Lower Duwamish Waterway Group

Port of Seattle / City of Seattle / King County / The Boeing Company

PHASE 1 REMEDIAL INVESTIGATION REPORT
FINAL

For submittal to:

The U.S. Environmental Protection Agency
Region 10
Seattle, WA

The Washington State Department of Ecology
Northwest Regional Office
Bellevue, WA

July 3, 2003

Prepared by: Windward environmental LLC

200 West Mercer Street, Suite 401 ♦ Seattle, Washington ♦ 98119

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[2] **Note: Oversize GIS maps are published in a separate volume with oversize tables.**

List of Acronyms

Acronym	definition
ac	acre
ACOE	US Army Corps of Engineers
AET	apparent effects threshold
AOC	Administrative Order on Consent
API	Asian and Pacific islanders
ARAR	applicable or relevant and appropriate requirement
ATSDR	Agency for Toxic Substance and Disease Registry
AVS	acid-volatile sulfides
BEHP	bis(2-ethylhexyl)phthalate
BMF	biomagnification factor
bw	body weight
CDI	chronic daily intake
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
COC	chemical of concern
COPC	chemical of potential concern
cPAH	carcinogenic polycyclic aromatic hydrocarbon
CSC	confirmed and suspected contaminated (site)
CSL	cleanup screening level (Washington State Sediment Management Standards)
CSO	combined sewer overflow
CT	central tendency
CWA	Clean Water Act
DG	data gaps (memorandum)
DMMP	Dredged Material Management Program
DNAPL	dense non-aqueous phase liquid
DQO	data quality objective
dw	dry weight

Acronym	definition
EPA	U.S. Environmental Protection Agency
EPC	exposure point concentration
ERA	ecological risk assessment
ESA	Endangered Species Act
GIS	geographic information system
ha	hectare
HHRA	human health risk assessment
HPLC/PDA	high pressure liquid chromatography / photodetector array
HPAH	high-molecular-weight polycyclic aromatic hydrocarbon
HQ	hazard quotient
IDW	investigation-derived waste
LDW	Lower Duwamish Waterway
LOAEL	lowest-observed-apparent-effects level
LOEC	lowest-observed-effects concentration
LPAH	low-molecular-weight polycyclic aromatic hydrocarbon
LUST	leaking underground storage tank
MeHg	methylmercury
MHHW	mean higher high water
mi	mile
ML	maximum level (Dredged Material Management Program)
MLLW	mean lower low water
MTCA	Model Toxic Control Act
NAPL	non-aqueous phase liquid
NCP	US Environmental Protection Agency's National Contingency Plan
NOAEL	no-observed-apparent-effects level
NOEC	no-observed-effects concentration
NPDES	National Pollution Discharge Elimination System
OC	organic carbon
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl
PCT	polychlorinated terphenyl
Phase 1	scoping phase, conducted using existing information sources
Phase 2	baseline phase, based on and following Phase 1
PPF	predator-prey factor
ppt	parts per thousand
POTW	publicly owned treatment works
PSAMP	Puget Sound Ambient Monitoring Program
PSCAA	Puget Sound Clean Air Agency
PSDDA	Puget Sound Dredged Disposal Analysis
QA/QC	quality assurance / quality control
RA	risk assessment
RBC	risk-based concentration
RCRA	Resource Conservation and Recovery Act

Acronym	definition
RCW	Revised Code of Washington
RfD	reference dose
RI	Remedial Investigation
RI/FS	Remedial Investigation / Feasibility Study
RME	reasonable maximum exposure
ROC	receptor of concern
ROD	record of decision
RPF	relative potency factor
SD	storm drain
SEM	simultaneously extracted metals
SF	slope factor
SL	screening level (Dredged Material Management Program)
SMS	Washington State Sediment Management Standards
SOW	statement of work
SPU	Seattle Public Utilities
SQS	sediment quality standards (Washington State Sediment Management Standards)
SRG	sediment remediation goal
STP	sewage treatment plant
SUF	site usage factor
SVOC	semivolatile organic compound
SWA	spatially weighted average
SWPPP	Stormwater Pollution Prevention Plan
TBC	[item] to be considered
TBT	tributyltin
TCDD	2,3,7,8-tetrachlorodibenzo-*p*-dioxin
TCLP	toxic characteristic leaching procedure
TEF	toxic equivalent factor
TEQ	toxic equivalent quotient
TPH	total petroleum hydrocarbons
TRI	Toxic Releases Inventory
TRV	toxicity reference value
TSPM	total suspended particulate matter
UCL	upper confidence limit
USC	United States Code
USCA	United States Code Annotated
USGS	U.S. Geological Survey
UST	underground storage tank
VOC	volatile organic compound
WAC	Washington Administrative Code
WARM	Washington Ranking Method
WDFW	Washington Department of Fish and Wildlife
WQA	Water Quality Assessment
ww	wet weight

Executive Summary

This Remedial Investigation (RI) is the first phase of a two-phase approach being used for the investigation of sediment in the Lower Duwamish Waterway (LDW) site in Puget Sound, Washington. The LDW study area extends from the southern tip of Harbor Island to just south of Turning Basin 3 (Map 1-1). A Remedial Investigation identifies areas that may need to be remediated because they pose an unacceptable risk to human health or the environment. This Phase 1 (scoping phase) document presents an assessment of what is already known from previous studies of environmental conditions in the LDW, aimed at answering three questions:

1. Based on existing data, what are the risks to human health and the environment associated with sediment-associated chemicals in the LDW?
2. Are there areas within the LDW that might be candidates for early remedial action?
3. What additional information is needed to understand the nature and extent of chemical distributions in the LDW and characterize risks to human health and the environment sufficiently to make final remedial decisions in the LDW?

This Phase 1 RI provides an understanding of the nature and extent of chemical distributions in the sediments of the LDW and presents preliminary risk estimates resulting from those distributions. Other Phase 1 documents[3] address the second and third questions by using the information generated in the RI (see Figure ES-1). These products will shortly follow the RI, allowing for early remediation to begin as additional information is collected for the second phase. The Phase 2 RI, which will start in 2003, will include collection of additional data to fill the data gaps identified in Phase 1. The Phase 1 risk assessments will be revised in Phase 2 to include the new data. The Phase 2 baseline risk assessments will assess risks to human health and the environment prior to early actions, and will also estimate risks that remain after completion of early remedial actions.

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[3] *Technical Memorandum on Selection of Candidate Early Action Sites* and *Technical Memorandum Identifying Data Needs.*

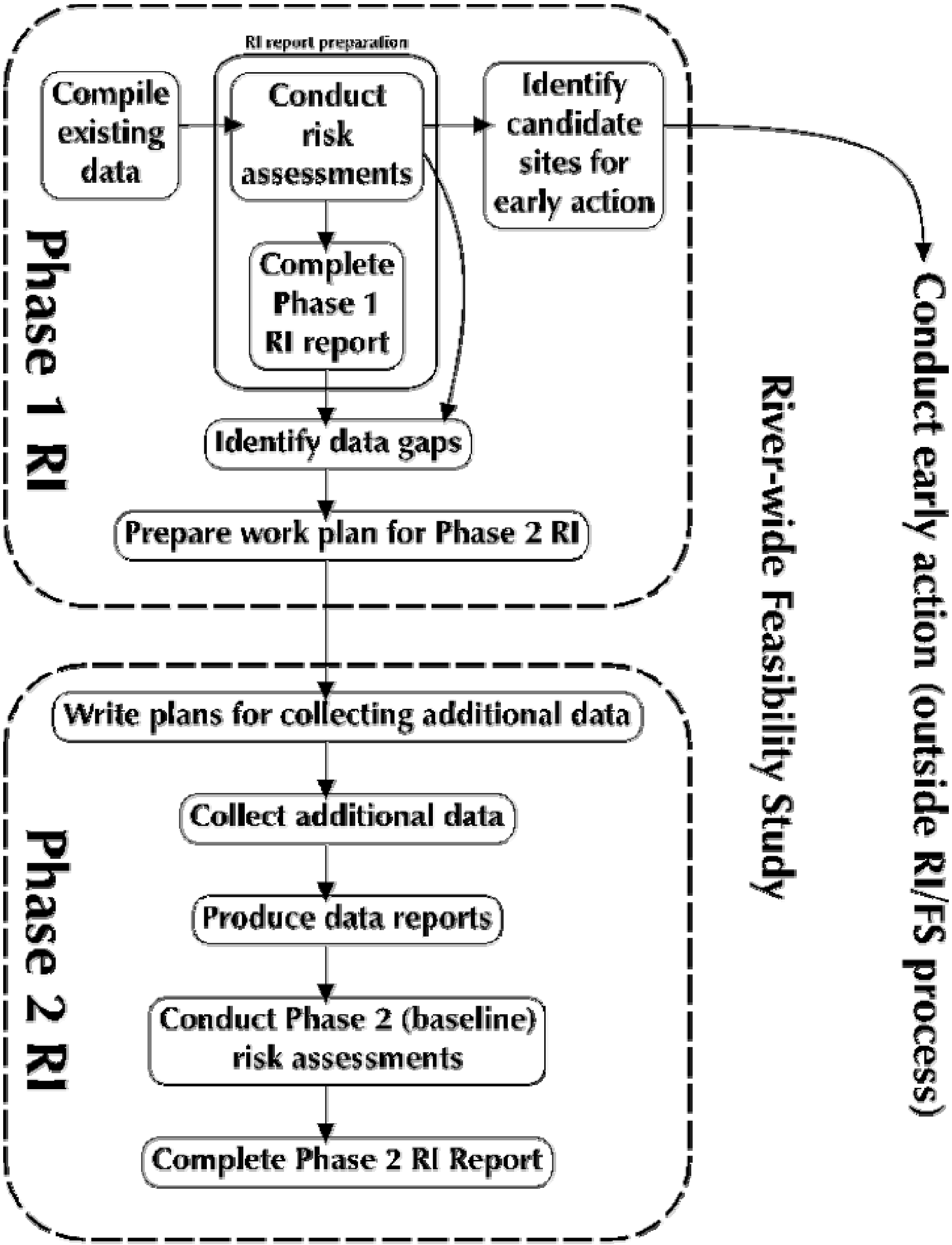

Figure ES-1. Overview of RI process

The Phase 1 RI report is divided into the following topics, summarized briefly below:

- The environmental setting of the LDW
- Previous environmental investigations in this area
- Rules and regulations that apply to the site

- The nature and extent of chemicals of concern in environmental media and in animals that inhabit the site, including the extent of available information about possible sources of those chemicals, as well as the processes that affect their fate and transport within the LDW
- Summaries of the Phase 1 ecological and human health risk assessments
- Conclusions

ES-1 NATURE AND EXTENT OF CHEMICAL CONTAMINATION

The presence of chemical contamination in the LDW has been recognized for many years, prompting numerous environmental studies. To keep the focus on current conditions, this RI considered only investigations conducted since 1990. The primary focus of investigations of the LDW has been on sediments, although fish and shellfish samples have also been collected for assessing risks to the environment and human health. Approximately 1,200 surface sediment samples (up to 15 cm [6 in.] deep), 230 subsurface sediment samples, and 200 fish and shellfish tissue samples have been collected and analyzed for metals and organic compounds. In total, these data were used to address the goals of the Phase 1 investigation, as outlined above.

One of the more significant findings based on existing sediment data is that the distributions of chemicals in sediment are not uniform throughout the LDW, but rather higher chemical concentrations are generally found in discrete locations separated by sections of the river in which chemical concentrations are lower. The distribution patterns for chemicals in sediment indicate that candidate sites for early remedial action can be identified with a relative level of certainty. In addition, the available environmental data are used to conduct the Phase 1 human health and ecological risk assessments and calculate preliminary risk estimates.

Although the Phase 1 RI is not intended to identify specific sources of these chemicals, it does summarize the available information on potential sources. General categories of potential sources are thought to include historical land use and disposal practices, industrial or municipal releases (including both permitted and unpermitted wastewater and stormwater discharges), spills or leaks, atmospheric deposition, and waste disposal either on land or in landfills. In many cases, there is reason to believe that chemicals currently found in the sediments are the result of historical practices dating back many years. In more recent years, there have been well-documented efforts to either eliminate or substantially reduce releases of chemicals to the LDW from multiple sources. While it is recognized that additional information both on specific sources and on sediment and chemical fate and transport will need to be assembled for the Phase 2 RI, sufficient information exists to conclude that any early actions to remediate sediment in the LDW can result in significant reductions in contamination.

Existing data indicate that almost all sediment transported into the LDW from upstream sources is deposited in the upper reaches of the LDW near Turning Basin 3.

Based on an evaluation of multiple bathymetry surveys, water depths generally are stable or decrease with time, indicating a net depositional or dynamic equilibrium environment for the areas measured. Transport of resuspended sediment occurs on a local scale as a result of episodic events such as propeller scour, dredging, and other erosional events. However, available data and modeling suggest that bottom currents are rarely high enough to initiate motion of bedded sediments outside the navigation channel. Thus, outside of peak flow events which require additional study, available evidence suggests that erosion and transport of resuspended sediment is not likely a system-wide phenomenon. Additional work on sediment stability, fate, and transport will be conducted in Phase 2.

