contaminants.

Definitions for the Executive Summary

- ***ARARs*** are defined as applicable or relevant and appropriate requirements (standards, criteria, or limitations) under federal environmental and state environmental or facility siting laws that are more stringent than the federal law. Remedial actions conducted under CERCLA must achieve them or formally waive them. For example, the Washington Model Toxics Control Act is an ARAR under a CERCLA cleanup action.
- ***Cleanup objective*** means the PRG or as close as practicable to the PRG when the PRG is not predicted to be achievable. Long-term model-predicted concentrations are used in the FS as estimates of "as close as practicable" to PRGs.
- ***Cleanup level*** means the concentration of a hazardous substance in an environmental medium that is determined to be protective of human health and the environment under specified exposure conditions.
- ***Enhanced natural recovery (ENR)*** refers to the application of thin layers of clean granular material, typically sand, to a sediment area targeted for remediation. Essentially, ENR reduces the time to achieve cleanup objectives over what is possible by relying solely on natural sediment deposition where burial is the principal recovery mechanism (EPA 2005b).
- ***In situ treatment*** refers to the application of an amendment to the material used in ENR or capping or mixed directly into surface sediments. Typically, the amendment is activated carbon or organoclays used to bind contaminants and make them unavailable for biological uptake by organisms.
- ***Monitored natural recovery (MNR)*** refers to the use of natural processes such as burial by incoming sediments to reduce sediment contaminant concentrations over time. It is used where conditions support natural recovery. A monitoring program is instituted to assess if, and at what rate, risks are being reduced and whether sufficient progress is being made toward achieving the RAOs, or alternatively, whether contingency actions are warranted.
- ***Natural background*** represents the concentrations of hazardous substances that are consistently present in an environment that has not been influenced by localized human activities.
- ***Preliminary remediation goals (PRGs)*** are specific desired contaminant endpoint concentrations or risk levels for each exposure pathway that are believed to provide adequate protection of human health and the environment, based on available site information (EPA 1997b).
- ***Remedial action levels (RALs)*** are contaminant-specific sediment concentrations that trigger the need for active remediation (e.g., dredging, capping, or enhanced natural recovery).
- ***Remedial action objectives (RAOs)*** describe what the proposed remedial action is expected to accomplish (EPA 1999b). They are narrative statements of the goals for protecting human health and the environment.
- ***Risk drivers*** are the contaminants of concern identified in the baseline risk assessments that present the principal risks; these are equivalent to indicator hazardous substances under MTCA.

Table ES-1: Preliminary Remediation Goals for Total PCBs, Arsenic, cPAHs, and Dioxins/Furans in LDW Surface Sediment

Risk-Driver Contaminants	Natural Background (UCL95)	Preliminary Remediation Goals (PRGs)				
		Spatial Scale of Exposure[a]	RAO 1: Human Seafood Consumption	RAO 2: Human Direct Contact	RAO 3: Benthic Organisms	RAO 4: Ecological (River Otter)
Total PCBs (µg/kg dw)	2	Site-wide	natural background	1,300[b]	n/a	128-159
		Clamming Areas	n/a	500[c]	n/a	n/a
		Individual Beaches[d]	n/a	1,700	n/a	n/a
		Point	n/a	n/a	SQS	n/a
Arsenic (mg/kg dw)	7	Site-wide	nc[e]	natural background[b]	n/a	n/a
		Clamming Areas	n/a	natural background	n/a	n/a
		Individual Beaches[d]	n/a	natural background	n/a	n/a
		Point	n/a	n/a	SQS	n/a
cPAHs (µg TEQ/kg dw)	9	Site-wide	nc[e]	380[b]	n/a	n/a
		Clamming Areas	n/a	150[c]	n/a	n/a
		Individual Beaches[d]	n/a	90	n/a	n/a
		Point	n/a	n/a	n/a[f]	n/a
Dioxins/Furans (ng TEQ /kg dw)	2	Site-wide	natural background[g]	37[b]	n/a	n/a
		Clamming Areas	n/a	13[c]	n/a	n/a
		Individual Beaches[d]	n/a	28	n/a	n/a
		Point	n/a	n/a	n/a	n/a
Other SMS Contaminants	n/a	Point	n/a	n/a	SQS	n/a

Notes:

a. The spatial scale of site-wide exposure is RAO-specific. The statistical metric for site-wide, clamming, and beach play areas is the SWAC for the evaluation of alternatives (compliance monitoring will be based on upper confidence limit on the mean or SWAC).

b. Site-wide PRG is based on netfishing scenario.

c. PRG is based on tribal clamming scenario.

d. See Section 3 of the FS (Figure 3-1) for the location of beach play areas.

e. Arsenic and cPAH PRGs are undefined for the human health seafood consumption pathway (RAO 1). Seafood consumption excess cancer risks for these two risk drivers were largely attributable to the consumption of clams. There is no credible relationship, based on site data, relating cPAH or arsenic concentrations in sediment to concentrations in clam tissue (Section 8 of the RI, Windward 2010). Section 8 of the FS discusses the need for future investigations of the sediment/tissue relationships for arsenic and cPAHs. Cleanup goals are to be determined based on future investigations.

f. There are no SMS criteria for cPAHs. However, SMS criteria are set for individual PAH compounds and low- and high-molecular weight PAH groupings.

g. Although risks associated with consumption of dioxins/furans in resident seafood were not quantitatively assessed in the baseline HHRA, those risks were assumed to be unacceptable, and the associated sediment concentration was assumed to be below natural background concentrations.

cPAH = carcinogenic polycyclic aromatic hydrocarbon; CSL = cleanup screening level; dw = dry weight; FS = feasibility study; HHRA = human health risk assessment; µg/kg = micrograms per kilogram; mg/kg = milligrams per kilogram; n/a = not applicable; nc = no value calculated; ng/kg = nanograms per kilogram; PCB = polychlorinated biphenyl; RAO = remedial action objective; RI = remedial investigation; RL = reporting limit; SMS = Sediment Management Standards; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; UCL95 = 95% upper confidence limit on the mean; WAC = Washington Administrative Code.

Physical and Chemical Modeling

A sediment transport model was developed to evaluate long-term sediment transport processes in the LDW. The model findings included:

- It is estimated that an average of more than 185,000 metric tons of sediment enter the LDW each year, of which 100,000 metric tons settle out within the waterway. More than 99% of the new sediment originates in the Green/Duwamish River, upstream of the LDW; less than 1% originates from storm drains, CSOs, and streams that discharge directly into the LDW. These newly deposited sediments are mixed with the existing surface sediments over much of the area through bioturbation and resuspension and redeposition processes associated with disturbances, such as ship-induced bed scour, high-flow events, and dredging.
- Based on the sediment transport model, net erosion is predicted to occur over about 18% of the LDW bed area during 100-year high-flow events. Most bed erosion is less than 10 centimeters (cm) in depth. During such high flows, maximum estimated net erosion depths are 22 cm or less in specific areas of the LDW. The majority of eroded sediment resettles within the LDW. Vessels under emergency and high-power operations may also cause localized scour. Modeling predicts typical vessel scour depths of less than 25 cm under these operating conditions. The effects of ship-induced bed scour are reflected in the present structure of the LDW sediment bed because ship movement has been occurring since the LDW was created in the early 20th century.
- To evaluate changes in sediment contaminant concentrations over time (considering both natural recovery and recontamination potential), sediment transport model results were combined with estimates of contaminant concentrations on solids that enter the LDW from upstream, as well as from storm drains, CSOs, and small streams discharging directly into the LDW. This analysis, conducted using a bed composition model, included both quantitative modeling and analyses of multiple lines of empirical evidence, and yielded the following results:

  – The physical conceptual site model of the LDW as a net depositional environment is supported by modeling and both physical and chemical lines of evidence from sediment core profiles. Empirically derived net sedimentation rates average 1 to 3 cm/yr in most of the subtidal areas, and more than 30 cm/yr in the Upper Turning Basin, which acts as a natural trap for incoming sediment. There are exceptions to the conceptual site model caused by location-specific features (i.e., vessel scour, outfalls, structures).

  – Contaminant concentrations in LDW surface sediments are predicted to be reduced as a result of remedial actions and then continue to gradually decrease over one to two decades to concentrations close to those found in upstream sediment and suspended solids. Localized areas near large storm drains, CSOs, or other upland sources may not recover as quickly, or may have persistently elevated concentrations of some contaminants, even after upland source control actions. Although less than 1% of new sediment entering the LDW is from storm drains, CSOs, and small streams discharging directly into the LDW, these lateral source sediments typically have higher contaminant concentrations than the average contaminant concentrations associated with upstream sediment and suspended solids. Localized areas in the immediate vicinity of these sources have higher contaminant concentrations. Areas that either have low sedimentation rates or are regularly physically disturbed also may not recover.

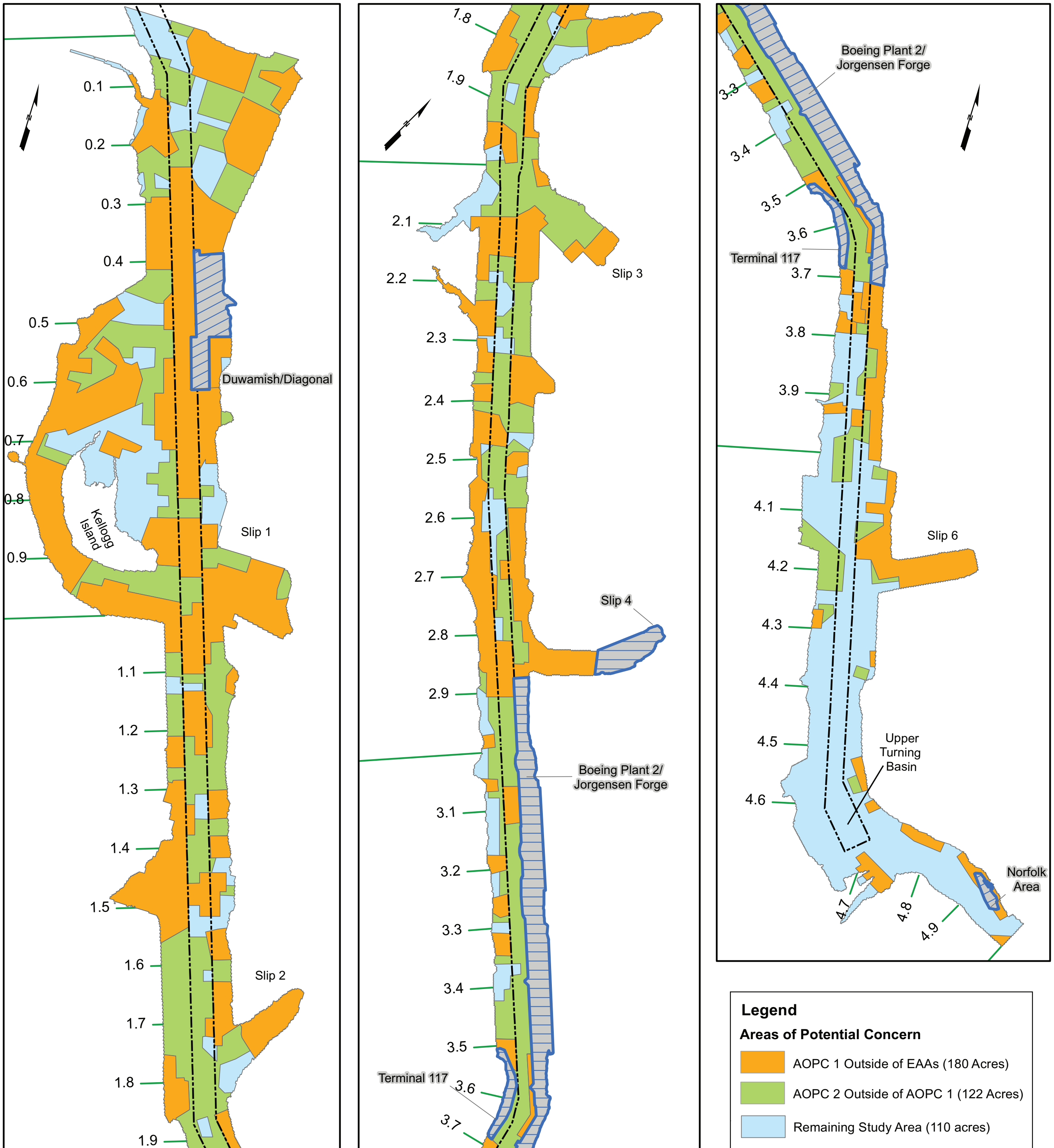
  – Model predictions of changes in surface sediment contaminant concentrations over time are uncertain. The primary sources of uncertainty in the physical and chemical model predictions are: 1) the rate of net sedimentation/burial from incoming sediments, 2) contaminant concentrations in incoming sediments and the extent to which they may change in the future, and 3) deep disturbances of subsurface contaminated sediments by mechanisms such as vessel scour and earthquakes. These uncertainties were considered in the development and comparative analyses of alternatives.

Areas of Potential Concern

A first step in development of remedial alternatives was to map Areas of Potential Concern which represent the areas of sediment that potentially have unacceptable risks and will likely require application of active remedial technologies or monitored natural recovery (MNR). Figure ES-3 shows two areas of potential concern (AOPC 1 and AOPC 2). The first area, AOPC 1, includes areas with contaminant concentrations above the SQS and areas with unacceptably high direct contact human health risks. The second area, AOPC 2, includes additional areas with total PCB concentrations above 100 micrograms per kilogram dry weight (µg/kg dw). The available baseline sediment data used to delineate the areas of potential concern include data collected over a 21-year time span, from 1990 – 2010. For this reason, existing contaminant concentrations in the LDW are somewhat uncertain. Some areas may have already recovered naturally, while others may have become more contaminated. Therefore, areas requiring cleanup will be refined through additional sampling during remedial design.

The effects of ship traffic on sediment transport were evaluated in the FS.

Figure ES-3: Early Action Areas and Areas of Potential Concern



Notes:
1. Total size of study area is 441 acres (RM 0-5).

Legend

Areas of Potential Concern

- AOPC 1 Outside of EAAs (180 Acres)
- AOPC 2 Outside of AOPC 1 (122 Acres)
- Remaining Study Area (110 acres)
- Early Action Areas (EAA; 29 Acres)
- Navigation Channel
- River Mile Marker

Feet
0 200 400 800

Evaluation and Screening of Technologies

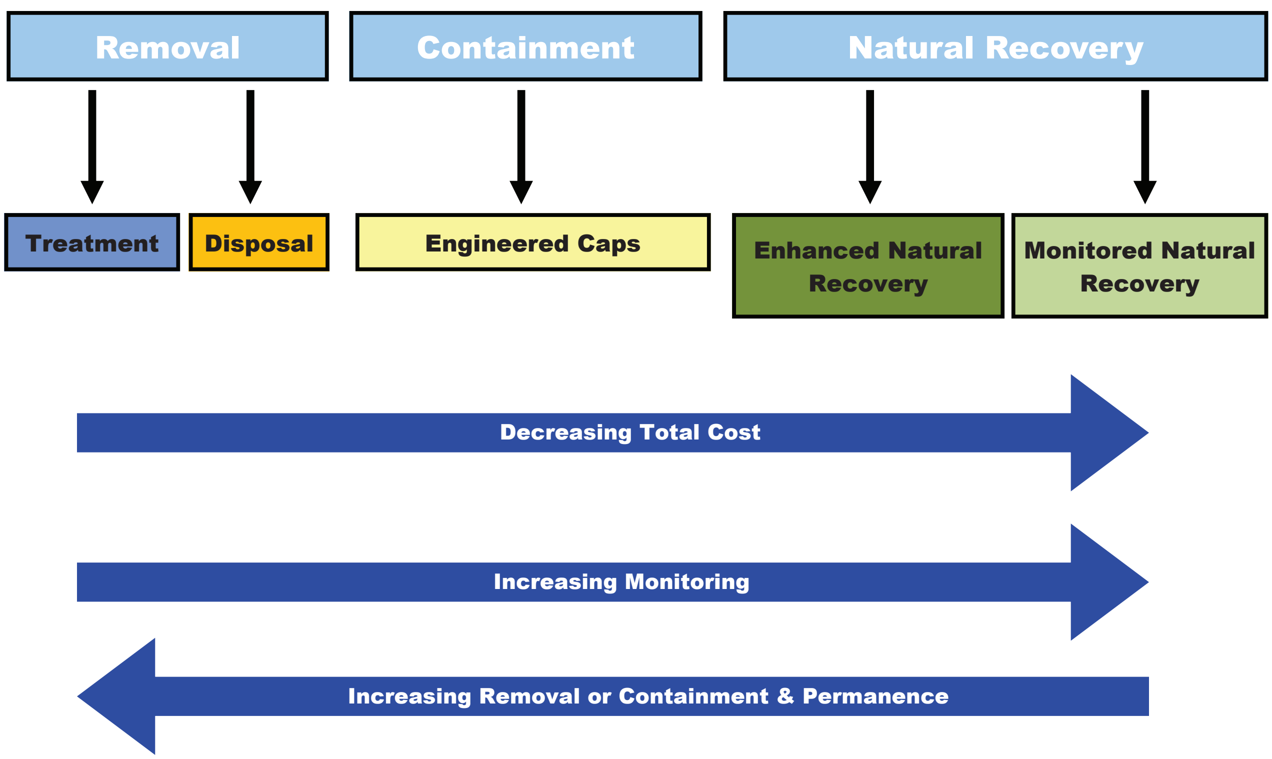
Several technologies applicable for remediating contaminated sediments in the LDW were selected to develop the remedial alternatives:

- Physical removal (e.g., dredging) of contaminated sediments. Options to process the dredged material include:
  - Treatment.
  - On-site and off-site disposal (e.g., in a permitted landfill).
- Containment (isolation or reactive capping) of contaminated sediments, typically using engineered layers of sand, gravel, or rock.
- Enhanced natural recovery (ENR) that uses a thin-layer placement of materials (e.g., sand) to enhance natural recovery processes.
- *In situ* treatment adds activated carbon or other sequestering agents to ENR, that is, to the thin layer placement upon sediment to reduce the bioavailability and toxicity of contaminants.
- MNR reduces surface sediment concentrations, primarily by the natural burial of contaminated sediments with cleaner sediments over time.

These technologies have been used in the Puget Sound region and nationally at other contaminated sediment sites. Other similar technologies may be considered during remedial design. Figure ES-4 illustrates the technologies selected for this FS to manage contaminated sediments.

Monitoring of sediments, biota, and water will provide the data needed to understand conditions before, during, and after remediation of the LDW by any combination of technologies. Further, information gathered during monitoring may indicate the need for contingency actions. To varying degrees, institutional controls will be needed to supplement the remedial technologies (e.g., advisories to limit consumption of resident seafood from the LDW or restrictions on activities such as dredging or anchoring in specified areas).

Figure ES-4: Technologies for Managing Contaminated Sediments



Development of Remedial Action Levels and Remedial Alternatives

Remedial action levels (RALs) were developed for each risk-driver contaminant. Remediation of the risk drivers is expected to reduce concentrations of other contaminants that pose a much smaller risk. RALs are contaminant-specific sediment concentrations that trigger the need for active remediation (i.e., dredging, capping, or ENR). By selecting different RALs, the alternatives vary in: 1) the amounts of active technologies versus MNR, 2) construction duration, and 3) the time required to achieve cleanup objectives.

In addition to a no further action alternative (Alternative 1), 11 remedial alternatives were developed to span the potential remedial design and implementation options, and the range of RALs. All the remedial alternatives assume that cleanup actions at the EAAs (29 acres) have already been completed. Approximately half of the alternatives focus on removal (denoted by the letter R) of sediments from areas where contaminant concentrations exceed the RALs, while other alternatives combine (denoted by the letter C) removal, containment, and ENR/*in situ* to manage contamination in those areas. Technologies were assigned to specific areas based on localized conditions, including sediment transport and chemical characteristics, navigation uses and depth requirements, habitat considerations, and potential for natural recovery. As the RALs decrease (become lower), the area actively remediated in the alternatives gets incrementally larger, increasing from 32 acres (Alternative 2) to 302 acres (Alternative 6).

In addition, options for on-site disposal or *ex situ* treatment (i.e., treatment after removal from the LDW) of dredged materials are included in Alternatives 2 and 5, respectively, to provide perspective on how these treatment options could affect costs, schedule, and performance. All alternatives rely to varying degrees on institutional controls to manage the effects of residual contaminant concentrations. An important institutional control, shared by all alternatives, is seafood consumption advisories. Alternatives 2 through 6 also include related education and public outreach programs designed to increase awareness of risks to those consuming resident seafood and to reduce unacceptable exposures.

Table ES-2 presents the RALs and the outcomes that each remedial alternative is predicted to achieve. Figure ES-5 presents essential aspects of the remedial alternatives (e.g., areas remediated by various technologies, costs) and also shows the estimated times to achieve cleanup objectives. Following are brief descriptions of the remedial alternatives.

Alternative 1 – No Further Action

Alternative 1 is the no further action alternative. It provides a basis for comparison of the other remedial alternatives and is required by CERCLA. Alternative 1 includes no additional action other than long-term LDW-wide monitoring and provides no institutional controls beyond those specific to the EAA projects and the existing Washington State Department of Health LDW seafood consumption advisory.

Photo courtesy King County

Table ES-2: Remedial Alternatives and Model-predicted Short-term and Long-term Outcomes

Remedial Alternative [a]	Construction Period	Remedial Action Levels	Evaluation Criteria and Estimated Times to Reach Model-Predicted Outcomes for Each RAO (years)										
			RAO 1: Human Health – Seafood Consumption[b, c, d] (see Tables 9-5 and 9-7a)					RAO 2: Human Health – Direct Contact[e] (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)[j]	RAO 4: Ecological Health: Seafood Consumption; HQ<1 – River Otter (see Table 9-7b)[c]
			10^{-4} total PCB risk for Adult Tribal, Child Tribal and Adult API	10^{-5} total PCB risk for Child Tribal[f]	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[g]	< 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 Beach3[h]	Arsenic reaches LTMPC range site-wide[i]		
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	Unlikely to be achieved by any of the remedial alternatives	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		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[k] **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[k] **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[d]	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. 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.

b. 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).

c. 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.

d. 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.

e. 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.