Site-specific groundwater data were examined for 12 sites identified by EPA and Ecology during this Phase 1 RI. Based on this analysis, available data do not indicate that chemicals of concern in groundwater are accumulating in sediment nor likely posing a risk to benthic invertebrates at most sites. Four sites have associated seep data. These data indicate a few sites where chlorinated solvents have been detected in seeps (i.e., Great Western and Boeing Plant 2). The significance of these low concentrations of chlorinated solvents in the LDW is unknown. As expected due to their low affinity to sediments and high solubility and volatility, chlorinated solvents have not been detected in sediment at any of the potential discharge zones based on the data available. Select metals have been measured in seeps at Boeing Isaacson, Boeing Plant 2, and Rhône-Poulenc; metals in seep samples exceeded AWQC at the latter two sites. Metals did not exceed SQS in sediment adjacent to Rhône-Poulenc, whereas metals SQS were exceeded in sediment adjacent to Boeing Plant 2, likely due to fill material. The seep data, particularly at Boeing Plant 2, are difficult to interpret with respect to the source of the chemicals because of additional influences (i.e., chemicals in seeps may be due to a mix of inputs from LDW water, groundwater, and sediment). This preliminary analysis of the available groundwater data suggests that certain groundwater chemicals do not appear to present a risk to benthic organisms, and do not appear to pose a potential for future recontamination if sediment is remediated at locations adjacent to these sites. Additional sampling in Phase 2 of the RI will determine whether chemicals entering the LDW via groundwater result in adverse effects to the benthic community. EPA and Ecology will continue to evaluate groundwater as a potential source of contamination to the LDW as part of the RI and source control efforts, and will reach final conclusions about groundwater as a source of sediment contamination as part of those efforts.

ES-2 ECOLOGICAL RISK ASSESSMENT

The Phase 1 ecological risk assessment (ERA) evaluated risks from sediment-associated chemicals to benthic invertebrates, fish, and wildlife species that may reside or forage in the LDW for at least a portion of their lives. Although there is relatively little suitable habitat presently available for rooted aquatic plants within the LDW, risks to this group were also evaluated. An earlier risk assessment (King County

1999a) evaluated risks to ecological species from chemicals in LDW surface water, and concluded that risks posed by surface water were low (see Attachment A-2 in Appendix A). Therefore, the Phase 1 ERA focused on whether there are risks from exposure to chemicals associated with sediments of the LDW. The Phase 1 ERA did not determine whether unacceptable risks exist or whether risk management is warranted, only whether further assessment is required based on conservative exposure assumptions.

Because it is impractical to evaluate every potentially exposed species, it is standard ERA practice to focus on representative receptor species that typify groups of organisms with specific exposure pathways. One objective of selecting representative receptors of concern (ROCs) is to choose species for which the risk conclusions will be protective of other species that are not explicitly evaluated. Representative species selected for this Phase 1 ERA were crabs, English sole, juvenile chinook salmon, bull trout, great blue heron, spotted sandpiper, bald eagle, river otter, and harbor seal. The primary reason for selecting juvenile chinook salmon and bull trout was because they are federally protected species with the potential for exposure in the LDW. Risks to the benthic invertebrate and rooted aquatic plant communities were also evaluated.

For each representative species selected, sediment-associated chemicals of potential concern (COPCs) were identified in the problem formulation using existing data. An initial screening, using highly conservative assumptions, identified 59 COPCs for benthic invertebrates and crabs, 7 COPCs for at least one fish species, 7 COPCs for at least one wildlife species, and 4 COPCs for plants. Following the initial risk-based screening, more detailed analyses were conducted to conservatively estimate the potential exposure of each representative species to COPCs, and the risk of adverse effects resulting from exposure. Based on these analyses using existing data, the Phase 1 ERA calculated preliminary risk estimates for each of the ROC/COPC pairs and discussed uncertainty associated with these estimates (e.g., the limited tissue dataset available). ROC/COPC pairs to be evaluated in the Phase 2 ERA will be determined in the Phase 2 problem formulation following a process described in the Phase 2 work plan. Pairs selected for further evaluation in Phase 2 will be based on the results of the Phase 1 ERA (Appendix A) and on interpretation of data collected in Phase 2. Below is a summary of recommendations from the Phase 1 ERA.

Benthic invertebrates – All Phase 1 COPCs are recommended for further analysis in Phase 2. Risks to crab will also be further evaluated in Phase 2, although risks appear to be low based on existing data, with the possible exception of arsenic.

Fish – Based on the existing data, **s**ix of the seven COPCs [arsenic, copper, polycyclic aromatic hydrocarbons (PAHs), mercury, tributyltin (TBT), and polychlorinated biphenyls (PCBs)] arising from the initial highly conservative screen are recommended for further analysis in Phase 2 for one or more of the fish species.[4] All six of these

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[4] In addition to data collection for the six COPCs listed, the collection of additional fish tissue data for analysis of DDT is also recommended, as discussed in Appendix A, Section A.7.2.

COPCs are recommended because the exposure estimate exceeded a "no effects" level. In addition to exceeding the "no effects" level, three of the COPCs (PCBs, arsenic, and copper) exceeded an established effects level for survival, growth, or reproduction in at least one fish species. Regional and natural background issues for arsenic will be further addressed as part of Phase 2 according to EPA (2002b) guidance.

Wildlife – Four of the seven COPCs (lead, mercury, arsenic, and PCBs) arising from the initial highly conservative screen are recommended for further analysis in Phase 2 for at least one or more of the wildlife species.[5] However, none of the COPCs had dietary exposure estimates greater than doses associated with effects on survival, growth, or reproduction of any wildlife species (i.e., all are recommended because the exposure estimates exceeded a "no effects" level). In contrast, preliminary risk estimates of PCBs to great blue heron using egg data indicated that exposure may be occurring at levels associated with adverse effects.

Rooted aquatic plants – Of the four COPCs evaluated for plants (lead, mercury, PCBs, and zinc), concentrations in marsh sediments were less than soil concentrations associated with no effects for PCBs, but were within the low end of the range of concentrations associated with effects for lead and zinc.[6] Due to the uncertainty in effects data, estimates of risk to plants are highly uncertain but do not generally appear to be significantly greater than background risk in marsh areas.

These findings do not constitute a definitive characterization of ecological risk. A recommendation for additional assessment resulting from this conservative screen does not necessarily indicate that high or unacceptable levels of risk exist for a given receptor species or chemical, only that the possibility of significant risk cannot be ruled out. In the Phase 2 ERA, risks associated with exposure of ecological receptors to COPCs within the LDW will be quantitatively characterized in a manner designed to support sound risk management decisions. The insights gained by the Phase 1 risk assessment are valuable in supporting early remedial action decisions by providing a risk-based rationale for selecting candidate areas.

ES-3 HUMAN HEALTH RISK ASSESSMENT

The Phase 1 human health risk assessment (HHRA) identified ways that people could be exposed to chemicals found in LDW sediments (termed exposure pathways), the potential extent of such exposures, and the grouping of exposure pathways into exposure scenarios. Direct contact with sediments during commercial netfishing or beach play in the LDW and consumption of seafood from the LDW were identified as primary exposure scenarios through input from site users, including the Muckleshoot and Suquamish Tribes, through review of prior risk assessments conducted in the LDW and Harbor Island, and through review of other relevant reports and studies

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[5] In addition to data collection for the four COPCs listed, the collection of additional sandpiper prey tissue data for zinc and copper is also recommended, as discussed in Appendix A, Section A.7.3.

[6] Effects data were not available for mercury.

conducted in the vicinity of the LDW, including a study of seafood consumption habits of Asian and Pacific Islanders. Quantitative risk estimates for other exposure scenarios, such as swimming, were included in this HHRA but were calculated in a previous risk assessment that suggested risks from these scenarios were insignificant.

In keeping with EPA risk assessment guidance, reasonable maximum exposure estimates were calculated for all exposure scenarios to avoid underestimating risks. Consequently, risk estimates may be overestimated for many individuals. However, this approach is consistent with EPA's policy of "reasonable maximum exposure", which uses high-end, but plausible estimates of exposure for assessing risks.

Once the exposure scenarios were selected, the chemical concentrations in samples from surface sediments and in fish and shellfish tissue were screened by comparing the maximum detected concentration, or the maximum detection limit for chemicals that were not detected, to risk-based concentrations. Using this screening procedure, 43 chemicals were identified as COPCs for at least one of the three scenarios.

Carcinogenic risks and noncarcinogenic health effects are evaluated separately in HHRAs because of fundamental differences in their critical toxicity values. Cancer risk is expressed as a lifetime excess cancer risk within a population of individuals exposed at the levels assumed in the risk assessment. Chemicals with noncarcinogenic health effects are generally not toxic below a certain threshold; a critical chemical dose must be exceeded before health effects are observed. The potential for noncarcinogenic health effects is expressed as a hazard quotient for an individual chemical and as a hazard index for summed hazard quotients from multiple chemicals.

Using the health-protective exposure assumptions, estimated cancer risks in the LDW were found to be highest for the seafood consumption scenario; the cumulative risk for all carcinogenic chemicals was 2 in 1,000 for the tribal seafood consumption scenario, with the primary contributors being arsenic (1 in 1,000), carcinogenic polycyclic aromatic hydrocarbons (cPAHs) (1 in 10,000), and polychlorinated biphenyls (PCBs) (4 in 10,000). Cancer risks for the netfishing scenario and the beach play scenario were much lower (i.e., all risk estimates were less than 1 in 100,000, including a risk estimate for dioxins and furans of 1 in 1,000,000 in each of these scenarios). In an evaluation of noncancer risks, only the tribal seafood consumption scenario had a hazard index (all chemicals) greater than 1, including hazard quotients greater than 1 for arsenic, PCBs, TBT, and mercury. These results indicate some potential for adverse effects other than cancer associated with seafood consumption. Based on the exposure scenarios evaluated in the Phase 1 HHRA, the following chemicals were identified as chemicals of concern (COCs) (i.e., a COC has a cancer risk estimate greater than 1 in 1,000,000 or a hazard quotient greater than 1) for one or more scenarios: PCBs, arsenic, cPAHs, dioxins/furans (expressed as a TCDD toxicity equivalent quotient), TBT, and mercury.

These findings do not constitute a definitive characterization of human health risks. There are many uncertainties associated with the site-specific risk estimates for each exposure scenario. Risks calculated for arsenic are particularly uncertain because arsenic concentrations in the Puget Sound area are influenced by historical Asarco smelter operations and naturally occurring arsenic. Another primary source of uncertainty with regard to arsenic is the fraction of arsenic present in seafood tissues in the more toxic inorganic form. Based on guidance from EPA Region 10, an inorganic arsenic fraction of 10% was assumed, although there is evidence that the actual inorganic arsenic fraction may be lower, which would lower the risks calculated for arsenic. Additionally, further research will be conducted on cPAH concentrations in seafood. Risks attributed to cPAHs may have been overestimated because one-half the detection limit was assumed for concentrations of these compounds in fish, even though none of the compounds were ever detected in these samples. Many of the uncertainties could be reduced through the collection of additional data or performance of additional analyses. Data will be collected on different forms and concentrations of inorganic arsenic in seafood. Additionally, further research will be conducted on cPAH concentrations in seafood. The HHRA assumed that shellfish consumption was limited to consumption of crabs and mussels. Exposure and consequently risk could be greater if further studies suggest that additional shellfish resources are available for consumption. Data collected in Phase 2 may result in the identification of additional COCs or eliminate COCs, and refine exposure pathways (e.g., shellfish consumption) identified in the Phase 2 HHRA. However, the results of the Phase 1 HHRA will be useful in providing risk-based information to contribute to the identification of candidate sites for early remedial action.

ES-4 NEXT STEPS

The risk estimates made in this Phase 1 RI are high enough to suggest that initial early remedial actions are warranted in some portions of the LDW. One objective of the Phase 1 studies was to determine if discrete areas within the LDW could be identified as candidates for early remedial action. Based on the analysis and conclusions presented in the Phase 1 RI, there will be some remediation of selected areas within the LDW on an expedited schedule before the completion of the full RI/FS, to reduce risks to human health or the environment. The distributions of chemicals within the sediments were found to be highly variable, with discrete areas, in some cases near known or suspected sources, having much higher concentrations than other areas. Risks associated with such discrete areas are considered to be sufficiently high that there is no need to wait for the results of the Phase 2 RI to undertake remedial action.

The next step in this first part of the Phase 1 process is to prepare a memorandum that identifies candidate sites for potential early remedial action based on the results of this RI report, the Phase 1 ERA and HHRA, and management criteria such as the ability to isolate the site from potential recontamination. EPA and Ecology will review the list of candidate sites and potentially enter into negotiations with one or more LDWG members and/or other parties to perform the early remedial actions outside of the RI/FS process.

Following the identification of candidate sites, additional investigations will be conducted during the Phase 2 RI to further characterize the nature and extent of chemical distributions and to refine estimates of risks to human health and the environment sufficiently to make final remedial decisions in the LDW. The results of the additional investigations will be incorporated into a Phase 2 RI that will contain a baseline (Phase 2) HHRA and ERA. These RAs will evaluate risk both with and without early remedial actions, and will assess how much the early remedial actions are likely to reduce overall risks. Thus, the baseline risk assessments will support a determination for remaining risk management decisions at the LDW.

1.0 Introduction

The Lower Duwamish Waterway (LDW) was added to EPA's National Priorities List (NPL, also known as Superfund) on September 13, 2001. Under Superfund regulations, EPA requires that a remedial investigation and feasibility study (RI/FS) be conducted for all listed sites. A Remedial Investigation identifies areas that should be cleaned up because they pose an unacceptable risk to human health or the environment. A Feasibility Study proposes a number of alternative approaches to cleaning up the areas that need it, and analyzes and compares these alternatives.

The key parties involved in the Duwamish RI/FS are the City of Seattle, King County, the Port of Seattle, and The Boeing Company, working together for this project as the Lower Duwamish Waterway Group (LDWG), plus the US Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology). These parties agreed (in an Administrative Order on Consent or AOC) to conduct the RI/FS for the LDW in two phases. A Statement of Work (SOW) was prepared in June 2000 to describe the scope of the two phases.