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

g. ≤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).

h. The BCM model output for Beach3 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. Given the uncertainty in this value and the fact that the beaches are actively remediated, the FS assumes that risk from cPAHs at these beaches will be 1 × 10^{-6} following construction.

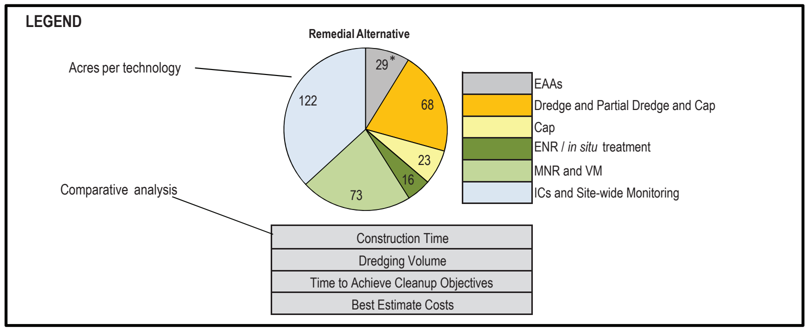
i. No alternative is expected to achieve the arsenic PRG based on natural background, but they all are predicted to achieve the LTMPC site-wide arsenic concentration of approximately 11.4 mg/kg dw, based on achieving a site-wide arsenic SWAC within 25% (≤11.4 mg/kg dw) of the 45-yr Alternative 6R arsenic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

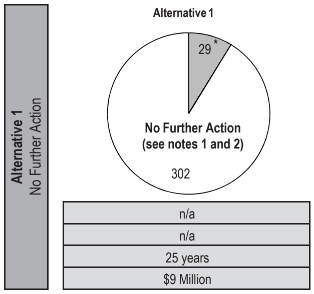
j. For FS purposes, compliance with the SMS is assumed when ≥98% of the study area is below the SQS; it does not represent a standard to be applied to compliance monitoring. Reducing SQS exceedances sufficient to achieve RAO 3 cleanup objectives depends on adequate source control and natural recovery 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.

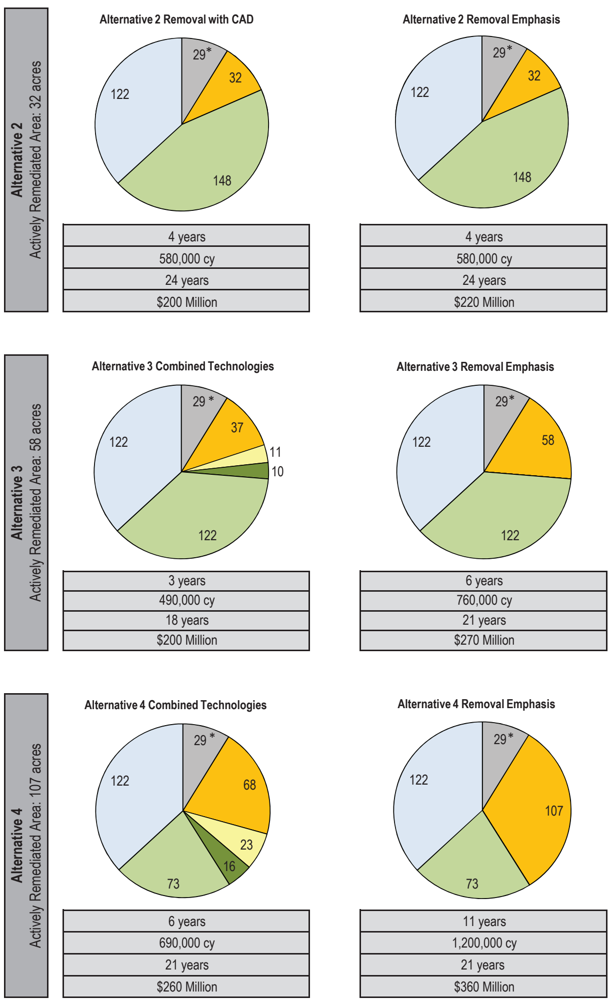
k. Dry weight equivalents of the SQS and the CSL SMS criteria of 12 and 65 mg/kg oc, assuming 2% TOC (average site-wide TOC value). If selected, actual implementation of this RAL would be based on organic carbon-normalized criteria defined by the SMS.

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

Figure ES-5: Summary of Alternatives







Notes:

1) Acreages for the EAAs are shown here for completeness; they are common to all the alternatives (marked with asterisk). Aternative 1 costs ($9 million) are for LDW-wide monitoring, Agency oversight, and reporting. The cost of cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided for informational purposes and are not used in the comparison of alternatives

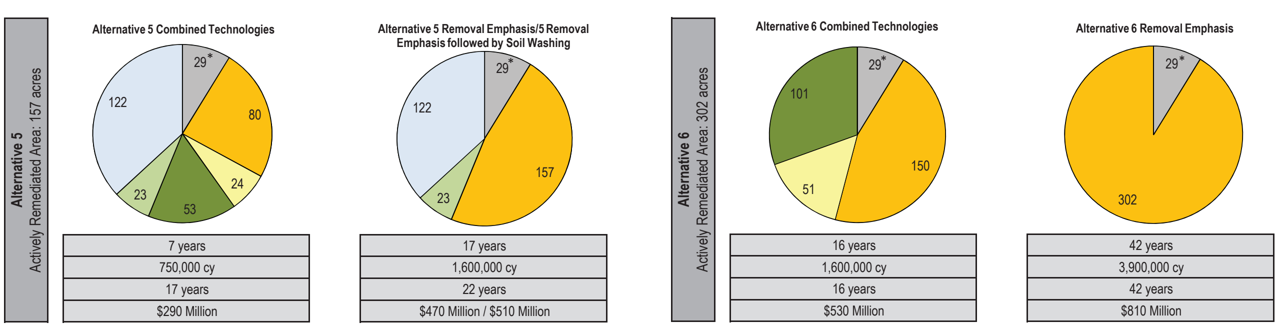
2) The pie represents 331 acres, i.e., the area where alternatives differ in the types of technologies evaluated. The total area of the FS study area 441 acres. The costs of monitoring and maintaining institutional controls over the entire LDW study area are included in the remedial alternative costs.

3) Time is for achievement of cleanup objectives for all RAOs.

4) Costs are expressed on a net present value basis. Costs are rounded to the nearest $10 million, with the exception of Alternative 1.

5) Best estimate cost assumptions are considered accurate to +50% and -30% (see Appendix I).

CAD = contained aquatic disposal; cy = cubic yards; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; ICs = institutional controls; LDW = Lower Duwamish Waterway; MNR = monitored natural recovery n/a = not applicable; RAL = remedial action level; RAO = remedial action objective; SQS = sediment quality standard; VM = verification monitoring



Alternatives 2R and 2R-CAD

Alternative 2 RALs target hot spots of sediment contamination for removal. The total active remediation area is 32 acres. Also, 125 acres are designated as MNR where reduction in sediment contaminant concentrations over time will be monitored and contingency actions will be taken if specified targets are not met. Alternative 2R (and all subsequent alternatives) includes upland disposal of dredged sediments, while Alternative 2R-CAD includes on-site disposal in a contained aquatic disposal (CAD) facility.

Alternatives 3C and 3R

Alternative 3 RALs are lower than the Alternative 2 RALs. In addition, Alternative 3 has RALs specific to the intertidal areas that address RAO 2 using active remediation. Alternative 3 actively remediates 58 acres and designates 99 acres as MNR.

Alternatives 4C and 4R

Alternative 4 RALs are lower than those for Alternative 3 resulting in an actively remediated area of 107 acres. Alternative 4 also designates 50 acres as MNR.

Alternatives 5C, 5R, and 5R-Treatment

The Alternative 5 RALs are lower than those for Alternative 4; RALs for PCBs and other SMS contaminants are based on the SQS. RALs for the other two risk drivers (cPAHs and dioxins/furans) are the same as for Alternative 4. Alternative 5 actively remediates 157 acres and does not rely on MNR, although further reductions in contaminant concentrations due to natural recovery are anticipated. Unlike Alternatives 5C and 5R, Alternative 5R-Treatment specifies soil washing or a similar technology to treat dredged sediment from these areas, which may reduce the volume of contaminated sediment requiring upland disposal. The *ex situ* treatment component could also be included in any of the other alternatives.

Alternatives 6C and 6R

The Alternative 6 RALs are the most stringent considered in the FS for PCBs, arsenic, and dioxins/furans. These RALs are a best professional judgment, considering available information on the potential for recontamination and resuspension and continued sediment input from the Green/Duwamish River and the LDW drainage basin. Alternative 6 relies solely on active remediation to achieve cleanup objectives. It also has the largest cleanup footprint, requiring active remediation of 302 acres.

Quick Reference: Remedial Action Objectives (RAOs)

- ***RAO 1:*** Reduce human health risks associated with the consumption of resident LDW fish and shellfish by reducing sediment and surface water concentrations of contaminants of concern to protective levels.
- ***RAO 2:*** Reduce human health risks associated with exposure to contaminants of concern through direct contact with sediments and incidental sediment ingestion by reducing sediment concentrations of contaminants of concern to protective levels.
- ***RAO 3:*** Reduce risks to benthic invertebrates by reducing sediment concentrations of contaminants of concern to comply with the Washington State SMS.
- ***RAO 4:*** Reduce risks to crabs, fish, birds, and mammals from exposure to contaminants of concern by reducing sediment and surface water concentrations of contaminants of concern to protective levels.

Removal with upland disposal involves transporting the dredged sediment by barge to a staging area where it would be loaded into rail cars for transport to an off-site regional landfill.

Detailed Evaluation and Comparative Analysis of Remedial Alternatives

The remedial alternatives were evaluated using both CERCLA and MTCA criteria, which are similar (see Table ES-3). CERCLA has nine criteria, (two threshold criteria, five balancing criteria, and two modifying criteria). The two CERCLA threshold criteria, which must be met before the others can be considered, are overall protection of human health and the environment and compliance with applicable or relevant and appropriate requirements (ARARs) of federal and state environmental laws and regulations. The five balancing criteria are:

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

The two modifying criteria are state/tribal and community acceptance. EPA will evaluate state, tribal, and community acceptance of the selected remedial action in the Record of Decision 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.

Because MTCA has similar requirements to CERCLA, the MTCA analysis of alternatives yielded similar results. The MTCA criteria are listed in Table ES-3. Figure ES-6 summarizes the predicted time required to achieve the cleanup objectives for each alternative. Figures ES-7 and ES-10 summarize the comparison of the alternatives according to both CERCLA and MTCA criteria.

Alternative 1 provides the least protection of human health and the environment because it does not include either contingency actions if cleanup objectives are not achieved or adequate institutional controls to manage remaining risks. Therefore, Alternative 1 is not discussed further in the Executive Summary. Alternatives 2 through 6 are predicted to achieve the cleanup objectives, although over different time frames with different technologies and degrees of uncertainty. The major differences among the alternatives are the amount of active remedial actions implemented versus MNR, as described above. The major differences among alternatives with the same RALs are the reliance on dredging for active remediation in the "R" alternatives versus a combination of dredging, capping, and ENR/*in situ* treatment for active remediation in the "C" alternatives.

How the Alternatives Protect People Who Eat Resident Seafood from the LDW

For the protection of people consuming resident seafood (Remedial Action Objective 1), the sediment preliminary remediation goals for PCBs and dioxins/furans are set at natural background, which is not predicted to be achieved in sediments under any alternative. The goal of Alternatives 2 through 6 is to reduce contaminant concentrations as low as practicable given the ongoing inputs from lateral sources and the Green/Duwamish River. They would each make progress toward achieving this goal through a combination of:

- Source control to reduce contaminant inputs to the LDW
- Active cleanup (dredging and capping) to reduce contaminant concentrations in sediment
- Natural recovery of the LDW to further reduce contaminant concentrations in sediment over time, with contingency actions if predicted goals are not achieved
- Monitoring of sediments and seafood to assess the anticipated reduction in contaminant concentrations
- Further reducing exposures through seafood consumption advisories, education, and public outreach programs
- Periodic reviews to assess the effectiveness of the remedy and identify the need for changed approaches

The key points of this comparative analysis are summarized in the following pages.

Table ES-3: CERCLA and MTCA Evaluation Criteria for Detailed Analysis of LDW Remedial Alternatives

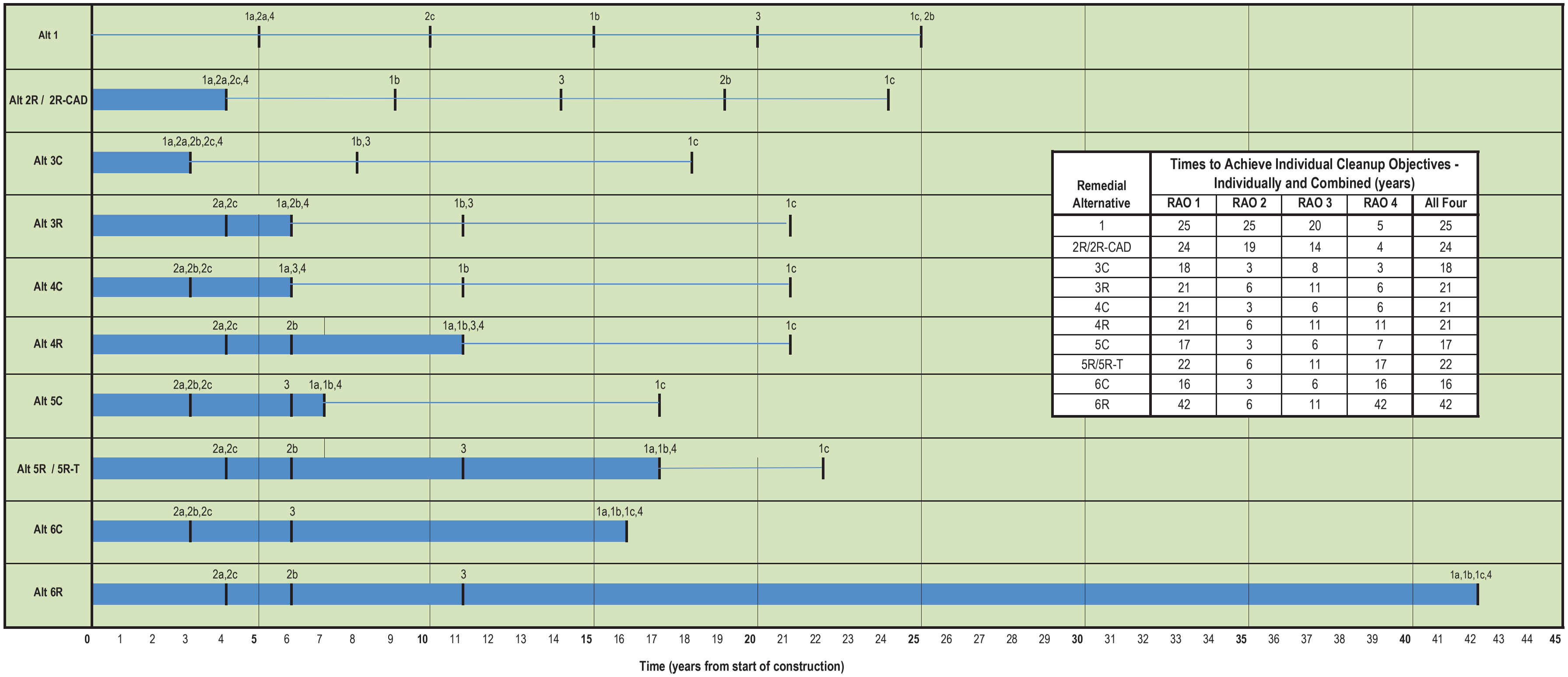
CERCLA		MTCA	
Type	**Criteria**	**Type**	**Criteria**
Threshold	Overall protection of human health and the environment	*Threshold*	Protect human health and the environment
			Comply with cleanup standards
	Compliance with ARARs		Comply with applicable state and federal laws
			Provide for compliance monitoring
Balancing	Long-term effectiveness and permanence	*Other Requirements*	Use permanent solutions to the maximum extent practicable[a]
	Reduction in toxicity, mobility, or volume through treatment		
	Short-term effectiveness		Provide for a reasonable restoration time frame[b]
	Implementability		
	Cost		
Modifying	State/Tribal acceptance		Consider public concerns
	Community acceptance		

Notes:

a. The MTCA requirement to "use permanent solutions to the maximum extent practicable" is evaluated using a disproportionate cost analysis that compares the alternatives against the following criteria:
   1. Protectiveness
   2. Permanence
   3. Cost
   4. Effectiveness over the long term
   5. Management of short term risks
   6. Technical and administrative implementability
   7. Consideration of public concerns.

b. The MTCA requirement to determine whether a cleanup action provides for a reasonable restoration time frame considers the following factors:
   1. Potential risks posed by the site to human health and the environment.
   2. Practicability of achieving a shorter restoration time frame.
   3. Current use of the site, surrounding areas, and associated resources that are, or may be, affected by releases from the site.
   4. Likely effectiveness and reliability of institutional controls.
   5. Potential future use of the site, surrounding areas and associated resources that are, or may be, affected by releases from the site.
   6. Ability to control and monitor migration of hazardous substances from the site.
   7. Toxicity of hazardous substances at the site.
   8. Natural processes that reduce concentrations of hazardous substances and have been documented to occur at the site or under similar site conditions.

Figure ES-6: 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 polycyclic 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 ES-7: Comparative Analysis of Remedial Alternatives

Remedial Alternative	Cost (Net Present Value)	CERCLA Evaluation of Alternatives [a]					
		Achieve Threshold Requirements[b]	Reduction in Toxicity, Mobility or Volume through Treatment [c]	Long-term Effectiveness and Permanence	Short-term Effectiveness	Implementability	Cost [d]
1	$9 MM [e]	No	Low	Low	Low	Relatively high	Very high
2R	$220 MM	Yes	Low	Low-moderate	Low-moderate	Moderate	Relatively high
2R-CAD	$200 MM	Yes	Low	Low	Low-moderate	Low-moderate	Relatively high
3C	$200 MM	Yes	Low-moderate	Moderate	Relatively high	Moderate	Relatively high
3R	$270 MM	Yes	Low	Moderate	Moderate	Moderate	Moderate
4C	$260 MM	Yes	Low-moderate	Relatively high	Relatively high	Relatively high	Moderate
4R	$360 MM	Yes	Low	Relatively high	Moderate	Relatively high	Low-moderate
5C	$290 MM	Yes	Moderate	Relatively high	Relatively high	Relatively high	Moderate
5R	$470 MM	Yes	Low	Very high	Low-moderate	Low-moderate	Low-moderate
5R-Treatment	$510 MM	Yes	Relatively high	Very high	Low-moderate	Low	Low-moderate
6C	$530 MM	Yes	Moderate	Relatively high	Low-moderate	Low-moderate	Low-moderate
6R	$810 MM	Yes	Low	Very high	Low	Low	Low

- Ranks very high compared to other alternatives
- Ranks relatively high compared to other alternatives
- Ranks moderate compared to other alternatives
- Ranks low-moderate compared to other alternatives
- Ranks low compared to other alternatives

Notes:

1. State, tribal, and community acceptance will be evaluated following formal public comment on EPA's Proposed Plan.

a. Ratings based on rankings shown in Table 10-1.

b. Threshold requirements are: 1) Overall Protection of Human Health and the Environment and 2) Comply with or waive ARARs.

c. *Ex situ* treatment (soil washing) is a component of only Alternative 5R-Treatment. *In situ* treatment is a component of the combined-technology alternatives.

d. Low costs are given a high rank and high costs are given a low rank.

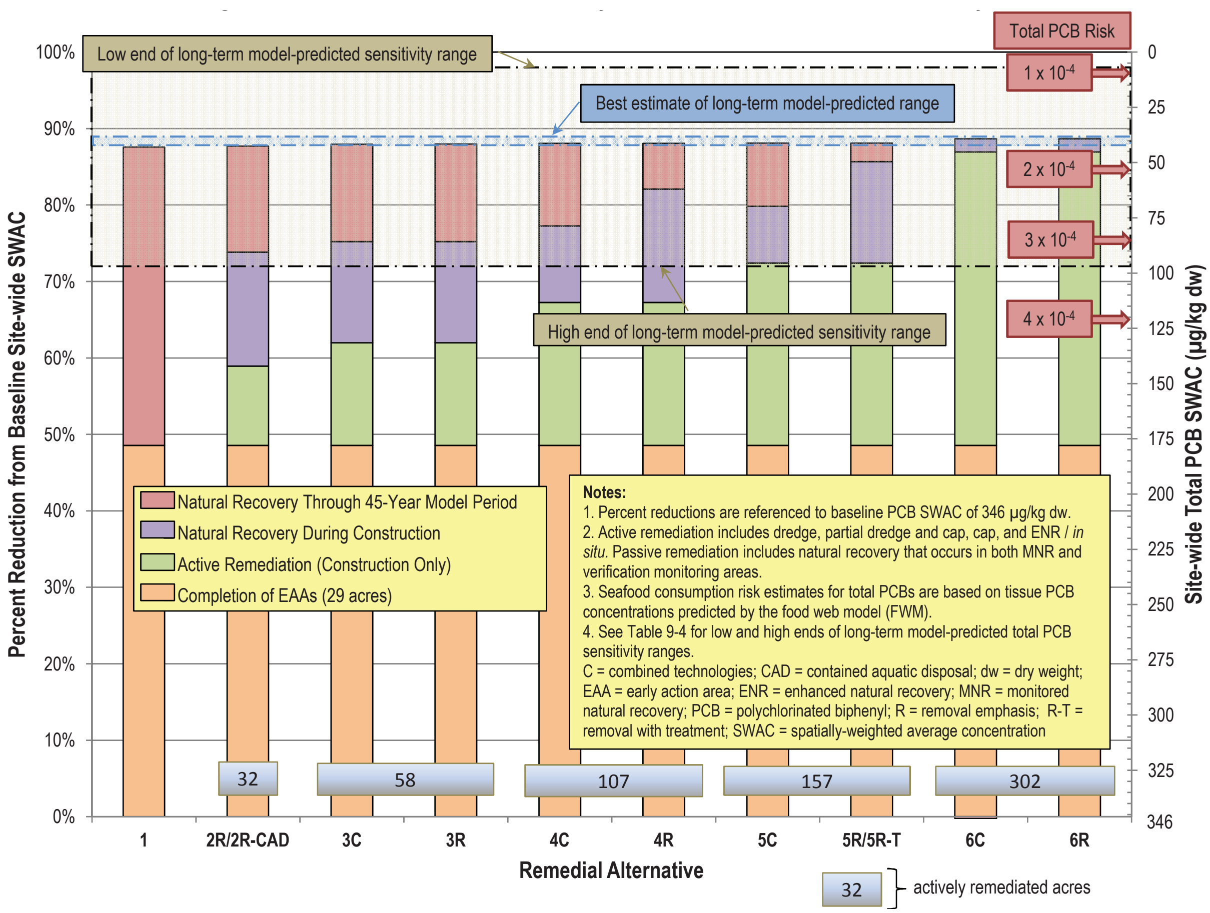
e. Alternative 1 costs ($9 million) are for LDW-wide monitoring, Agency oversight, and reporting. The cost of cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided for informational purposes and are not used in the comparison of alternatives.