The first phase of the RI (this document) used existing data to provide an understanding of the nature and extent of chemical distributions in the sediments of the LDW and present preliminary risk estimates resulting from those distributions. This information from the Phase 1 RI is then used to support identification of locations within the LDW that may be candidates for early remedial action (Figure 1-1). Early action is of great interest because cleanup under Superfund normally takes many years. Candidate early action sites are being identified as described in a technical memorandum submitted to EPA and Ecology in February 2002 (Windward Environmental [Windward] 2002) using a risk-based approach to identify high-priority areas. These sites will then be further evaluated, using feasibility criteria, to identify potential candidate sites for early remedial action.[7] For the sake of brevity, the term "Phase 1" is used in this document rather than the terms "scoping-phase" and "Phase 1 scoping-phase."

Following identification of candidate early action sites, additional investigations will be conducted to fill critical data gaps identified in the Phase 1 process. The results of these investigations will be incorporated into a Phase 2 RI that will contain baseline human health and ecological risk assessments. These baseline risk assessments and other factors will be used by EPA and Ecology to set sediment cleanup levels for the LDW beyond the early action sites.

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[7] The additional criteria used for this process are also described in the February 2002 memorandum (Windward 2002).

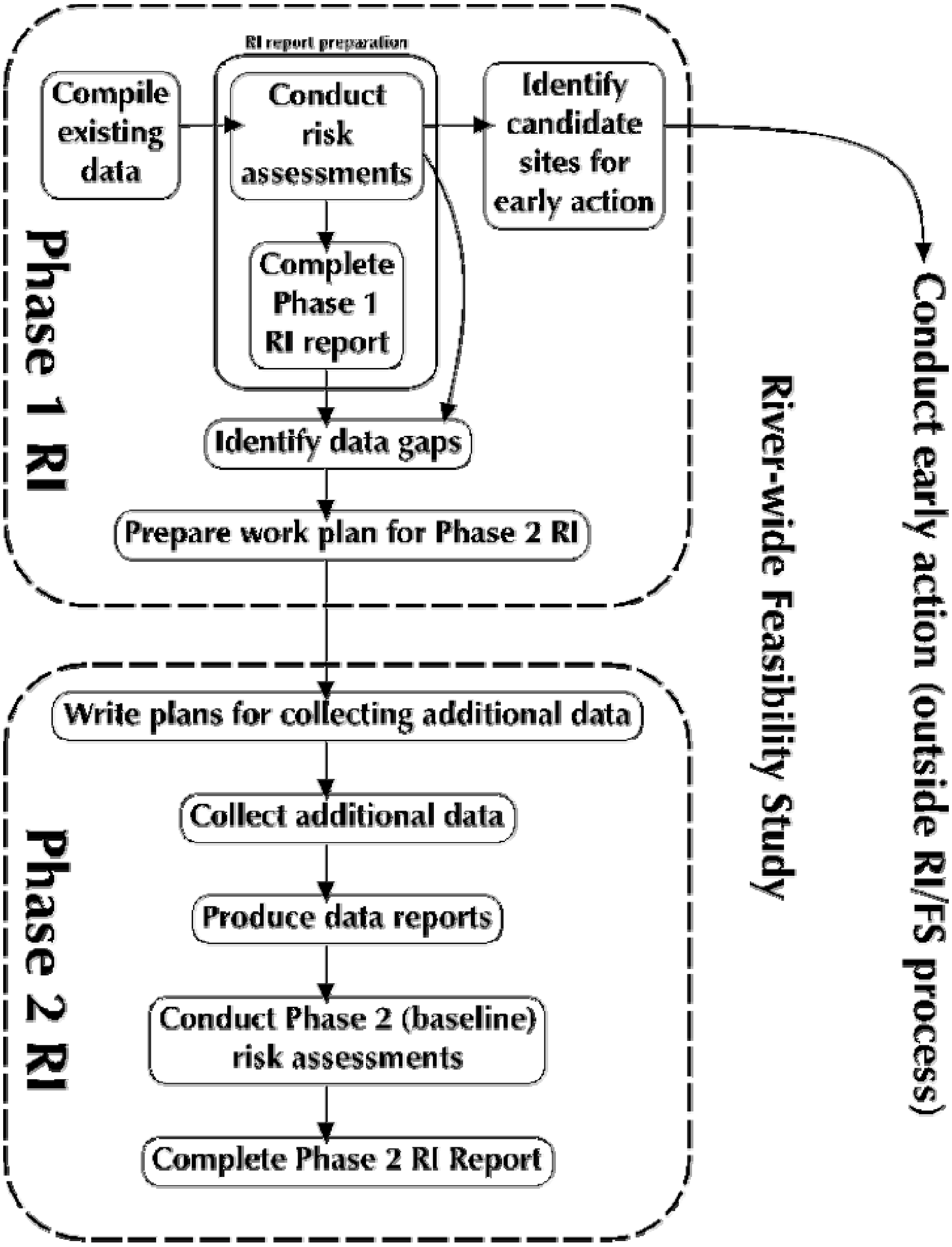

Figure 1-1. Flowchart of work products for two RI phases

1.1 DOCUMENT ORGANIZATION

Section 1.2 of this report summarizes the objectives of the Phase 1 RI. Section 1.3 then provides an overview of the site, including its geographic setting and a brief summary of the history of the area. Section 2 describes the environmental setting and previous investigations, and how the site is currently used by people and wildlife. Section 3 discusses and lists the potential applicable or relevant and appropriate requirements (ARARs) for the LDW site. Section 4 describes the nature and extent of contamination, potential sources of contamination, and chemical fate and transport. Sections 5 and 6 summarize the results of the Phase 1 ecological risk assessment (ERA) and human health risk assessment (HHRA), respectively. Section 7 presents the conclusions of this RI. Section 8 is a list of references. Appendices A and B are the complete ERA and HHRA, respectively. Appendix C describes data management procedures relating to GIS mapping. Appendix D contains tables of summary statistics for sediment, porewater, and tissue samples referred to in Section 4. Appendix E is a collection of information regarding potential sources of contamination to the LDW. Appendix F contains maps of LDW waste disposal and dredge fill sites. Appendix G provides an analysis of groundwater transport and water quality data. Some figures and many tables are embedded in the text; large-format figures (including all GIS maps) and some accompanying large-format tables are located in a separate volume titled Oversize Maps and Tables accompanying this RI.

1.2 OBJECTIVES

The primary Phase 1 RI objectives are:

- compile and synthesize existing relevant information for the site
- calculate preliminary risk estimates for ecological species and human health from sediment-associated chemicals
- identify areas for potential early remedial action using a risk-based framework
- identify key data gaps in nature and extent information as well as information important to the human health risk assessment (HHRA) and ecological risk assessment (ERA)

The first objective is addressed in the RI report (this document). The second objective is addressed in the Phase 1 HHRA and ERA, which are attached to this report as appendices. The third and fourth objectives are part of the Phase 1 RI scope of work, but are not specifically addressed in this document. Separate memoranda are being prepared to describe the identification of candidate sites for early action and the data gaps that may be filled during the Phase 2 RI.

1.3 SITE BACKGROUND

1.3.1 Site description

The Duwamish River originates at the confluence of the Green and Black Rivers near Tukwila, WA, then flows northwest for approximately 19 km (12 mi), bifurcating at the southern end of Harbor Island to form the East and West Waterways prior to discharging into Elliott Bay (Map 1-1; GIS maps and companion tables are located in a separate volume titled Oversize Maps and Tables accompanying this RI). The LDW Superfund study area comprises the downstream portion of the Duwamish River, excluding the East and West Waterways around Harbor Island[8]. The portion of the river that is maintained by the US Army Corps of Engineers (ACOE) as a federal navigation channel (i.e., the reach downstream of Turning Basin 3) is customarily referred to as the LDW (Weston 1999). Navigation depths maintained by the ACOE within the LDW generally range from –4.6 m (–15 ft) mean lower low water (MLLW) from Turning Basin 3 north to Slip 4, -6 m (–20 ft) MLLW from Slip 4 to the 1st Avenue Bridge, and -9.1 m (-30 ft) MLLW from this bridge to Harbor Island (Weston 1999).

The shorelines along the majority of the LDW have been developed for industrial and commercial operations, as the LDW serves as a major shipping route for containerized and bulk cargo. Common shoreline features within the LDW include constructed bulkheads, piers, wharves, buildings extending over the water, and steeply sloped banks armored with riprap or other fill materials (Weston 1999). Intertidal habitats are dispersed in relatively small patches (i.e., generally less than one acre in size), with the exception of Kellogg Island, which represents the largest contiguous area of intertidal habitat remaining in the Duwamish River (Tanner 1991). Additional areas of low intertidal mudflats are present below upper bank riprap in the reaches upstream of the 1st Avenue Bridge. Additional habitat information is presented in Section 2.4.1.

1.3.2 Site history

Prior to the 20th century, the Duwamish River meandered widely through a valley consisting of floodplains, freshwater wetland, and tidal marshes before emptying into Elliott Bay (see Map 1-2). Flooding was a common natural occurrence in the river valley. The Duwamish River was fed by the Green, Black, and White rivers, with a combined drainage area of approximately 4,250 km^2 (1,640 mi^2) (Blomberg et al. 1988).

Today, the Green River is the main source of water for the Duwamish River. The White River was diverted to the Puyallup River in 1906 to control flooding (Patmont 1983). In 1916, the Black River, which drained from Lake Washington and was fed by the Cedar River, was reduced to a minor stream when the level of Lake Washington was lowered by the construction of the Ship Canal and the Cedar River was diverted to Lake Washington (Patmont 1983). The Duwamish / Green River drainage area is currently 1,466 km^2 (566 mi^2) (King County 2000b). Over the past century, the watershed area and flows have been reduced by about 70% due to flow diversions (King County 2000b)

To facilitate navigation and industrial development, the LDW has been straightened and dredged in many areas by Commercial Waterway District No. 1 (Washington Statute RCW91.04). Dredging in 1903-1905 created the East and West Waterways, and dredged material from the river was used to create Harbor Island (Weston 1993). The river has been dredged and channelized from just upstream of Turning Basin 3 to the southern tip of Harbor Island, since about 1916. Upstream of the Turning Basin, the

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[8] The East and West Waterways are being addressed as separate Superfund sites.

river is contained by dikes. The ACOE has subsequently authorized and maintained the dredged channel.

Most of the upland areas adjacent to the LDW have been heavily industrialized for many decades. Historical and current commercial and industrial operations include cargo handling and storage, marine construction, boat manufacturing, marina operations, concrete manufacturing, paper and metals fabrication, food processing, and airplane parts manufacturing. Although the LDW is often viewed primarily as an industrial corridor, two residential neighborhoods are near the LDW. The LDW has been a receiving water body for many different types of industrial and municipal wastewater. There are currently no permitted industrial discharges of wastewater directly into the LDW. However, there are still industrial and municipal stormwater discharges that currently enter the LDW. In addition, the combined sewer overflow system, which receives wastewater from a variety of industries, discharges into the LDW intermittently during periods of high rainfall.

2.0 Environmental Setting and Previous Investigations

This section describes the environmental setting of the LDW, including physiography, physical characteristics, biological habitat, and human site use. This section also lists and describes available data that have been collected during previous investigations within the LDW. Chemical characteristics are not described in this section; the data from previous environmental investigations are discussed in Section 4.2. Data collected on sediment transport processes are presented in Section 4.4.

2.1 PHYSIOGRAPHY

The LDW is located at the downstream end of the 1,466-km^2 (566 mi^2) Green-Duwamish watershed, which includes parts of the cities of Seattle, Tukwila, SeaTac, Renton, Kent, Federal Way, Auburn, Black Diamond, and Enumclaw, plus forested areas in unincorporated southeastern King County. From Harbor Island to just south of Turning Basin 3, the LDW is about 8 km (5 mi) in length. The highly developed LDW shoreline consists primarily of piers, riprap, constructed seawalls, and bulkheads for industrial and commercial use. The depth of the river varies from approximately 17 m (56 ft) at MLLW near the mouth to 3.0 m (10 ft) at MLLW (Weston 1993) near the head of navigation. The navigation channel is maintained at approximately 9.1-m (30-ft) depth up to the 1st Avenue bridge, approximately 6-m (20-ft) depth from the 1st Avenue bridge to Slip 4, and approximately 4.6-m (15-ft) depth between Slip 4 and Turning Basin 3. The average width of the LDW is 134 m (440 ft), although it is wider downstream of the 1st Avenue Bridge.

2.2 PHYSICAL CHARACTERISTICS

This section discusses physical characteristics of the LDW, including meteorology, geology, hydrology, estuarine features, and sediment characteristics.

2.2.1 Meteorology

The climate in the LDW vicinity is characterized as “Pacific marine,” typical of the Puget Sound area. The prevailing winds move moist air inland from the Pacific Ocean, moderating winter and summer temperatures. Winters tend to be mild and wet, and summers are usually dry. Fifty percent of the annual precipitation falls from October to January. Annual precipitation ranges between 49.5-143.5 cm (19.5-56.5 in.) measured at Sea-Tac Airport (Culhane et al. 1995). Monthly average winter temperatures range from 0-7°C (32-45°F). Monthly average summer temperatures range from 11-24°C (52-76°F). Winds are typically from the southwest at 8-16 km/hr (5-10 mi/hr) (Canning et al. 1979).

2.2.2 Hydrogeology

The hydrogeology of the Duwamish basin provides the framework for understanding the groundwater flow system. The geologic history provides a regional basis for interpreting the nature of the subsurface materials and geologic units. The geologic materials influence the occurrence of aquifers and aquitards, the hydrogeologic units that define groundwater flow pathways. Regional recharge and discharge patterns also play a significant role in defining the groundwater flow system.