ARAR = applicable or relevant and appropriate requirement; C = combined technologies; CAD = contained aquatic disposal; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; EAA = early action area; EPA = U.S. Environmental Protection Agency; FS = feasibility study; LDW = Lower Duwamish Waterway; MM = million; R = removal emphasis

Overall Protection of Human Health and the Environment

- Alternatives 2 through 6 are predicted to reduce risks to human health by achieving similar levels of residual excess cancer risks, in the range of 1 in 10,000 (10^{-4} magnitude risk) or less, depending on the exposure pathway. None of the alternatives reach the MTCA risk threshold of 1×10^{-6} for individual contaminants for the seafood consumption pathway.
- Alternatives 2 through 6 are predicted to reduce risks to people who consume resident LDW seafood containing PCBs to a lifetime excess cancer risk in the range of 1×10^{-4} based on Adult Tribal and Asian and Pacific Islander RME scenarios (RAO 1). Lifetime excess cancer risks for the Child Tribal RME scenario are reduced to the range of 1×10^{-5}. Alternatives 2 through 5 rely to a certain extent on natural recovery to achieve this result (Figure ES-8). All alternatives have residual non-cancer hazard quotients greater than one (predicted to range from 3 to 5 for Adult Tribal and Asian and Pacific Islander RME scenarios and from 9 to 10 for the Child Tribal RME scenario).
- It is highly unlikely that any of the alternatives could achieve the total PCB and dioxin/furan PRGs for the human seafood consumption scenario because these PRGs are set at natural background concentrations. Therefore, the cleanup objective for Alternatives 2 through 6 for total PCBs and dioxins/furans is as close to natural background as technically practicable. The long-term model-predicted concentrations are used in this FS to approximate these values. The sidebar on page ES-24 explains how the alternatives would make progress toward achieving RAO 1.
- Alternatives 2 through 6 are predicted to reduce surface sediment contaminant concentrations to levels that protect people from adverse effects associated with

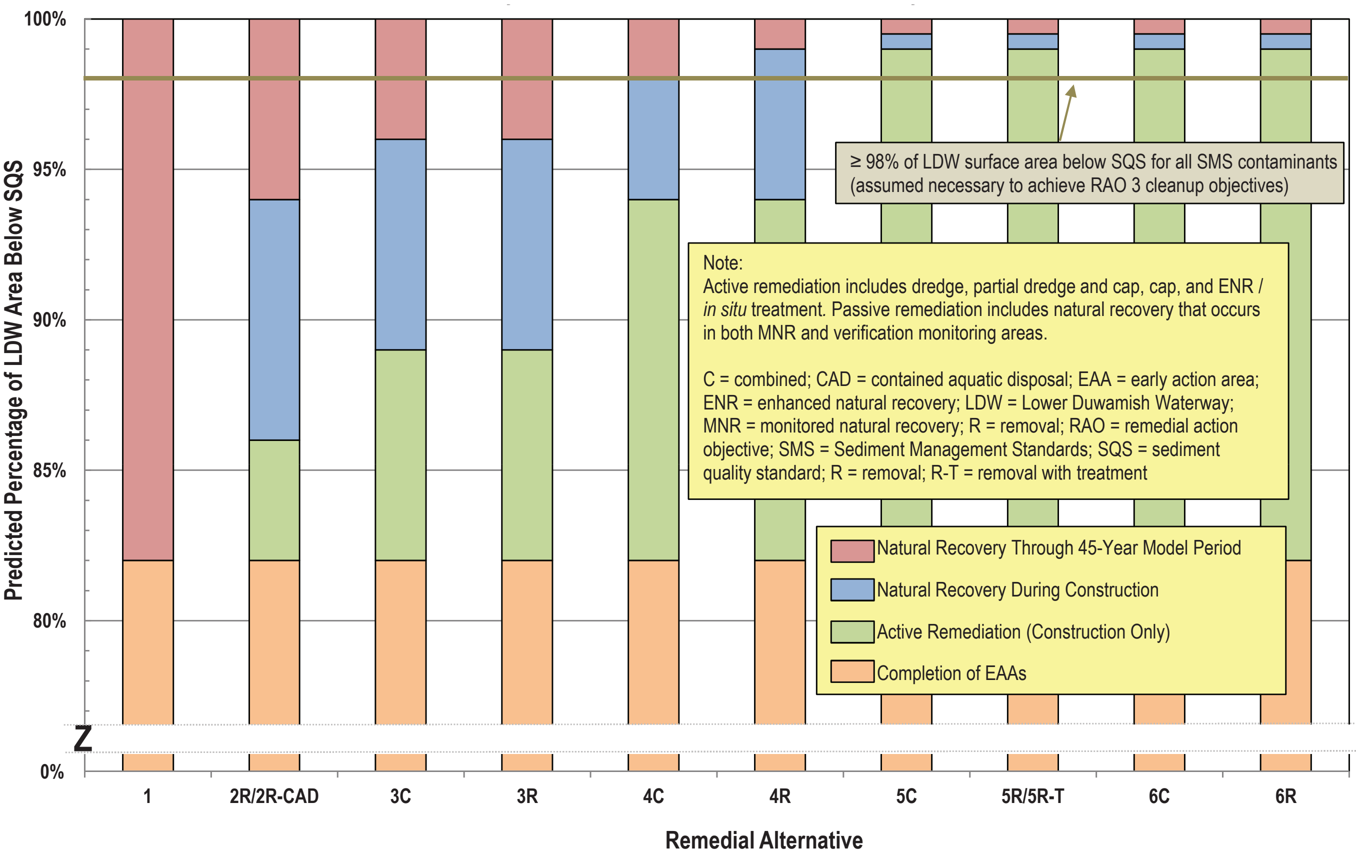
Figure ES-8: Reduction of Total PCB SWAC by Active Remediation and Natural Recovery



direct contact with sediment (RAO 2). In all cases, active remediation alone reduces total excess cancer risks from all four risk drivers for all exposure scenarios to no higher than 1 in 100,000 (1×10^{-5}). Alternatives 2 through 6 are predicted to achieve 1 in 1,000,000 (1×10^{-6}) or less excess cancer risk for direct contact scenarios for total PCBs, dioxins/furans, and cPAHs, except for cPAHs in one beach area (Beach 3) due to recontamination. However, the individual cancer risk posed by arsenic is greater than 1×10^{-6} because the natural background concentration of arsenic yields greater risks. Alternatives 2 through 6 are predicted to result in non-cancer hazard quotients less than one.

- Alternatives 2 through 6 are predicted to achieve the RAO 3 PRGs (the SQS of the SMS) for protection of the benthic community. Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 4R rely to varying degrees on natural recovery to achieve this result (Figure ES-9).
- Alternatives 2 through 6 are predicted to protect wildlife (RAO 4) by actively reducing total PCB concentrations below levels that correspond to a hazard quotient of 1 for wildlife that consume resident seafood. For Alternatives 4, 5, and 6, active remediation alone is sufficient to achieve the predicted concentration reductions; no contributions from natural recovery are required. Alternatives 2 and 3 require small incremental reductions in LDW-wide average total PCB concentrations by natural recovery to protect wildlife.
- Differences in overall protectiveness of Alternatives 2 through 6 can be viewed in the context of short-term and long-term effectiveness. The alternatives with smaller active remedial footprints rely more on natural recovery to achieve the cleanup objectives, while alternatives with larger active remedial footprints rely more on engineering controls such as dredging, capping, and ENR. Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 5C can be implemented more quickly and result in lower impacts to workers, the community, and the environment during construction. However, use of dredging and capping rather than MNR provides

Figure ES-9: Contributions to Achievement of RAO 3 (Benthic Invertebrates) Cleanup Objectives by Active Remediation and Natural Recovery



RAO 3 = Protection of Benthic Invertebrates using Washington State SMS Criteria more certainty in estimated times to achieve cleanup objectives and in contaminant concentrations left after cleanup. Alternatives with smaller active footprints (e.g., Alternatives 2 and 3) leave more subsurface contamination in place that could potentially be exposed.

- Alternatives that rely more on dredging have higher impacts in the short term and maintain high seafood tissue contaminant concentrations over the construction time frames. Construction time frames are longer for dredging than for other active technologies over a similar area. However, dredging also leaves less subsurface contamination in place and therefore has a reduced potential for subsurface contamination to be exposed in the future.

Compliance with ARARs

Because this FS is being conducted under a joint CERCLA and MTCA order, provisions of MTCA, including the SMS, are applicable or relevant and appropriate requirements known as ARARs under CERCLA and governing requirements under MTCA. Excluding Alterative 1, Alternatives 2R and 2R-CAD will take the longest to comply with the SMS. Natural background PRGs for PCBs, dioxins/furans, and arsenic in sediment are ARARs under MTCA because human health risk-based thresholds for seafood consumption (RAO 1: PCBs and dioxins/furans) and direct contact (RAO 2: arsenic) are lower than natural background concentrations. None of the alternatives are expected to comply with these ARARs.

Significant water quality improvements are anticipated from sediment remediation and source control. Water quality is likely to be variable throughout the LDW, depending on the extent of inputs from local sources. The more quickly and thoroughly sources are controlled, the more quickly water quality improvements should occur. None of the alternatives are anticipated to bring the LDW into compliance with all federal or state ambient water quality criteria or standards, particularly those based on people consuming seafood containing bioaccumulative contaminants (e.g., PCBs) that magnify through the food chain, because upstream concentrations exceed those criteria or standards.

CERCLA requires that all ARARs be met or waived at or before completion of remedial actions. By far the most common waiver has 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 actions 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.

Long-term Effectiveness and Permanence

Alternatives 2 through 6 are predicted by modeling to achieve similar residual surface sediment contaminant concentrations and risk levels in the long term, with varying degrees of uncertainty. Active remediation alone (i.e., ignoring any contribution from natural recovery) is responsible for the majority of progress toward achievement of residual risk levels for all alternatives. However, Alternatives 2, 3, and 4 rely more on natural recovery and thus have more uncertainty associated with: 1) the rate and effectiveness of natural recovery and 2) the potential for subsurface contamination to be exposed. This uncertainty is reduced from lower to higher number alternatives and for those that rely more on dredging than on ENR/*in situ* and MNR. Allowing for these uncertainties, surface sediment contaminant concentrations are expected 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 Alternatives 2 though 6.

The remedial alternatives also differ in the amount of contaminated subsurface sediment remaining with concentrations above levels needed to achieve cleanup objectives, which, if exposed or brought to the surface, could pose human health and/or ecological risks. The differences in how much remains stem from alternative-specific variations in the relative areas managed by dredging, capping, ENR, or natural recovery. Alternatives that dredge across a greater surface area leave less contaminated subsurface sediment in place, which, in turn, reduces the risk of potential future exposures (e.g., as a result of vessel scour or earthquakes). More capped surface area translates into lower risk from subsurface sediments than for areas addressed by ENR/*in situ* or MNR because caps are engineered to remain structurally stable under location-specific conditions. Alternative 2R has the highest likelihood of increases in average surface sediment contaminant concentrations over long-term model-predicted values, resulting from disturbances of contaminated subsurface sediments. Alternatives 3R, 3C, and 4C have a lower (or moderate) likelihood that such disturbances would increase average surface sediment contaminant concentrations. The surface sediment contaminant concentrations for Alternatives 4R, 5C, 5R, 6C, and 6R are least likely to be affected by exposure of subsurface contamination.

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 cleanup objectives are achieved. Among these alternatives, post-remediation differences in the level of effort and reliability of these control mechanisms are related primarily to the areal extent of subsurface contamination left in place.
Alternatives 2 through 6 rely on continued use of seafood consumption advisories and may include other public education and outreach programs designed to increase seafood consumers' awareness of risks and to reduce unacceptable exposures. The relative importance of these institutional controls in overall risk communication and reduction is similar across Alternatives 2 through 6.

Outreach and notification to waterway users, review of U.S. Army Corps of Engineers construction permit applications, and, where appropriate, the use of environmental covenants or similar controls to avoid disturbance of subsurface contamination, will be required to varying degrees depending on the remedial alternative. The relative importance of this set of institutional controls is greater for the combined-technology alternatives that emphasize capping, ENR, and natural recovery. Similarly, among the removal alternatives, this set of institutional controls is least important for Alternative 6R (the most removal) and has the greatest importance for Alternatives 2R and 2R-CAD.

Alternatives 2 through 6 progressively rank from low to high for long-term effectiveness and permanence, and the combined-technology alternatives rank lower than the removal-emphasis alternatives. This ranking is based primarily on the increased long-term effectiveness and permanence associated with removing contaminated sediments from the LDW, on decreasing institutional controls, and on the lower uncertainty associated with lesser amounts of contaminated sediment remaining in the subsurface following construction.

Reductions in Mobility, Toxicity, or Volume through Treatment

Removal and disposal, capping, ENR, and MNR are not categorized as treatment technologies under CERCLA. Alternative 5R-Treatment is the only alternative that includes an *ex situ* treatment technology (soil washing). Soil washing could decrease the volume of dredged sediment requiring upland disposal but not the mass of contaminants. Soil washing creates three fractions: 1) separated fine-grained material containing the majority of the contaminants, 2) the separated "clean" sand and gravel material containing low residual contaminant concentrations, and 3) a large amount of wastewater containing low contaminant concentrations. The treated sand fraction would require testing to quantify residual contaminant concentrations and assess its suitability for potential beneficial reuse. Process wastewater requires treatment to reduce concentrations of residual contaminants prior to discharge. Depending on how the material fractions are handled, residual contaminants can pose a different exposure potential to human health and the environment.

Half 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. Sequestering agents could also be incorporated into caps to reduce contaminant bioavailability.

Based on these considerations, the removal-emphasis alternatives rank low, except for Alternative 5R-Treatment, because they don't treat contaminated sediment. Alternative 5R-Treatment ranks the highest because it is the only alternative that removes and treats sediment (via soil washing). The combined-technology alternatives receive intermediate ranks proportional to the relative contribution (area) of *in situ* treatment.

Short-term Effectiveness

Alternatives are evaluated for their ability to protect the community, workers, and the environment during construction. Also, the evaluation of short-term effectiveness considers the time required to achieve cleanup objectives. The short-term impacts for any alternative are directly related to the construction period. The construction period ranges from 3 years (Alternative 2) to 42 years (Alternative 6R).

Alternatives with longer construction times and greater dredge volumes present proportionately larger risks to workers, the community, and the environment, and therefore generally rank lower for these short-term effectiveness factors. Longer construction times increase equipment and vehicle emissions, noise, and other resource uses. Larger actively remediated footprints increase short-term disturbance of the benthic community and other resident aquatic life and release more bio-available contaminants over longer construction periods. Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 5C have relatively short construction times (3 to 7 years) and therefore lower short-term risks. 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 times (17, 16, and 42 years respectively), the most dredging, and thus, particularly Alternative 6R, the greatest short-term impacts. All of the alternatives have extended construction times because of the requirement to conduct construction activities during only a portion of the year (generally from October through February) to avoid impacts to migrating salmon.

Figure ES-6 illustrates the time required for the remedial alternatives to achieve the cleanup objectives. The combined-technology alternatives generally have the shortest construction periods and achieve cleanup objectives 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.

Alternatives 3C, 4C, and 5C are ranked relatively high for short-term effectiveness, because of their short construction periods, lower 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. Alternatives 5R, 5R-Treatment, 6C, and 6R are ranked low because they have the largest impacts on workers, the community, and the environment during construction and relatively long construction time frames. Alternatives 2R and 2R-CAD are also ranked low because they have the second longest time to achieve cleanup objectives and the greatest uncertainty with respect to the predicted times to achieve cleanup objectives.

Implementability

Technical feasibility, administrative feasibility, and availability of services and materials are factors considered under this criterion. The implementability evaluation focuses primarily on the first two factors because, with one exception (5R Treatment), the alternatives use the same types of technologies or use the same types of equipment and methods, all of which are available and for which expertise exists in the Puget Sound region.

Alternatives with shorter construction periods are easier to implement than those with longer construction periods. This reduces the overall level of difficulty both technically and administratively (e.g., coordination with agencies) and the potential for technical problems leading to schedule delays. Alternative 2R is highly implementable. Alternative 2R-CAD has technical and administrative challenges from the standpoint of locating, using, and maintaining one or more CAD facilities. Alternatives 3C, 4C, and 5C have relatively short construction periods and use a combination of technologies, which allows for construction using some technologies to continue when use of others is delayed due to technical problems. In this same context, Alternatives 3R and 4R are less flexible and therefore have greater potential for technical difficulties and delays. Alternatives 5R, 5R-Treatment, 6C, and 6R are the most complex

Photo courtesy King County

Greater sediment removal through dredging means greater permanence, but has higher costs and impacts over a longer period than other technologies. Also, for people and wildlife that eat resident seafood from the LDW, risks will likely remain high throughout the dredging period under any alternative. Seafood consumption advisories can help manage these increased risks to people, but not wildlife.

to implement in that they have the longest construction periods. These alternatives have low action levels. Low action levels can complicate compliance verification during dredge operations despite best efforts at managing resuspension and dredge residuals. Also, Alternative 5R-Treatment has technical and administrative challenges associated with siting and operating a treatment facility, and finding an acceptable use for treated sediment.

After construction, additional implementability considerations come into play and must be balanced against those discussed above. Alternatives that rely more on MNR to achieve cleanup objectives have an increased potential for requiring actions in the future (e.g., more dredging). This results in an increased technical and administrative burden of evaluating monitoring data over time, considering the need for and implementation of contingency actions. In this context, alternatives that rely to a greater extent on active construction to achieve cleanup objectives are more favorable.

In combination, these considerations result in lower implementability rankings for Alternatives 2R, 2R-CAD, 5R, 6C, and 6R. Alternatives 3C, 3R, and 5C receive moderate implementability rankings. Alternatives 3C and 3R are in the low to mid-range for complexity and Alternative 5C does not rely to a great extent on natural recovery, and therefore has a lower potential for requiring contingency actions. Alternatives 4C and 4R receive the highest rankings because they represent the best balance of the implementability factors.

Cost

Alternative 6R has the highest cost ($810 million) and therefore ranks lowest for this criterion. Alternatives 4R, 5R, and 6C are ranked next; costs for these alternatives range from $360 to $530 million. Alternatives 3R, 4C, and 5C ranked higher, with costs ranging from $260 to $290 million. Alternatives 2R, 2R-CAD, and 3C have the lowest costs ($220 to $200 million, respectively) and are ranked highest.[2] All of these costs are net present values calculated using a discount rate of 2.3%.

Courtesy of Port of Seattle

[2] Alternative 1 includes LDW-wide monitoring, agency oversight, and reporting for a cost of $9 million. The estimated cost of completing the in-water design and cleanup actions for the five EAAs is $95 million, not including costs associated with upland cleanup and source control (not estimated). The EAA costs are not included in the cost estimates for the alternatives, are not used in the comparison of alternatives, and are provided for information only.

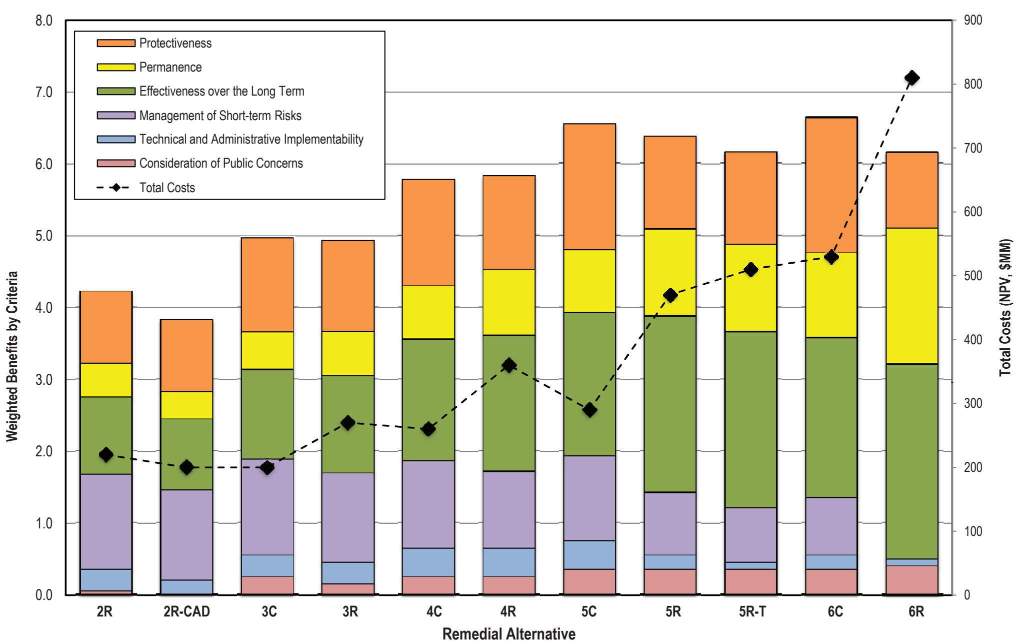
Summary of MTCA Disproportionate Cost Analysis

MTCA provides a method of summarizing the net benefits of alternatives across the multiple criteria discussed above. Figure ES-10 on page 34 summarizes the total benefits and costs of the alternatives using the MTCA criteria.