The geology of the Duwamish basin has been widely studied. The following subsections provide an overview of the relevant geologic features that help to characterize the groundwater flow pathways to the LDW. Information presented in these subsections was summarized from the *Duwamish Basin Groundwater Pathways Conceptual Model Report* prepared for the Duwamish Industrial Area Hydrogeologic Pathways Project (Booth and Herman 1998). Please refer to this report for more comprehensive discussion of the geology and hydrogeology of the LDW area.[9]

2.2.2.1 Geologic history

The Duwamish Valley is a relic arm of Puget Sound, which was carved by the overriding ice sheet that last advanced into this area from British Columbia about 15,000 years ago. At the time of the ice retreat about 5,700 years ago, the Duwamish arm of Puget Sound extended as far south as Auburn, about 32 km (19 mi) upstream of the present mouth of the LDW at Elliott Bay. A tremendous mudflow (the Osceola Mudflow) descended from the flanks of Mount Rainier at that time, building a voluminous fan of sediment into the marine waters at Auburn and progressing down-valley as a submarine flow at least as far north as Kent. This mudflow diverted the White River, at that time a tributary of the Puyallup River, to the Green River.

The alluvial fill within the Duwamish valley, built up over time through deposition from upstream fluvial sediments of the White, Green, and Black Rivers, caused advancement of the shoreline up the Duwamish arm. The fill typically includes beds of fine silts and sands deposited as riverine and floodplain deposits, with coarser

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[9] Booth and Herman (1998) can be obtained through the City of Seattle.

sands and gravels marking the lateral advance at the water's edge. This sediment completely buried the previous form of the valley so that presently only a few bedrock knobs remain exposed at the ground surface. As the river episodically flooded and migrated back and forth across the floodplain, the sediments already there were reworked by the river and locally augmented by additional riverine and floodplain deposits (Booth and Herman 1998).

In the late 1800s and early 1900s, extensive topographic modifications were made to the river, including the filling of tideflats and floodplains to create a straightened river channel, which resulted in the abandonment of about 6 km (3.7 mi) of old river bed (Map 1-2). Current side slips are frequently remnants of old river bed meanders. The channel was dredged for navigational purposes and the excavated waterway material was used to fill the old channel areas and the lowlands above flood levels. Because the dredge fill materials were similar to the native deposits, they are typically difficult to distinguish from the native silts and sands. Subsequent filling for land development purposes has resulted in a surficial layer of fill over most of the lower Duwamish Valley. This material is typically more granular because it was generally placed to allow for stable construction conditions and/or building foundations.

2.2.2.2 Regional hydrostratigraphy

This section describes the regional stratigraphic units that define the Duwamish Valley aquifer system. There are essentially three principal geologic assemblages within the Duwamish basin that help define the hydrogeologic system, as follows:

1. The Duwamish Valley alluvial deposits that constitute the principal aquifer and groundwater pathway of interest to this study.
2. Bedrock, which bounds the valley aquifer system where it occurs and limits groundwater flow.
3. The sequence of glacial and non-glacial sediments that make up the upland plateaus east and west of the Duwamish Valley. These sediments are largely glacially overridden and dense, geologically bounding the valley alluvium along the valley walls and at depth in some portions of the valley.

The following sections describe the influence each of these stratigraphic units has on the groundwater flow patterns in the Duwamish valley. Figures 2-1 and 2-2 (from Booth and Herman [1998]) provide schematic cross sections of the regional stratigraphy illustrating the alluvial sequence within and adjacent to the valley. Figure 2-1 crosses the LDW study area at its mouth at Harbor Island approximately 0.1 mi north of the confluence of the East and West Waterways. Figure 2-2 provides the geology interpreted in the central LDW midway between Harbor Island and Turning Basin 3, at about RM 3.

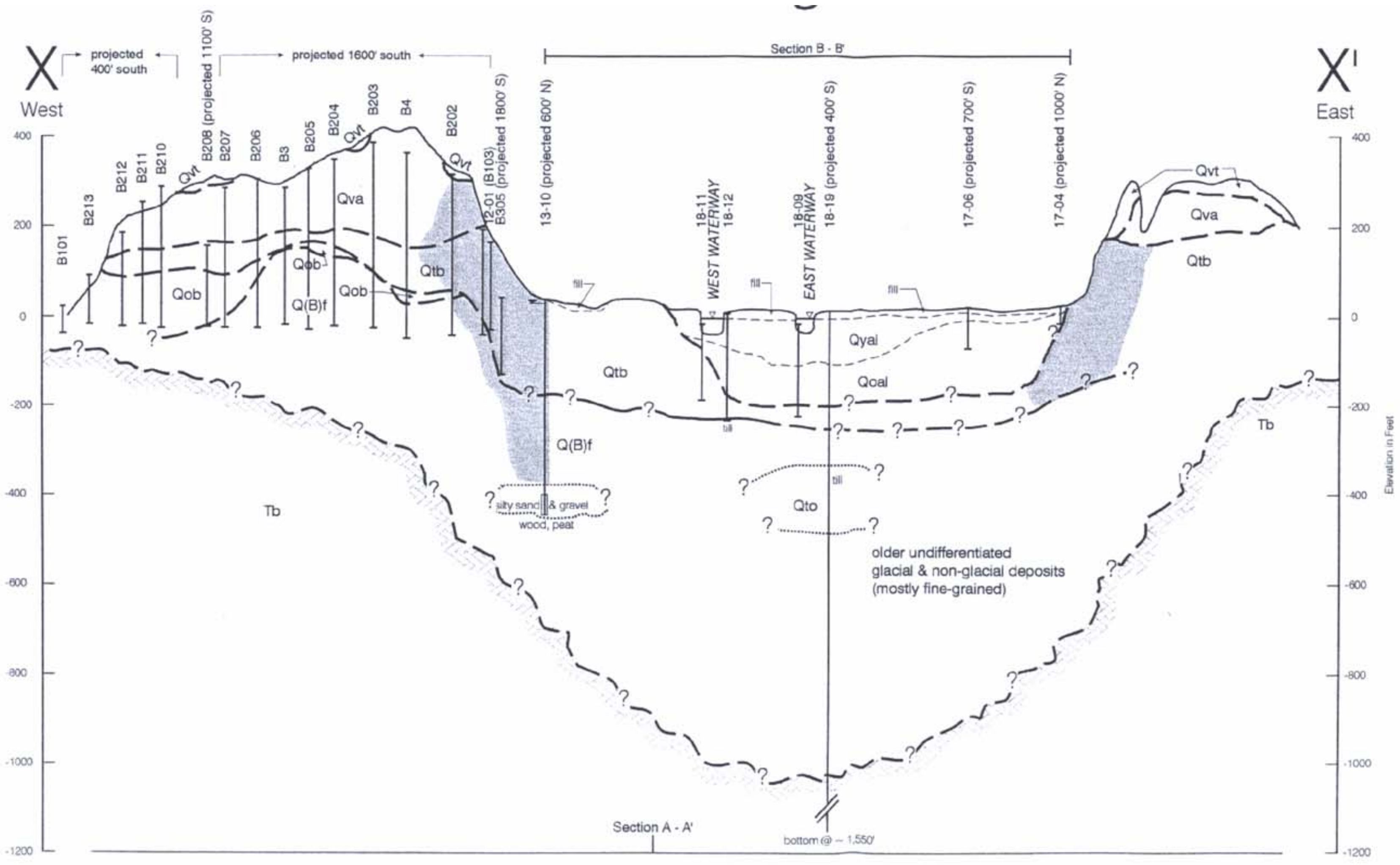

Figure 2-1. **Cross-section of LDW stratigraphy at south end of Harbor Island**[10]

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[10] Source: Booth and Herman (1998)

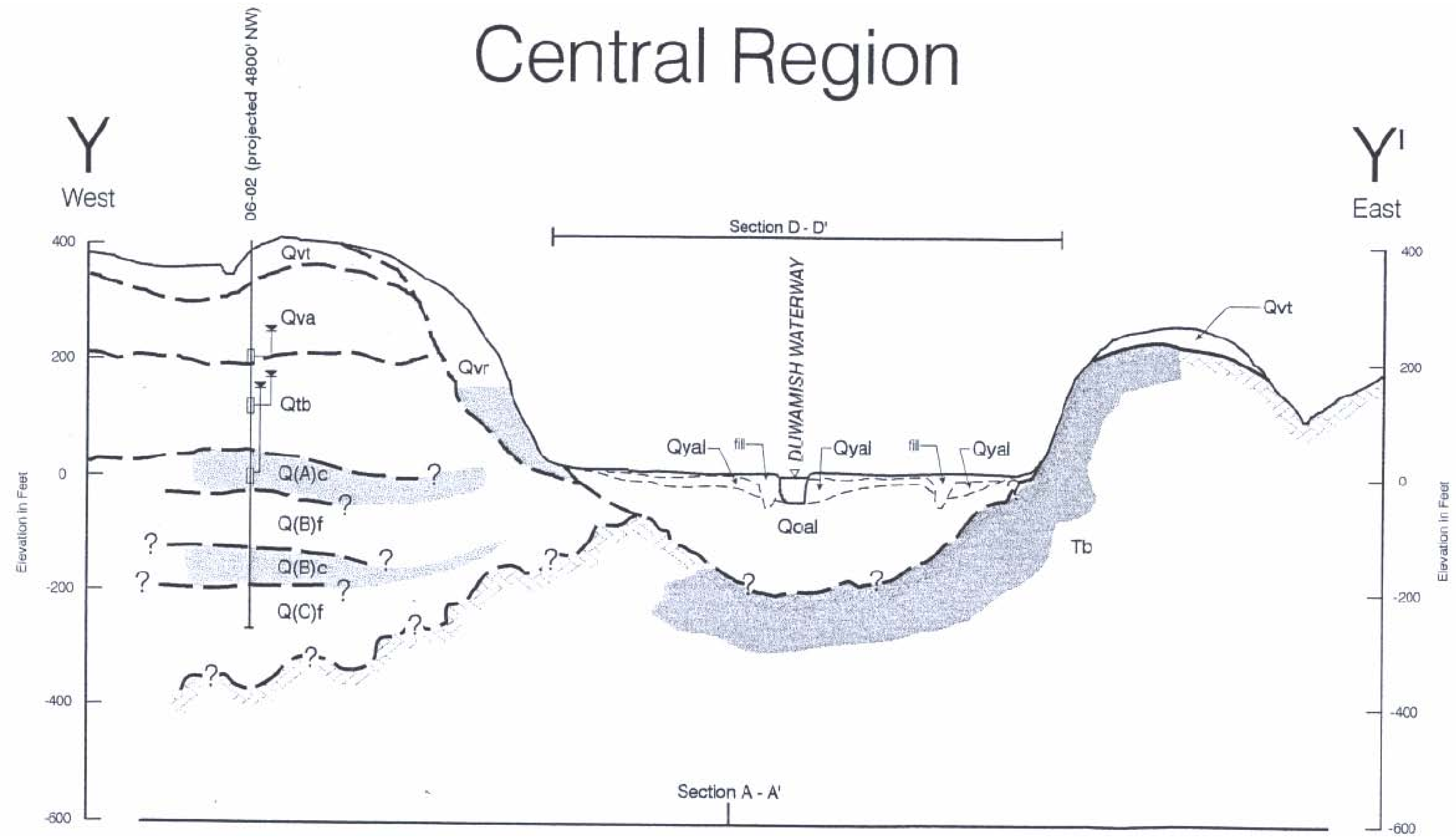

Figure 2-2. Cross-section of LDW stratigraphy midway between Harbor Island and Turning Basin 3[11]

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[11] Source: Booth and Herman (1998)

Valley Alluvial Deposits

The sediments of the Duwamish Valley are set within the trough of the Duwamish River, which was carved by glacial ice and subsequently filled in with river sediment. This trough lies roughly 60 m (200 ft) below ground surface along the axis of the valley, and is bounded by bedrock or by the very dense sediment of the upland glacial and non-glacial deposits. The geologic history of this area suggests that the alluvial sequence includes estuarine deposits, typically fine sands and silts (often marked by shells), that progress upward into a more complexly interbedded river-dominated sequence of sand, silt, and gravel. These alluvial deposits form a sedimentary wedge marking the advance of a prograding delta increasing in thickness from south to north.

The valley alluvium can be divided into one anthropogenic and three geologic units: fill, a younger alluvium, an older alluvium, and glacially overridden sediments, described as follows for the LDW valley (as identified in Figures 2-1 and 2-2):

- **Fill**. In the LDW area, variable amounts of fill are present, ranging in thickness from 1 to 6 m (3 to 20 ft). Locally, the shallowest aquifer (water table) occurs within the lower portion of the fill material, especially in the northern portion of the LDW where dry land has been created in the last century. Although the fill can be highly variable, it is most commonly composed of sand and silty sand where it is saturated. Much of the fill placed in the old river channels is dredged material, which is similar in hydraulic conductivity to the native younger alluvium.
- **Younger alluvium (Qyal).** In the central valley (Figure 2-2), these deposits are of relatively constant thickness and depth, with a base that is generally within 1.5 to 3 m (5 to 10 ft) of modern sea level. The younger alluvial deposits thicken from south to north within the LDW; and at the thickest point in the north end are estimated to occur to a depth of roughly 30 m (100 ft). The younger alluvium consists of sands, silts, and clays, and includes abundant natural organic material. The younger alluvium is often distinguished from the overlying fill by abundant fibrous organic material typical of tide marsh deposits.
- **Older alluvium (Qoal).** The older alluvium is characterized primarily by estuarine deposits and is often marked by shells in its lower portion. This unit commonly extends to depths of 15 to 30 m (50 to 100 ft) in the central valley, thickening toward the mouth of the LDW, to depths below ground surface of 45 to 60 m (150 to 200 ft). This unit has been most carefully characterized at the Boeing properties in the central valley, where the older alluvium becomes systematically finer with increasing depth. In this area, the upper two-thirds of the older alluvium typically consists of sand and silty sand, and the lower third of sandy silt. The older alluvium also becomes significantly finer toward the north, with the sand almost completely absent near the mouth of the Duwamish

River at Harbor Island. The older alluvium here is almost entirely silt and clay, representing the farthest extent of the deltaic deposits into the marine environments and thus displaying the finest grained material of the alluvial sequence.