The MTCA disproportionate cost analysis (DCA) is used to screen out alternatives with disproportionately higher costs. The analysis uses six remedy evaluation criteria, which are similar to, but not exactly the same as the CERCLA comparative analysis criteria. Under MTCA, the evaluation criteria are protectiveness, permanence, cost, effectiveness over the long term, management of short-term risks, technical and administrative implementability, and consideration of public concerns. Like the CERCLA comparative analysis, the DCA compares remedial alternatives using summary data for each alternative, such as the predicted risks resulting from contamination following remediation (e.g., carcinogenic risk from resident seafood consumption), the amount of time to achieve cleanup objectives, the volume of contaminated sediment removed, construction time frame, and others. However, specific differences in the factors are considered under each evaluation criterion, which can result in different results among the alternatives between the CERCLA and MTCA analyses. Unlike the CERCLA comparative analysis, these metrics have been converted into numerical scores, which are combined for a total benefit score. Finally, these scores are compared with the cost of each alternative as a means of comparing the benefit of each alternative relative to its cost. Alternative 1, No Further Action, is included in the CERCLA comparative analysis, but is not included in the DCA because it does not satisfy MTCA threshold requirements.

MTCA requirements do not prescribe standard metrics and methods for conducting a DCA; therefore, best professional judgment and precedent from other sites were used to construct the DCA for the LDW. In comparing benefit scores to costs, Figure ES-10 shows that Alternatives 5C, 5R, and 6C have the highest weighted benefits scores among the alternatives. Alternatives 4C, 4R, 5R-Treatment, and 6R have lower weighted benefit scores, and Alternatives 2R and 2R-CAD (contained aquatic disposal) have the lowest scores. The analysis indicates that the additional costs incurred for alternatives beyond Alternative 5C do not add any appreciably greater benefits. Final determinations about disproportionate costs will be made by Ecology in consultation with EPA.

Figure ES-10: MTCA DCA Weighted Benefits by Criteria and Associated Costs for the Remedial Alternatives



Notes:

1. See Table 11-6 for details on weighted benefits for individual evaluation criteria.
2. Total weighted benefit represents rounded values and weighted benefits by criteria represent unrounded values.

C = combined-technology alternative; CAD = contained aquatic disposal; DCA = disproportionate cost analysis; MM = million; MTCA = Model Toxcis Control Act; NPV = net present value; R = removal-emphasis alternative; R-T = removal with treatment

Uncertainties

Decision-making on a site of the size and complexity of the LDW means accommodating areas of uncertainty. Uncertainties associated with predicting risks to people and the environment and the impact of reducing sediment contaminant concentrations on resident fish and shellfish tissue concentrations are described in both the RI (Windward 2010) and the FS. In the FS, uncertainty associated with residual risks from the exposure of surface sediment is largely influenced by the quality of incoming sediment from the Green/Duwamish River, the amount of contaminant inputs from lateral sources, and the potential for future vessel scour, construction, or natural disturbances to expose subsurface contamination left in place following remediation.

The following factors emerge as particularly important for managing uncertainty relative to the time predicted for achieving cleanup objectives and the anticipated performance of the alternatives:

- As a result of the large amounts of relatively clean sediments from upstream that deposit within the LDW, surface sediment contaminant concentrations are predicted to converge to levels similar to the quality of incoming sediment from the Green/Duwamish River and other inputs, resulting in similar levels of risk over time among the alternatives. The concentrations of these inputs are uncertain and will change over time in response to many factors, including source control.
- Predictions of average surface sediment contaminant concentrations do not account for the potential for deep disturbances of subsurface contaminated sediments by mechanisms such as vessel scour and earthquakes. Contaminant concentrations could be higher than model predictions, especially if disturbances are widespread and persistent. Lower numbered alternatives such as Alternative 2 have the most uncertainty. The predicted contaminant concentrations for alternatives that leave less subsurface contamination (the higher numbered alternatives) are less sensitive to any increase associated with disturbances. The persistence of any such increase in surface sediment contaminant concentrations should be mitigated to some extent by monitoring and repairs consistent with the monitoring and operation and maintenance programs.
- The performance of each remedial technology has some uncertainty associated with it. Dredging can disturb sediments, which are transported in the waterway by currents. These disturbed sediments elevate fish and shellfish tissue contaminant concentrations over the short term. Capping and ENR/*in situ* may need periodic repairs and continued maintenance. MNR performance may be slower (or faster) or simply different than predicted and may require additional monitoring or contingency actions based on monitoring results. Mitigation of these potential uncertainties was incorporated into the remedial alternatives in the form of contingency actions, repairs, or additional monitoring.
- Uncertainty exists in the predictions of resident seafood tissue contaminant concentrations and associated human health risks (from the total PCB average surface sediment concentration estimates). This uncertainty is driven by: 1) exposure assumptions from the human health risk assessment and 2) assumptions used in the food web model such as uptake factors and future water concentrations. The predictions of resident seafood tissue contaminant concentrations and risks are nevertheless useful for comparing the alternatives to one another because the uncertainties are the same for all alternatives, and therefore all of the alternatives should be affected similarly.


Photo courtesy City of Seattle

Conclusions

Many factors need to be considered in selecting a cleanup remedy for the LDW. EPA, in coordination with Ecology, will select the cleanup plan in the Record of Decision for the LDW based on input received from public review of the Proposed Plan in 2013. To aid the public in understanding this FS, Table ES-4 highlights some of the key differences and similarities among the alternatives in the CERCLA and MTCA comparative analysis. These similarities and differences are summarized below along with key conclusions.

CERCLA and MTCA Compliance: Alternatives 2 through 6 are predicted to achieve cleanup objectives and meet CERCLA and MTCA threshold criteria, although long-term compliance with certain ARARs will need to be evaluated based on future monitoring.

Predicted Residual Risks for Seafood Consumption: Alternatives 2 through 6 are predicted to have similar risks for people eating resident seafood containing PCBs (RAO 1), both immediately after construction and over time, although the time to reduce sediment contaminant concentrations to the lowest extent practicable is predicted to range from 16 to 42 years. Total excess cancer risks from seafood consumption from all contaminants cannot be reliably predicted, but are expected to be similar among alternatives based on similar residual sediment contaminant concentrations. Elevated contaminant concentrations in fish and shellfish tissue will persist under all alternatives and necessitate continuation of seafood consumption advisories in the LDW. However, it is possible that the seafood consumption advisories could be modified over time.

Other Risks: Alternatives 2 though 6 achieve similar levels of risk reduction for direct contact, benthic protection, and protection of wildlife (RAOs 2, 3, and 4 respectively). These alternatives are predicted to be protective of people who come into contact with sediments and protective of the organisms that live in and use the LDW.

Predicted Reduction in Surface Sediment Contaminant Concentrations: All alternatives are predicted to achieve similar reductions in the surface sediment concentrations of PCBs and other risk drivers over varying time frames and with varying degrees of certainty. The alternatives differ in how PCB reductions are achieved. Figures ES-8 and ES-10 show that the alternatives rely on active remediation and natural recovery to differing degrees. Figure ES-11 illustrates the expected time frames for reducing LDW-wide average total PCB concentrations during and after construction of the remedial alternatives. This figure also illustrates the long-term model-predicted sediment PCB concentrations and the uncertainty around the model input parameters.

Subsurface Contamination Remaining In Place: Alternatives that emphasize dredging leave less contaminated subsurface sediment in place after construction is complete. Therefore, disturbance mechanisms (e.g., vessel scour and earthquake-induced displacements) have less potential to expose subsurface contamination in the future, and thus alternatives that emphasize dredging provide greater long-term effectiveness and permanence.

Monitoring Requirements: Alternatives 2 through 6 each require long-term monitoring to be protective. The alternatives differ in the total area that requires maintenance and certain types of monitoring, as illustrated in Table ES-4.

Using MNR and ENR/*in situ* Performance: Alternatives 2R, 2R-CAD, 3C, and 3R include 125 and 99 acres of MNR, respectively. Alternatives 4C and 4R include 50 acres of MNR. The largest ENR/*in situ* areas are in Alternatives 5C and 6C (see Figure ES-5). Alternatives that use more MNR have more uncertainty in the time to reduce contaminant concentrations. The cost estimates for alternatives include contingency actions for both ENR/*in situ* and MNR areas if contaminant reduction does not occur at an acceptable pace, as part of an adaptive management strategy.

Short-term Impacts throughout Construction: The alternatives have significantly different short-term impacts such as disturbances to habitat, elevated contaminant concentrations in resident fish and shellfish tissue, traffic and air emissions related to off-site transport of dredged material, and consumption of landfill space. The impacts are largely a function of the extent and duration of dredging and disposal activities. Alternatives

Table ES-4: Summary of Similarities and Differences among Remedial Alternatives

Evaluation Criteria		Representative Measures of Difference	Remedial Alternative: 1	2R	2R CAD	3C	3R	4C	4R	5C	5R	5R-T	6C	6R
Overall Protection of Human Health and the Environment / Compliance with ARARs	Risk Reduction	Residual Risk from Total PCBs: Excess Cancer Risk for Adult Tribal RME Seafood Consumption[a]	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}	2×10^{-4}	2×10^{-4}	2×10^{-4}
		Non-cancer Hazard Quotients for Adult and Child Tribal RME Seafood Consumption[a]	5/10	5/10	5/10	4/10	4/10	4/9	4/9	4/9	4/9	4/9	4/9	4/9
		Direct Contact: Total Excess Cancer Risk[b]	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 0^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$	$\leq 1 \times 10^{-5}$
		Benthic Protection: Percent of Stations with SQS Exceedances Remediated[c]	95%	98%	98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%	>98%
		Ecological Protection: HQ for Consumption of Seafood (Without Juvenile Fish) by River Otter (immediately following construction)	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
		% PCB SWAC Reduction from Baseline Attributable Only to Construction (Active Remediation)[d]	49	59	59	62	62	67	67	72	72	72	87	87
		% PCB SWAC Reduction Attributable to Natural Recovery when the modeled long-term concentrations are achieved (from baseline)	See note e	29	29	26	26	21	21	15	15	15	2	2
	Meets Threshold Requirements		No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Long-Term Effectiveness and Permanence		Total Dredge Volume (cy)[f]	Not estimated	580,000	580,000	490,000	760,000	690,000	1,200,000	750,000	1,600,000	1,600,000	1,600,000	3,900,000
		Monitoring (area in acres remediated by MNR)	0	125	125	99	99	50	50	0	0	0	0	0
		Monitoring and Notification of Waterway Users (based on total cap, ENR, and MNR area; acres)	No institutional controls	128	128 + 23 acres of CAD	128	107	107	64	100	14	14	114 in AOPC 1[g] and 80 outside of AOPC 1	16 in AOPC 1[g] and 12 outside of AOPC 1
Short-Term Effectiveness	Effects Due to Construction	Ecological – Area Above -10 ft MLLW Disturbed (acres)	n/a	13	13	23	28	33	42	37	59	59	67	99
		Greenhouse Gas Emissions (CO_2; metric tons)	Not calculated	20,000	17,000	19,000	27,000	27,000	42,000	30,000	59,000	51,000	64,000	139,000
		Truck and Train Transportation (miles)[h]	Not calculated	480,000	227,000	404,000	620,000	560,000	940,000	610,000	1,380,000	1,010,000	1,380,000	3,170,000
	Time Frames	Construction Period (years)[i]	0	4	4	3	6	6	11	7	17	17	16	42
		Time to Achieve Cleanup Objectives for all RAOs (years)[j]	25	24	24	18	21	21	21	17	22	22	16	42
Costs		Total Costs (net present value, MM$)[k]	9[l]	220	200	200	270	260	360	290	470	510	530	810