Bedrock

The Duwamish area bedrock occurs as a basement material and bounds the aquifers in the valley. Bedrock is significant because relative to the valley sediments, the bedrock generally provides a boundary to any groundwater flow. Bedrock is exposed in the eastern and southern parts of the Duwamish Valley (see Figure 2-2). Within the LDW study area, the bedrock surface descends from roughly 60 m (200 ft) to over 500 m (1,640 ft) below ground surface at the north end (see Figure 2-1).

Where it is exposed, the bedrock consists of marine and continental sedimentary rocks and isolated igneous intrusions, all deposited during the Tertiary period (between about 40 and 10 million years ago in this area). The sedimentary rocks are generally not important sources of groundwater, because the cementation and fine-grained nature preclude rapid movement of subsurface water. The intrusive rocks are generally massive and even less able to store and transmit water.

Glacial and Non-Glacial Sediments

The glacial and non-glacial sediments within the Duwamish basin are a complex sequence of interbedded, unconsolidated deposits of glacial and non-glacial origin. This sequence bounds the valley sediments, where bedrock does not occur. These deposits make up the extensive upland plateau to the west of the valley, and where bedrock is absent, the upland east of the valley (see Figures 2-1 and 2-2). Although these deposits provide a geologic boundary to the alluvial deposits, they provide a potential hydraulic pathway for the flow of upland groundwater to the Duwamish alluvial sediments.

The relative elevation difference between groundwater within the upland deposits and the Duwamish River creates a regional flow system with significant hydraulic potential for flow from the upland areas to the valley system. Groundwater elevations in the uplands range from 30-60 m (100-200 ft) elevation, while the valley aquifer hovers within 3-6 m (10-20 ft) of sea level. A detailed review of the glacial and non-glacial sediment sequence completed for the Duwamish Pathways study (Booth and Herman 1998) indicated that upland flow to the Duwamish Valley primarily occurs along the west valley wall within the sandier sediments of the glacial deposits. The hydraulic potential of inflow from the upland areas was seen throughout the valley at depth by upward hydraulic gradients within the lower portion of the older alluvium. Booth and Herman (1998) also identified the potential for bedrock and thick sequences of the Transitional Beds silt (Qtb) to limit the upland groundwater inflow to the valley where these deposits occur (see shading along valley walls in Figures 2-1 and 2-2). This concept was supported by evidence of saline water in deep alluvial sediments away from the river (i.e., outside current tidal influence), suggesting limited freshwater flushing of the original marine delta deposits.

2.2.2.3 Valley aquifer and groundwater flow system

Groundwater within the Duwamish Valley alluvium is typically encountered within about 3 m (10 ft) of ground surface and under unconfined conditions (Booth and Herman 1998). On a regional scale, the valley alluvium may be considered to make up a single, large aquifer system, although locally its flow characteristics vary based on the nature of materials that constitute the alluvium; proximity to the river and tidal fluctuations; and its thickness, depth, and proximity to upland discharge areas. The alluvial aquifer generally occurs to about 30 m (deep in the Central Valley thinning to the north where finer-grained silts and clays dominate. The aquifer also thins to about 10-12 m (30-40 ft) deep toward the margins of the valley (Booth and Herman 1998).

Site-specific studies in the LDW basin often differentiate shallow, intermediate, and deep aquifers. The shallow aquifer is almost always located with the fill and/or younger alluvium, and the deep aquifer is almost always located within the older alluvium. In between, aquifer zones are differentiated by silt layers. These silt horizons are rarely continuous throughout the valley, thus providing only local groundwater flow constriction. The discontinuous nature of the silt layers allows for hydraulic connection of the shallower and deeper sand layers.

The general direction of groundwater flow in the Duwamish Valley is toward the LDW (Map 2-1), although the direction may vary locally depending on the nature of subsurface material, and temporally, based on proximity to the LDW and the influence of tidal action. Although high tides can cause temporary groundwater flow reversal, the net groundwater flow direction was found to be toward the LDW where more detailed water level studies were available (Booth and Herman 1998). The area affected by tide-related flow direction reversals is generally within 100-150 m (300-500 ft) of the LDW (Booth and Herman 1998). Map 2-1 presents the groundwater flow patterns obtained from site-specific investigations as described in Appendix G. The water level elevation data presented is for the shallowest aquifer system where reliable data were available.

Groundwater flows in three dimensions. The water level elevation contour maps typically represent the groundwater flow within the horizon tapped by the wells from which the water levels were obtained. The vertical flow components that exist within an aquifer system such as the Duwamish alluvium can be described by reviewing vertical gradient data. Vertical gradients reviewed as part of the Duwamish Pathways study indicated that downward flow gradients occur within the shallower alluvium to depths of roughly 10-15 m (30-50 ft), and that below this depth, upward gradients typically occur (Booth and Herman 1998; Figure 2-3). Upward gradients were lowest (0.002 to 0.07) beneath the east side of the central valley where inflows from the adjacent uplands are limited by bedrock and thick silt deposits. On the west side of the waterway, upward gradients ranged from 0.02 to 0.3, indicating more substantial inflows from upland areas to the west. The downward gradient within the shallower alluvium causes a downward migration of dissolved constituents until the effect of the regional inflow is seen by upward flow gradients. The upward flow gradients limit further downward flow of dissolved constituents, generally forcing the shallower flow upward toward the LDW.

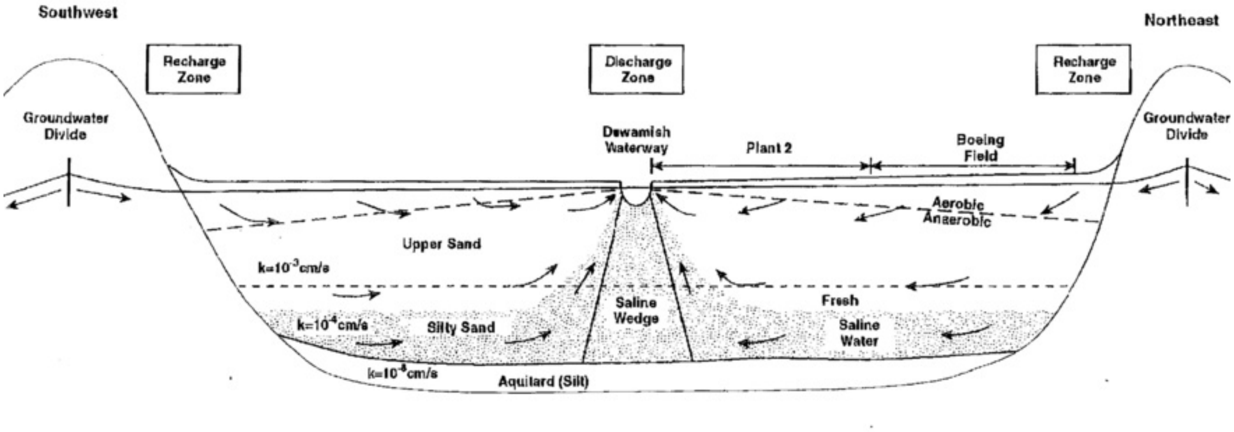

Figure 2-3. Conceptual groundwater model

Source: Weston (1996)

In the eastern area of limited freshwater inflow, brackish, non-tidally fluctuating groundwater has been encountered, suggesting zones of stagnant or connate groundwater (Booth and Herman 1998). Brackish and saline water are significant to groundwater flow as the less dense, fresh groundwater tends to migrate above the higher density saline water. This density contrast minimizes the potential for shallower groundwater to mix and/or migrate into the brackish or saline zones. The density difference between the freshwater aquifer system and the salt water of the LDW tends to focus the outflow of the surficial aquifer into the intertidal area.

2.2.3 Hydrology

The Green River, which is currently the main water source for the LDW, originates at the crest of the Cascade Mountains near Stampede Pass and flows through Howard Hanson Dam at 105 km (River Mile [RM] 65) and Tacoma Headworks Dam at 98 km (RM 61) (Culhane et al. 1995). Major tributaries to the Green River include Sunday Creek, Smay Creek, and the North Fork upstream of Howard Hanson Dam, and Newaukum Creek, Soos Creek, and Mill Creek downstream of Howard Hanson Dam. In addition to the Green River, the Black River continuously discharges fresh water to the Duwamish River in Tukwila, several km south of the LDW. Flow from the Black River is normally low (approximately 2.6 m^3/s [92 cfs]), but substantially increases during storms from runoff.

In the mid 1800s, discharge from the Duwamish ranged from an estimated 70 to 250 m^3/s (2,500 to 9,000 cfs) (Blomberg et al. 1988). The lower 10 km (6.2 mi) of the river was contained within a tidal marsh that opened into a broad expanse of intertidal flats. The Howard Hanson Dam was installed in the upper part of the Green River primarily for flood control and low-flow augmentation to preserve fish life when river flows were naturally low (Sato 1997). The dam effectively decreased peak flows, which now do not exceed 340 m^3/s (12,000 cfs), but increased moderate flows from 85 to 140 m^3/s (3,920 to 6,460 cfs) as a result of the metered release of floodwaters stored behind the dam (King County 2000b).

Flow has decreased 78% from historic levels, attributable mostly to the diversion of the White River to the Puyallup and the diversion of the Cedar River to Lake Washington; the former diversion was natural while the latter was anthropogenic, conducted to support creation of the Ballard Locks and Cut. These changes lowered Lake Washington and caused increased drainage through the locks rather than through the Black River. Collectively, these irreversible changes have resulted in the present LDW hydrology and landscape.

Recent annual average discharge from the river was 43 to 51 m^3/s (2,300 to 2,350 cfs), measured at the U.S. Geological Survey (USGS) Tukwila gaging station, with flow rates varying from 4.3 to 329 m^3/s (200 to 15,200 cfs) (the record high) at the Auburn gaging station from 1962 to 1994 (NOAA 1998). Most (80%) of the water flows out of the West Waterway due to the presence of a sill on the East Waterway (Weston 1999). Flow rates are greatest in the winter as a result of seasonal precipitation and lowest throughout the late summer dry season. Streamflow can be increased by surface water sources within the LDW area, such as storm drains, combined sewer overflows (CSOs), industrial effluents, and nonpoint inputs, although these sources of flow are expected to be less than 1% of total discharge, even during peak flow events.[12] However, these influences are small relative to the influence of upstream dams in controlling river flow.

Streamflow in the LDW is also influenced by water diversions, particularly by the City of Tacoma's Headworks Dam, which diverts at least 3.2 m^3/s (110 cfs) daily for municipal use. Discharge of effluent from the Renton Sewage Treatment Plant to the Duwamish River was eliminated in 1986, decreasing summer flows by as much as 25% (~1.6 m^3/s [56 cfs]) (Harper-Owes 1981; Bernhardt and Yake 1981).

The USGS, ACOE, EPA, Metro (now King County Department of Natural Resources and Parks), King County, the University of Washington and others have measured current velocities within the LDW as part of a wide range of environmental investigations (Santos and Stoner 1972; Stevens Thompson & Runyan 1972; Stoner et al. 1975; Prych et al. 1976; Harper-Owes 1983; Weston 1993; King County 1999a). The most extensive current velocity measurements within the LDW were recently collected by King County, which deployed current velocity meters at two locations in the LDW

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[12] Storm drain discharges to the LDW were estimated at 1,868 MGY (0.2 m^3/s [7 cfs]) by Tetra Tech (1988) and CSO discharges are estimated at 20-25 MGY (0.002-0.003 m^3/s [0.07–0.1 cfs-]) in Tables 4-11 and 4-12.

(RM 1.1 and RM 3.5) for a three-month period beginning August 1996, recording currents at 15 minute intervals along a vertical profile (King County 1999a). The two deployment locations reasonably represent the LDW study area with respect to channel width. The width at RM 1.1 is as large as any other location south of Kellogg Island, while the width is at its narrowest at RM 3.5. Measured current velocities within the LDW during this study only rarely exceeded 40 cm/s (1.3 ft/s), the empirically derived scour velocity for fine-grained sediment in Puget Sound (Lavelle et al. 1984). Mean velocity profiles with depth along with cumulative frequency distributions of measured bottom water velocities at the two LDW stations are presented in Section 4.4.2, which discusses hydrodynamics with respect to sediment transport.

2.2.4 Estuarine features

The LDW is a well-stratified, salt-wedge type estuary that is influenced by river flow and tidal effects; the relative influence of each is highly seasonally dependent. Freshwater moving downstream overlies the tidally driven saltwater wedge. Typical of salt-wedge estuaries, the Duwamish has a sharp interface between the freshwater outflow at the surface and saltwater inflow at depth.

Santos and Stoner (1972) characterized the primary circulation regime within the salt-wedge portion of the LDW (typically extending from Harbor Island to near the head of navigation). A schematic of the net circulation pattern observed within the estuary and typical salinity profiles measured at different points within the LDW channel are presented in Figure 2-4. Salinity is the simplest characteristic for distinguishing the upper and lower layers because of their fresh and saline origins. The 25 part-per-thousand (ppt) salinity layer near the river mouth occupies most of the water depth, but tapers toward the upriver portion of the estuary. Freshwater inflow exerts a strong influence on the relative thicknesses of the two layers. The thickness of the freshwater layer increases with increasing river flow rates (as measured at the Tukwila gage) throughout the LDW (Figure 2-5). Salinity was observed to exert primary influence on the density structure within the LDW, so the salinity profiles also reflect the vertical density distribution.

Salt water enters the LDW principally through the lower water column of the West Waterway. The salt wedge discharges into the flowing surficial freshwater lens as a result of upward entrainment of saline water across the interface separating the two layers (Figure 2-4). To replace the entrained saltwater, the net transport of the salt wedge is in the upstream direction even if the salt wedge is stationary. Dye studies indicate that downward vertical mixing over the length of the salt-wedge is almost non-existent (Schock et al. 1998). Tidal forcing superimposes an additional velocity component associated with the migration of the salt wedge up and downstream in response to tidal cycles. Santos (1975) described how the upstream location or “toe” of the salt wedge, which is typically located between Slip 4 and the head of navigation, is determined by both tidal elevation and freshwater inflow (Figure 2-6). Fluctuations in tidal elevation also influence flow in the upper freshwater layer, which varies over the tidal cycle. In the southern reaches of the LDW, the cross section varies significantly with the tidal cycle.

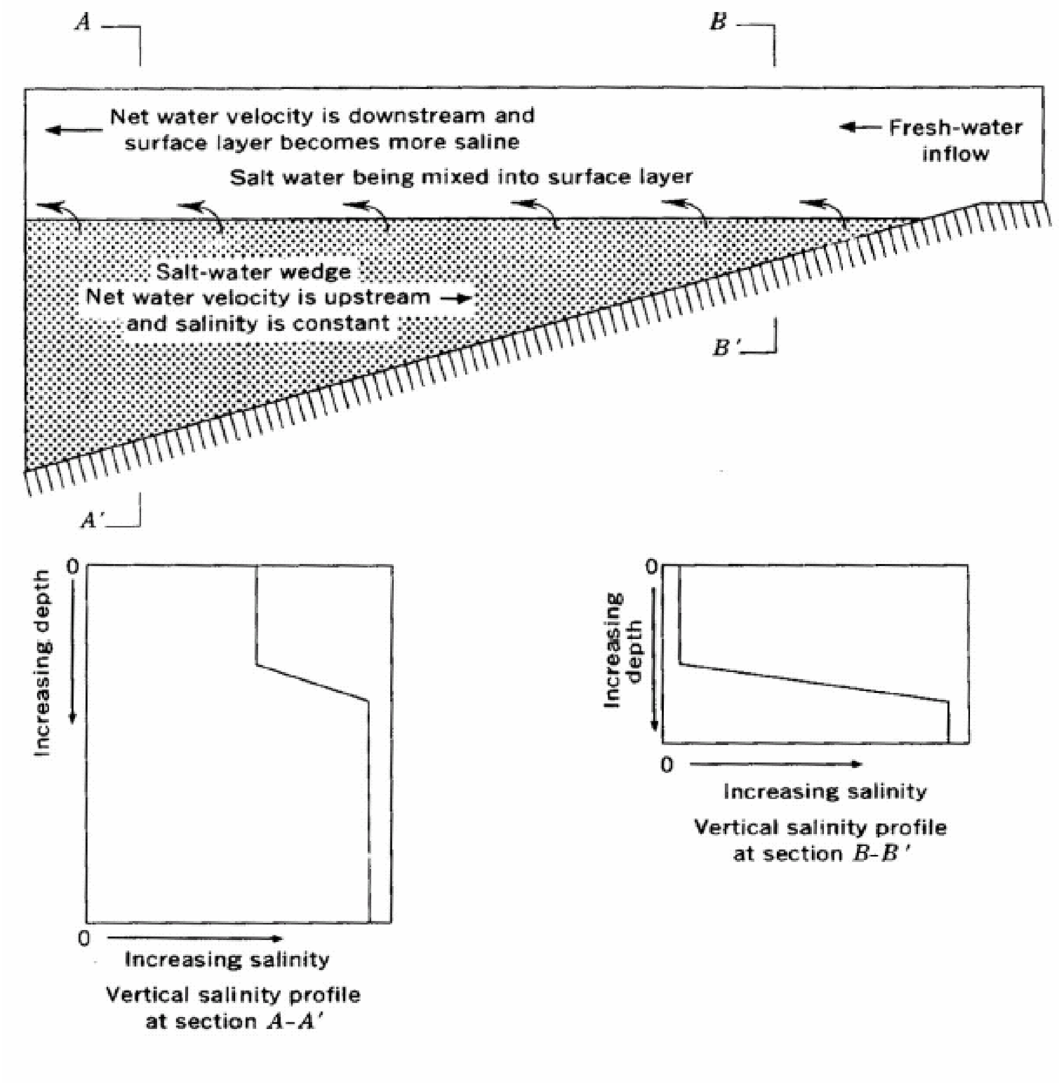

Figure 2-4. Schematic diagram of an idealized stratified estuary, showing net circulation pattern and salinity profiles[13]

The USGS measured the average net upstream transport of saltwater below the Spokane Street Bridge to be approximately 5.4 m^3/s (190 cfs),[14] with upstream transport varying with the tidal prism (Santos and Stoner 1972; Stoner et al. 1975). During seasonal low-flow conditions, saltwater inputs from the West Waterway represent more than one-third of the total discharge from the LDW (Harper-Owes

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[13] Source: Santos and Stoner (1972).

[14] Compared to up to 12,000 cfs of freshwater flow downstream.

1983). Additional discussion on salt wedge effects on sediment transport is provided in Section 4.4.2.

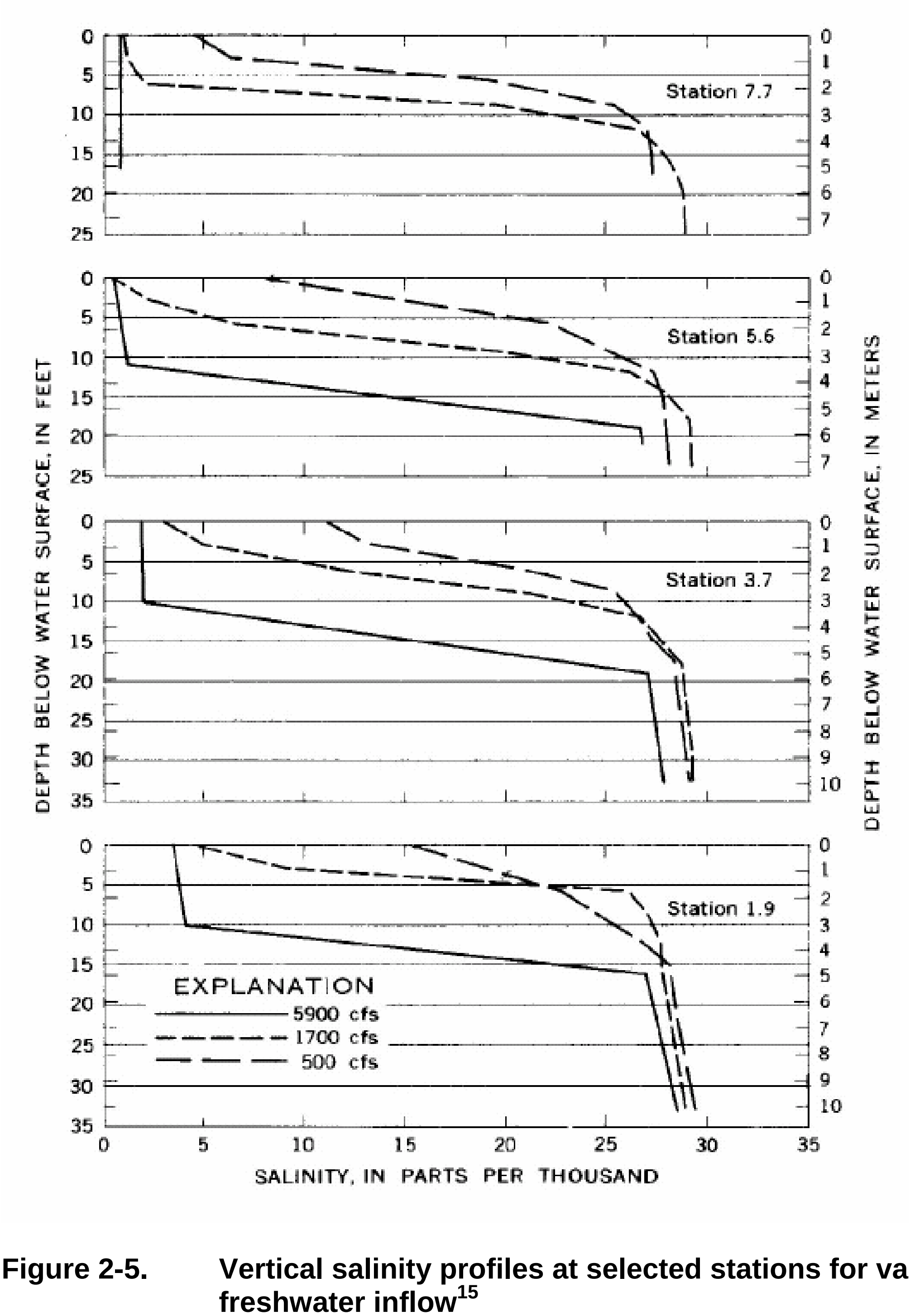

Figure 2-5. **Vertical salinity profiles at selected stations for various rates of freshwater inflow**[15]

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[15] Source: Santos and Stoner (1972).

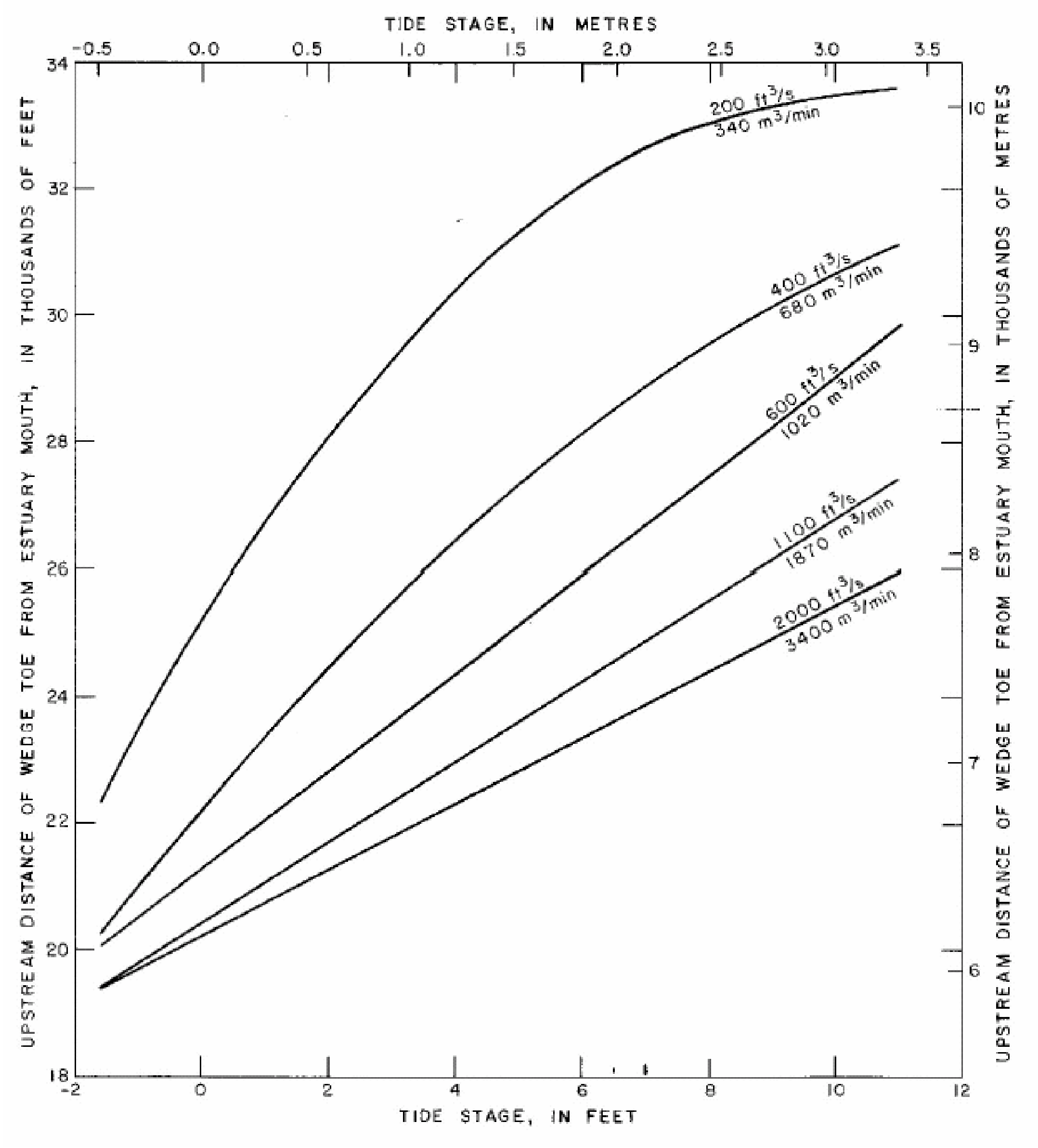

Figure 2-6. **Variation of wedge toe location with tide stage and freshwater inflow of the Duwamish River estuary**[16]

2.2.5 Sediment characteristics

Bottom sediment composition is variable throughout the LDW, ranging from sands to mud, depending on the sediment source and current speed. Sediment grain size and total organic carbon data compiled in the LDWG database from the studies listed in Section 2.3.1 are presented in Maps 2-2 and 2-3. The sediment typically consists of slightly sandy silt with varying amounts of organic detritus. Coarser sediments are present in nearshore areas adjacent to CSO and storm drain discharges (Weston 1999).