Notes:

a. Risk estimates are based on the tissue PCB concentrations estimated from the food web model using the long-term PCB concentration range in surface sediment predicted by the bed composition model. A substantial portion of the baseline risks associated with consumption of resident seafood in the LDW is attributable to total PCBs. Therefore, it is reasonable to assume the total excess cancer risks (all carcinogens combined) are expected to be similar to total PCBs (see section 9.3.3.1). See Tables 9-7a and 9-7b for all RME risk seafood consumption scenarios. See Appendix M for non-RME risk seafood consumption scenarios.

b. All alternatives achieve 1×10^{-6} excess cancer risk for direct contact scenarios for total PCBs, dioxins/furans, and cPAHs, except for cPAHs in one beach area (Beach 3) due to recontamination. For arsenic, all the direct contact scenarios are predicted to achieve excess cancer risk range between 1×10^{-5} and 1×10^{-6} because background exceeds the 1×10^{-6} risk level. Non-cancer hazard quotients are less than or equal to 1 in netfishing, clamming, and beach areas.

c. SQS station exceedances remediated as a percent of total stations in FS dataset (n=1,395) 10 years following end of construction.

d. PCB SWAC reduction attributable to construction of EAAs is included (48%).

e. While natural recovery processes would occur, no monitoring or evaluation of these processes is included in Alternative 1.

f. Estimated total dredge volume for EAAs is not available. The total dredge volume is the preliminary dredge volume plus additional volume for technology assignment and performance-based contingency assumptions (e.g., 15% of MNR areas are assumed to require dredging based on long-term monitoring results).

g. The total number of acres includes 19 acres of verification monitoring in AOPC 1 that are actively remediated in Alternative 6.

h. Transportation (truck and train miles) is a surrogate for total volume managed. It is one particular metric that affects the community. 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 (round trip) 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.

i. Construction period is the estimated period for completing in water construction activities (it is rounded to the nearest year). Fish and shellfish tissue contaminant concentrations are expected to remain elevated during construction and up to 2 years after construction as a result of resuspension and release of total PCBs into the water column.

j. No remedial alternative is expected to achieve the RAO 1 PRGs. All alternatives achieve protectiveness with some combination of active and passive remediation and ICs. See Figure ES-6 for times to achieve cleanup objectives for specific RAOs.

k. See footnote (f) for removal volume assumptions used in cost estimates.

l. Alternative 1 costs ($9 million) are for LDW-wide monitoring, agency oversight, and reporting. The cost for completing of the cleanup actions in the EAAs is estimated at approximately $95 million. The EAA cleanup action costs are provided 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; ARAR = applicable or relevant and appropriate requirement; BCM = bed composition model; C = combined alternative; CAD = contained aquatic disposal; CO_2 = carbon dioxide; cPAH = carcinogenic polycyclic aromatic hydrocarbons; cy = cubic yards; dw = dry weight; EAA = early action area; ENR = enhanced natural recovery; FS = feasibility study; HQ = hazard quotient; IC = institutional control; kg = kilograms; µg = micrograms; mg = milligrams; MLLW = mean lower low water; MM = million; n = number of surface locations; n/a = not applicable; MNR = monitored natural recovery; ng = nanograms; PCB = polychlorinated biphenyl; R = removal alternative; RAO = remedial action objective; RME = reasonable maximum exposure; R-T = removal alternative with treatment; SQS = sediment quality standard; SWAC = spatially-weighted average concentration; TEQ = toxic equivalent; yr = year.

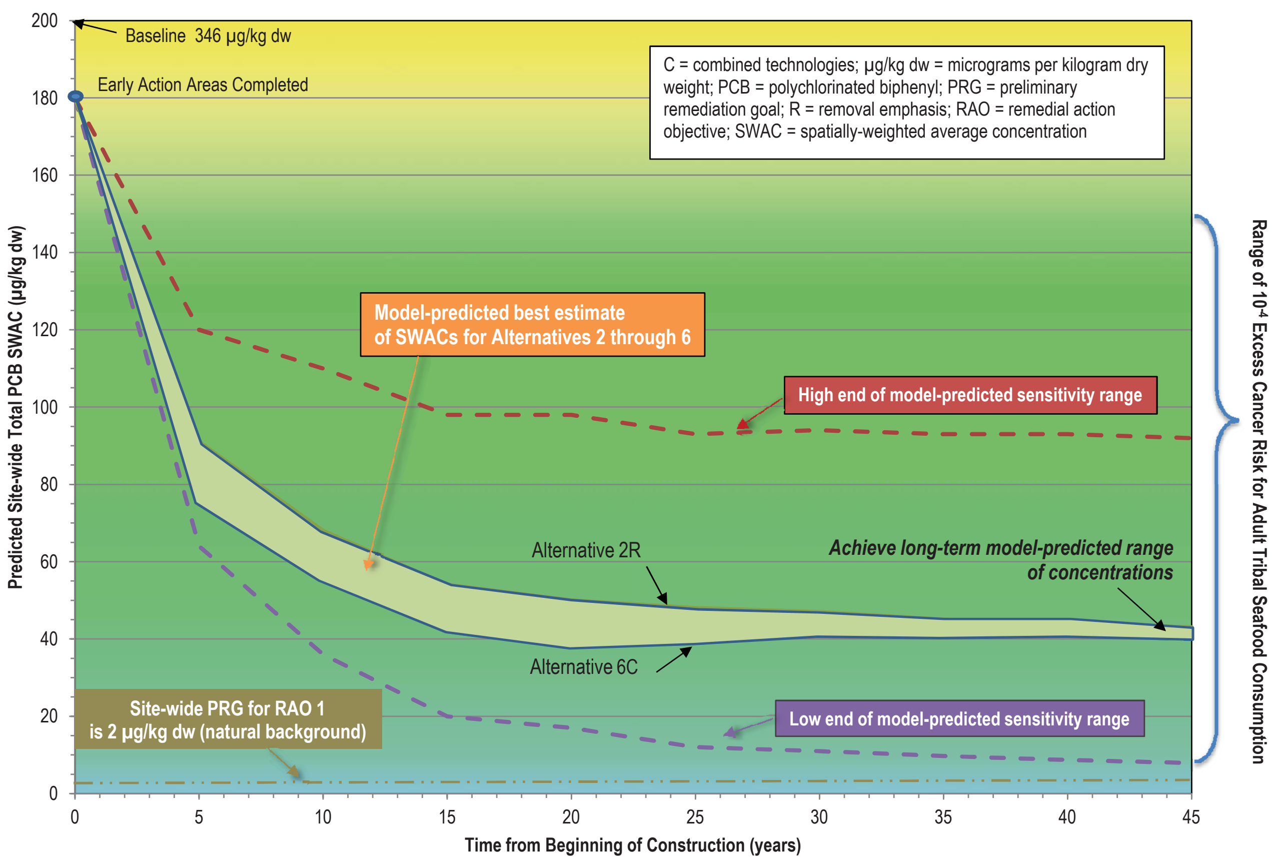
with greater removal volumes have longer construction periods and greater short-term impacts.

Construction Time Frames: Alternatives 2R, 2R-CAD, 3C, 3R, 4C, and 5C have estimated construction time frames of 3 to 7 years, whereas 4R, 5R, 5R-Treatment, and 6C have construction time frames ranging from 11 to 17 years. Alternative 6R has the longest construction time frame (42 years).

Predicted Time to Achieve Cleanup Objectives: The predicted time to achieve cleanup objectives is influenced by: 1) how long it takes to construct an alternative, 2) what is achieved by construction alone, 3) the rate of natural recovery, and 4) the success of source control measures. Greater reliance on natural recovery has a minor effect on the long-term surface sediment contaminant concentrations but increases the uncertainty of how long it will take. The alternatives differ in their predicted time to achieve the cleanup objectives as shown in Table ES-2. Alternatives 3C, 4C, 5C, and 6C are predicted to achieve all cleanup objectives in the shortest time frames (between 16 and 21 years). Alternative 6R has the longest predicted time frame to achieve the cleanup objectives (42 years), by virtue of its long construction period. The other alternatives all have intermediate time frames of 21 to 24 years. Further incremental reductions in risk-driver concentrations are expected to occur over time as a result of source control and natural recovery processes. There is uncertainty in time frames associated with both natural recovery predictions and construction.

Costs: Alternatives 2 through 6 vary significantly in costs, with a range of $200 million to $810 million (net present value). For a given set of RALs, the combined-technology alternatives are less expensive than the removal-emphasis alternatives. Noticeable differences are also present among the alternatives in the MTCA benefit-to-cost relationship. Alternatives 2R, 2R CAD, 3C, 3R, 4C, and 5C have significantly lower costs per benefit achieved than the other alternatives.

Figure ES-11: Predicted Site-wide Total PCB SWACs Versus Time for Alternatives 2 through 6



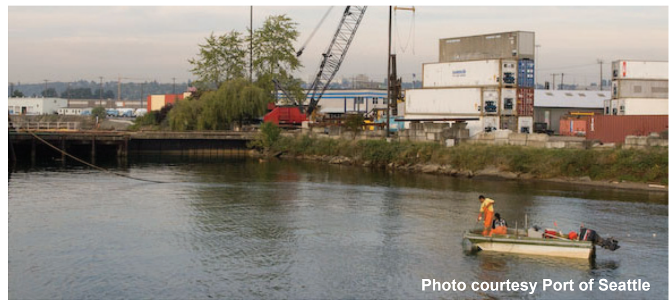
Next Steps

EPA, Ecology, and LDWG solicited input from the public, including a broad range of stakeholders, and incorporated this input into this Final FS. EPA will issue a Proposed Plan that identifies a preferred remedial alternative for the LDW. Formal public comment will be received on the Proposed Plan. After public comments on the Proposed Plan are received and evaluated, EPA will select the final remedial alternative, after seeking concurrence with Ecology.

This FS has assumed that a period of 5 years would be required following the Record of Decision and before the start of remedial construction. During this period, the following activities would occur:

- Completion of the EAA cleanups.
- Completion of source control sufficient to begin remedial actions. It is anticipated that source control will be implemented in parallel with the sequencing of remedial actions.
- Negotiation and entry of consent decrees or issuance of unilateral administrative orders for remedial design and construction.
- Sampling to refine cleanup areas and complete remedial design.
- Site-wide sampling (for example, of sediments, surface water, and fish and shellfish tissue) to establish baseline conditions with which future post-remediation monitoring results will be compared.
- Implementation of institutional controls addressing seafood consumption risks under RAO 1.


Photo courtesy Windward Environmental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