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[16] Source: Stoner et al. (1975).

Finer-grain sediments are typically located in remnant mudflats, along channel sideslopes, and within portions of the navigation channel. Main channel sediments near Turning Basin 3 are predominantly sands, whereas sediments toward the mouth are predominately fine-grained silts. Sediments in the navigation channel upstream of Turning Basin 3 are generally coarser than in the remaining downstream portion of the LDW.

Because of the affinity of organic compounds for fine-grained sediment with high organic carbon content (as discussed in Section 4.4.1.1), sediment type is an important indicator of areas where chemicals may accumulate. Transport of sediment in the LDW is discussed in Section 4.4.2.

2.3 PREVIOUS ENVIRONMENTAL INVESTIGATIONS

This section discusses the availability of sediment, surface water, porewater, groundwater, and tissue chemical data, but does not present the data. The data are presented in Section 4 (Nature and Extent of Contamination) and in the Phase 1 risk assessments (Appendices A and B). Groundwater data are presented in Appendix G.

2.3.1 Sediment quality

Approximately 1,200 surface (i.e., 15 cm [6 in.] or less) [17] and 230 subsurface sediment samples have been collected from the LDW since 1990 (Table 2-1).

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[17] For the purposes of this assessment, surface sediment samples are those collected from the top 15 cm (6 in) of the sediment horizon, but not deeper. This depth horizon is often referred to as the biologically active zone.

Table 2-1. Sediment chemistry samples collected in the LDW since 1990

Sampling Event	Event Code	Year Conducted	Chemical Groups Analyzed	Number of Samples		Reference
				Surface (<15 cm)	Subsurface (> 15 cm)	
Norfolk CSO five-year monitoring program, Year Two, April 2001	Norfolk-monit4	2001	Metals, PCB Aroclors, SVOCs	8	0	King County (2001a)
Norfolk CSO five-year monitoring program – Twelve-month post construction	Norfolk-monit3	2000	Metals, PCB Aroclors, SVOCs	8	0	King County (2000c)
Norfolk CSO five-year monitoring program – Supplemental nearshore sampling	Norfolk-monit2b	2000	PCB Aroclors	6	0	King County (2000c)
Norfolk CSO five-year monitoring program – Six-month post construction	Norfolk-monit2a	1999	Metals, PCB Aroclors, SVOCs	8	0	King County (2000d)
Norfolk CSO five-year monitoring program – Post backfill	Norfolk-monit1	1999	Metals, PCB Aroclors, SVOCs	4	0	King County (1999b)
Dredge material characterization Duwamish Yacht Club	Duwam Yacht Club	1999	Metals, pesticides, PCB Aroclors, SVOCs, VOCs, TBT	0	6	Hart Crowser (1999)
Sediment sampling and analysis James Hardie Gypsum Inc. – Round 1	Hardie Gypsum-1	1999	Metals, pesticides, PCB Aroclors, SVOCs, VOCs	0	5	Spearman (1999)
Sediment sampling and analysis James Hardie Gypsum Inc. – Round 2	Hardie Gypsum-2	1999	Metals, pesticides, PCB Aroclors, SVOCs, VOCs	0	9	Spearman (1999)
Dredge material characterization Hurlen Construction Company & Boyer Alaska Barge Lines berthing areas	Hurlen-Boyer	1998	Metals, pesticides, PCB Aroclors, SVOCs, TBT, TPH	0	6	Hart Crowser (1998)
Sediment quality in Puget Sound. Year 2 – Central Puget Sound	PSAMP	1998	Metals, PCB Aroclor & selected congeners, pesticides, SVOCs, TBT	3	0	Ecology (2000)
EPA Site Inspection: Lower Duwamish River	EPA SI	1998	Metals, pesticides, PCB Aroclors & selected congeners, dioxins & furans, TBT, SVOCs, VOCs	300	33	Weston (1999)
King County combined sewer overflow water quality assessment for the Duwamish River and Elliott Bay	KC WQA	1997	Metals, PCB Aroclors, SVOCs, TBT	57	0	King County (1999a)

SAMPLING EVENT	EVENT CODE	YEAR CONDUCTED	CHEMICAL GROUPS ANALYZED	NUMBER OF SAMPLES		REFERENCE
				SURFACE (<15 cm)	SUBSURFACE (> 15 cm)	
Duwamish Waterway Phase 1 site characterization [a]	Boeing SiteChar	1997	Metals, PCB Aroclors, SVOCs	88	0	Exponent (1998)
Duwamish Waterway sediment characterization study	NOAA SiteChar	1997	Total PCBs, selected PCB congeners, total PCTs	328	0	NOAA (1997, 1998)
Seaboard Lumber site, Phase 2 site investigation	Seaboard	1996	Metals, PCB Aroclors, SVOCs	20	0	Herrera (1997)
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 2b	Plant 2 RFI-2b	1996	Metals, PCB Aroclors, SVOCs	39	44	Weston (1998)
Proposed dredging of Slip No. 4, Duwamish River, Seattle, WA	Slip4-Crowley	1996	Metals, pesticides, PCB Aroclors, SVOCs, VOCs, TBT	0	4	PTI (1996)
Duwamish/Diagonal cleanup Study – Phase 2	Duw/Diag-2	1996	Metals, PCB Aroclors, SVOCs, TPH	36	53	King County (2000a)
1996 USACE Duwamish O&M	ACOE96	1996	Metals, pesticides, PCB Aroclors, SVOCs, VOCs,	0	4	Striplin (1996)
Duwamish/Diagonal cleanup Study – Phase 1.5	Duw/Diag-1.5	1995	Metals, PCB Aroclors, SVOCs, TBT	12	0	King County (2000a)
Lone Star Northwest and James Hardie Gypsum – Kaiser dock upgrade	Lone Star-Hardie Gypsum	1995	Metals, pesticides, PCB Aroclors, SVOCs, VOCs	0	5	Hartman Associates (1995)
Norfolk CSO sediment cleanup study – Phase 3	Norfolk-cleanup3	1995	PCB Aroclors	16	0	King County (1996)
Norfolk CSO sediment cleanup study – Phase 2	Norfolk-cleanup2	1995	Metals, pesticides, PCB Aroclors and selected congeners, SVOCs, VOCs, TPH	12	27	King County (1996)
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 2a	Plant 2 RFI-2a	1995	Metals, PCB Aroclors SVOCs	54	0	Weston (1998)
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 1	Plant 2 RFI-1	1995	Metals, PCB Aroclors, TPH, SVOCs, VOCs	65	22	Weston (1998)

SAMPLING EVENT	EVENT CODE	YEAR CONDUCTED	CHEMICAL GROUPS ANALYZED	NUMBER OF SAMPLES		REFERENCE
				SURFACE (<15 cm)	SUBSURFACE (> 15 cm)	
Duwamish/Diagonal cleanup Study – Phase 1	Duw/Diag-1	1994	Metals, pesticides, PCB Aroclors, SVOCs, TBT	40	12	King County (2000a)
Norfolk CSO sediment cleanup study – Phase 1	Norfolk-cleanup1	1994	Metals, pesticides, SVOCs, PCB Aroclors, VOCs	21	3	King County (1996)
Rhône-Poulenc RCRA Facility Investigation for the Marginal Way facility – Round 2	Rhône-Poulenc RFI-2	1994	Metals, SVOCs, PCB Aroclors 1254 and 1260, pesticides	7	0	Rhône-Poulenc (1995)
Rhône-Poulenc RCRA Facility Investigation for the Marginal Way facility – Round 1	Rhône-Poulenc RFI-1	1994	Metals, SVOCs, PCB Aroclors 1254, pesticides	7	0	Rhône-Poulenc (1995)
Baseline sediment characterization at Duwamish Shipyards [b]	Duwamish Shipyard	1993	Metals, PCB Aroclors, SVOCs, TBT	5	0	Hart Crowser (1993)
Lone Star Northwest – West Terminal US ACOE – Seattle	Lone Star 92	1992	Metals, pesticides, PCB Aroclors, SVOCs, VOCs	0	1	Hartman Associates (1992)
Harbor Island Remedial Investigation	Harbor Island RI	1991	Metals, pesticides, PCB Aroclors, SVOCs, VOCs, TPH, TBT	34	0	Weston (1993)

Sample totals do not include laboratory replicates

[a] Sample total does not include three reference samples that were collected upstream of the study area

[b] This dataset is included on this table for the sake of completeness, but the existence of this dataset was not known until after completion of all analyses for the Phase 1 RI, ERA, and HHRA. These data will be considered for inclusion in Phase 2. None of the subsequent text, tables, or maps in this document refers to the data from this event.

PCB – polychlorinated biphenyl

PCT – polychlorinated terphenyl

SVOC – semivolatile organic compound
VOC – volatile organic compound
TBT – tributyltin
TPH – total petroleum hydrocarbons

With the exception of the Duwamish Waterway sediment characterization study (NOAA SiteChar), sediment samples were all analyzed for metals, semi-volatile organic compounds, organic carbon, and PCBs. The NOAA SiteChar event included only analyses of PCBs, polychlorinated terphenyls, organic carbon, and grain size. Older data exist, but are not included in this project, based on the data quality objectives established in the first LDW RI Task 2 deliverable (Windward 2001a), which suggest that these data are not representative of current conditions. The data from these sampling events are summarized in Section 4.2. Available QA / QC documentation for these data is summarized in Section 4.1.2. Note that, although these data met the DQO requirements of Phase 1, additional data quality evaluations will be conducted in cooperation with the agencies regarding the suitability of these data for Phase 2.

Sediment sampling locations by event are shown in Maps 2-4a and 2-4b (surface sediment) and 2-5 (subsurface sediment). In addition, maps were prepared with specific sampling locations identified by unique identifiers (location numbers). Surface sediment sampling locations are labeled by location numbers on nine maps (Maps 2-6a to 2-6k). The Surface Sampling Location Table that accompanies those maps (Map Table 1 in the Oversize Maps and Tables volume) provides a key to the figures so that all samples associated with a specific location can be identified. Similar maps (Maps 2-7a to 2-7d) and a Subsurface Sampling Location Table were prepared for subsurface sampling locations. Maps 2-4a, 2-4b, and 2-5 show all sampling locations for the event on the map legend. Some of the sediment chemistry data from these locations no longer reflect current conditions because sediment was removed during the dredging events shown on these maps. Consequently, these samples were excluded from RI and risk assessment analyses. The excluded samples are identified in Tables D-1 (surface sediment) and D-2 (subsurface sediment) in Appendix D. One exception to this exclusion policy was made for the segment of the ACOE maintenance dredging from channel centerline stations 254 to 275.56 (approximately RM 4.3 to RM 4.7) that is dredged every one to two years. Sediment data from this reach, though it has been dredged since sampling, likely adequately characterize the sediment quality of these frequently dredged sediments. Consequently, these data were included in the analyses.

2.3.2 Surface water quality

Ongoing ambient water quality monitoring data are collected from a single location within the LDW. King County collects monthly samples from the center of the 16th Ave South bridge at two depths, 1 m below the surface and 1 m above the sediment. Washington Department of Ecology conducts monthly sampling at two stations on the

Green River, but both are upstream of the LDW (Table 2-2). Ecology has also sampled other stations upstream of the LDW in the past, but these stations are not part of the current monitoring program (Table 2-2). Water from the ambient monitoring stations is analyzed only for conventional water quality parameters.

Table 2-2. Selected ambient monitoring stations within the Green River watershed

STATION ID	DESCRIPTION	RIVER MILE [a]	MONITORING STATUS
0307	LDW at 16th Ave S bridge	3.3	Current; monthly sampling
09A060	Duwamish River at Allentown bridge	8.3	Historical; last sampled in 1990
09A080	Green River at Tukwila	12.4	Current; monthly sampling
09A090	Green River at 212th St near Kent	18.3	Historical; last sampled in 1994
09A130	Green River above Big Soos/Auburn	33.9	Historical; last sampled in 1994
09A190	Green River at Kanaskat	57.6	Current; monthly sampling

[a] River mile as measured from the southern tip of Harbor Island. The LDW as a waterway is bounded by the upstream extent of commercial vessel navigation at Turning Basin 3 (at River Mile 4.7).

Water quality sampling within the LDW was conducted by King County during their Water Quality Assessment project (King County 1999a) at the stations listed in Table 2-3. Samples were collected from Brandon and Southwest Michigan at three locations corresponding to the east and west banks and the center of the channel. Only the east and west banks were sampled at Norfolk. Samples were collected from 1 m below the surface and 1 m above the sediment. Samples were collected weekly from October 1996 to June 1997, except during storm events, in which case sampling was conducted on three successive days following the storm.

Table 2-3. Sampling design for receiving water quality – King County Water Quality Assessment

LOCATION	TRANSECT	DEPTHS	DATE RANGE [a]	PARAMETERS [b]
Brandon CSO (RM 1.1)[c]	west, center, east	1 m below surface and 1 m above bottom sediment	Oct 30, 1996 to June 3, 1997	Conventionals, metals, organic compounds, bacteria
Southwest Michigan CSO (RM 1.9)[c]	west, center, east			
Norfolk CSO (RM 4.9)[c]	west, east			

[a] Storm events occurred on December 5, March 16, April 21, May 14, May 20, and June 1

[b] Analytical schedule varied by parameter; most conventionals measured in every sample, but metals and organics were measured less frequently

[c] River miles measured from the southern tip of Harbor Island.

2.3.3 Porewater quality

Chemistry data from sediment porewater were collected during only one of the sediment studies summarized in Table 2-1. In 1998, porewater samples from 15 locations were collected as part of the EPA Site Inspection of the LDW (Weston 1999) from locations throughout LDW subtidal areas (Map 2-8). These samples were analyzed for 28 trace elements and butyltins.

2.3.4 Groundwater quality

Groundwater data are available from 12 sites as listed in Table 2-4. These groundwater data were collected for site-specific investigations. Groundwater from each site was analyzed for various analytes depending upon chemicals of concern in groundwater at each site. In general, the most frequently analyzed chemicals were VOCs, metals, and PCBs. Frequency and extent of sampling at each site ranges from extensive sampling on a quarterly basis to infrequent monitoring at a limited number of monitoring wells. Chemicals of potential concern are briefly summarized in Section 4.2.6, and described in greater detail on a site-specific basis in Appendix G.

Table 2-4. Industrial facilities with groundwater chemistry data

SITE NAME	REFERENCE
Advance Electroplating	Ecology & Environment (1997); Cutler (1999); Sanga (2002)
Boeing Developmental Center	Landau (2001, 2002)
Boeing Isaacson	ERM and Exponent (2000); ERM (2000)
Boeing Plant 2	Weston (1996, 1998, 2002a,b)
Great Western International	Terra Vac and Floyd-Snider (2000)
Long Painting	Kleinfelder (2000)
Malarkey Asphalt	Secor (1998); Onsite (2000)
PACCAR	GeoEngineers and Kennedy/Jenks (1990); Kennedy/Jenks (1996, 1999, 2002)
Philip Services Corporation	PSC (2001, 2002a,b)
Rhône-Poulenc	Rhône-Poulenc (1995, 1996); GeoEngineers (2002)
South Park Landfill	King County (2000e); Holmes (2002)
T108/Chiyoda	AGI (1992)

2.3.5 Fish and shellfish tissue chemistry

Tissue chemistry data for the study area are available from six projects (Table 2-5). The tissue collection locations by event and sample type are shown in Map 2-10; the accompanying Tissue Sampling Location Table lists the samples associated with each location. Tissue data are most abundant for chinook and coho salmon, followed by English sole, mussels, perch, and crab. Polychlorinated biphenyls (PCBs)[18] were measured in most samples. Pesticides and semivolatile organic compounds were also measured frequently. Mercury, arsenic, lead, copper, and TBT were measured in fewer samples.

Available data are from several different tissue types, not all of which are suitable for the various analyses in the Phase 1 risk assessments (see Appendices A and B) and thus were not described in the nature and extent of contamination in Section 4.2.7. Table 2-5 describes all available tissue data and indicates which samples are used in the RI (Section 4.2.7) and the risk assessments (Appendices A and B). Some data were

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[18] PCB tissue data are most commonly available asAroclors, a common commercial name for PCB mixtures, but limited homologue and PCB congener data are also available for some tissues.

excluded from the risk assessments because they do not represent the exposure being characterized (e.g., amphipod chemistry data are not relevant to the seafood consumption pathways for humans). Additional discussion of data selection procedures and results is provided in Section 4.2.7 and Appendices A and B.

Table 2-5. Tissue chemistry samples collected from the LDW since 1990

TITLE	YEAR	SPECIES	N [a]	SAMPLE TYPE	NUMBER OF ANIMALS PER SAMPLE	CHEMICALS	RI[b]	HHRA[c]	ERA BENTHIC[d]	ERA FISH[d]	ERA WILDLIFE[d]
Waterway Sediment Operable Unit Harbor Island Superfund Site - Assessing human health risks from the consumption of seafood (Environmental Solutions Group 1999)	1998	English sole	3	skinless fillet	5	Hg, TBT, PCBs	X	X			
		red rock crab	3	edible meat	5		X	X	X		
		Dungeness crab	1	edible meat	1		X	X	X		
		striped perch	3	skinless fillet	1-5		X	X			
King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay (King County 1999a) [e]	1996-1997	Dungeness crab	2	edible meat	3	metals, TBT, semivolatiles, PCBs	X	X	X	X	X
			1	hepatopancreas	3			X	X	X	X
		English sole	3	skinless fillet	20		X	X		X	
			3	whole body [f]	20		X			X	X
		amphipods	4	whole body	~ 2000		X		X	X	X
		shiner surfperch	3	whole body	10		X			X	X
		mussels	22	whole body	50-100		X	X		X	X
Puget Sound Ambient Monitoring Program – annual sampling (West et al. 2001)	1992	English sole	3	skinless fillet	5-20	semivolatiles, pesticides, PCBs, As, Cu, Pb, Hg	X	X		X	
	1992	Coho salmon	6	skinless fillet	5		X				
	1992	Chinook salmon	6	skinless fillet	5		X				
	1993	Coho salmon	5	skinless fillet	5	pesticides, PCBs, As, Cu, Pb, Hg	X				
	1993	Chinook salmon	6	skinless fillet	5		X				
	1994	Coho salmon	5	skinless fillet	5		X				
	1994	Chinook salmon	7 [g]	skinless fillet	1-5		X				
	1995	Coho salmon	7 [g]	skinless fillet	1-5		X				
	1995	Chinook salmon	15 [h]	skinless fillet	1-5		X				
	1995	English sole	3	skinless fillet	5-20		X	X		X	
	1996	Chinook salmon	49 [i]	skinless fillet	1		X				
	1996	Coho salmon	19 [j]	skinless fillet	1-5		X				
	1997	English sole	3	skinless fillet	5-20	Hg, pesticides	X	X		X	
	1998	Coho salmon	13	skinless fillet	4		X				

TITLE	YEAR	SPECIES	N[a]	SAMPLE TYPE	NUMBER OF ANIMALS PER SAMPLE	CHEMICALS	RI[b]	HHRA[c]	ERA BENTHIC[d]	ERA FISH[d]	ERA WILDLIFE[d]
Elliott Bay/Duwamish River Fish Tissue Investigation (Battelle Marine Research Laboratory 1996; EVS 1995; Frontier Geosciences 1996)	1995	English sole	3	skinless fillet	6	PCBs, Hg, MeHg, TBT	X	X		X	
NMFS Duwamish injury assessment project (NMFS 2002)	2000	Chinook salmon (juveniles)	29[k]	whole body	1-10	PCBs, pesticides	X			X	X
			6	stomach contents	5-10					X	
Contaminant exposure and associated biochemical effects in outmigrant juvenile chinook salmon from urban and non-urban estuaries of Puget Sound (Varanasi et al. 1993)[l]	1989-1990	Chinook salmon (juveniles)	14	whole body	2-10	pesticides, PCBs, PAHs	X			X	X
			6	stomach contents	10					X	

MeHg – methylmercury

[a] Number of individual or composite samples

[b] Section 4.2.7

[c] Appendix B

[d] Appendix A

[e] Data from crab and English sole samples that were cooked were collected during the King County Water Quality Assessment, but were not used in the RI (Section 4.2.7) or in the quantitative sections of the risk assessment. These data were used by King County (1999a) in their HHRA. Approximately 30 additional mussel samples, beyond those indicated in the table, were analyzed as part of four- to six-week caged mussel deployments designed to assess the portion of bioaccumulative chemicals from CSO inputs. Data from these samples were not used in the Phase 1 RI or risk assessments because the resident mussel tissue data are more representative of natural exposure conditions.

[f] Samples are remnants following the subsampling of fillet tissue. In addition, livers were removed from some fish in the composite samples.

[g] One sample was an individual fish, not a composite sample

[h] Two samples were individual fish, not composite samples

[i] All samples were individual fish, not composite samples

[j] Five samples were individual fish, not composite samples

[k] Twenty samples were individual fish, not composite samples

[l] Six composite samples of juvenile chinook livers were also analyzed. Data from these samples were not used in the RI or risk assessments because whole body concentrations were available for the purpose of the RI and available toxicological data based on liver concentrations were unavailable for comparison in the ERA (Section A.2.4.3.1 in Appendix A).

2.4 HABITAT AND BIOLOGICAL COMMUNITIES

This section presents a summary of the habitat types in the LDW as well as the species that use this habitat, including benthic invertebrates, fish, wildlife, and plants. The key objective of this section is to provide a list of available studies investigating the presence of these species in the LDW and to provide a summary of the results from these site-specific studies; Section A.2.2 in Appendix A (Phase 1 ERA) provides greater detail regarding the life history characteristics and dietary preferences of these species.

2.4.1 Habitat

The river channel, its shoreline, and intertidal habitats of the LDW have been modified extensively since the late 1800s through hydraulic changes (see Section 2.2.3), channel dredging and filling of surrounding floodplains, and the construction of overwater structures, levees, dikes, and other bank stabilization structures. The remnants of natural meanders along the LDW, now used as slips, and the area west of Kellogg Island are the only evidence of the river's original winding course. Major habitat types identified in Puget Sound nearshore environments include eelgrass meadows, kelp forests, flats, tidal marshes, subestuaries, sand spits, beaches and backshore, banks and bluffs, and marine riparian habitat (Battelle et al. 2001). In the LDW, tidal marshes, subestuaries, intertidal flats, and marine riparian vegetation are the dominant natural nearshore habitat types present (Map 2-11;[19] Battelle et al. 2001). Man-made structures such as pilings also provide habitat for fish and encrusting invertebrates such as barnacles and mussels.

Tidal marshes are characterized by the presence of emergent aquatic plants and low shrubs, are tidally inundated, and regionally occupy areas of floodplain from approximately 2.4 m (8 ft) above mean lower low water (MLLW) to 0.6 m (2 ft) above mean higher high water (MHHW; Blomberg et al. 1988). Tidal marsh plant assemblages are tolerant of a narrow range of salinity. They support productive communities and can serve as sources of organic matter for estuarine ecosystems (Mitsch and Gosselink 1993). The shallow water and dense vegetation of tidal marshes provides refuge and foraging and rearing habitat for benthic invertebrates and fish, such as juvenile salmonids (Battelle et al. 2001). In addition, tidal marshes provide important foraging and nesting habitat for many birds including great blue heron, kingfishers, and marsh wrens (Battelle et al. 2001). Tidal marshes can also provide important physical functions in estuaries such as wave buffering and flood attenuation (Battelle et al. 2001).

Subestuaries are defined as the area of a river mouth, such as the mouth of Duwamish River, that is most exposed to tidal inundation (Battelle et al. 2001). These areas are mixing zones of fresh and salt water and provide many important ecosystem functions

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[19] Habitat types in map are based on aerial photo interpretation and are classified more generally than in Battelle et al. (2001).

such as buffering floodwaters and providing habitat for salinity-tolerant plant communities. Similar to tidal marshes, subestuaries are important foraging and resting habitat for many fish species and have been recognized as transition zones for salmonids (Battelle et al. 2001).

Intertidal flats[20] are generally defined as the gently sloping area from MLLW up to the edge of tidal marsh vegetation (Blomberg et al. 1988). These habitats can include mudflats, which consist of unconsolidated silts and clays, and sandflats, which consist of unconsolidated, predominantly sand sediments (Simenstad et al. 1991). Intertidal flats serve many ecosystem functions such as providing food and habitat for benthic invertebrates, fish, shorebirds, and aquatic mammals. A diverse assemblage of invertebrate species, including chironomid larvae (midges, a type of fly), clams, polychaetes (a type of worm), oligochaetes, (a type of worm), and amphipods (small epibenthic crustaceans), can be abundant in intertidal habitats and many fish and bird species rely on these invertebrate communities for food (Battelle et al. 2001; Cordell et al. 2001; Leon 1980). In addition, flats containing gravel may support high densities of bivalve populations (Battelle et al. 2001). Other functions that intertidal flats serve include sources of nutrients to primary producers and wave attenuation for up-slope tidal marshes (Battelle et al. 2001).

Marine riparian vegetation zones are generally defined as the area intermediate to aquatic and terrestrial habitats. Vegetation in these zones can encompass many marsh and swamp plant species including emergent macrophytes, shrubs, and large trees (Blomberg et al. 1988). Depending on the type of vegetation present, these riparian zones can serve various ecosystem functions such as habitat and prey resources for birds and aquatic mammals, and sources of nutrients, woody debris, and shade to adjacent aquatic habitats (Battelle et al. 2001). These riparian zones protect water quality and bank erosion, as well as provide water storage during flooding. Such riparian zones are relatively sparse throughout the LDW due to the urban development of shoreline and upland habitats and changes in hydrology and salinity. Thus, the functions provided by this habitat type are limited in the LDW.

Most (98%) of the approximately 510 hectares (ha) (1,270 acres [ac]) of tidal marsh and 590 ha (1,450 ac) of flats and shallows, and all of about 500 ha (1,230 ac) of tidal wetland historically in the LDW, have been either filled or dredged (Blomberg et al. 1988), or altered by the hydrologic changes discussed in Section 2.2.3. Remnant tidal marsh account for only 2 ha (5 ac), and mudflats for 22 ha (54 ac) (Map 2-10; Leon 1980). Kellogg Island, located south of Harbor Island, is the largest remnant of habitat remaining in the LDW and is presently designated as a wildlife refuge. Habitat associated with the island includes high and low marsh, intertidal flats, and filled uplands (Canning et al. 1979). Kellogg Island is highly altered from its historic size, shape, and function. It was filled with dredge spoils by ACOE in the 1950s and 1960s, altering its interior. In 1974, when the Port of Seattle deposited 1,700 m^3 (2,200 cubic

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[20] The elevation boundary between intertidal and subtidal is approximately -0.6 m (-2 ft) MLLW.

yards [cy]) of dredged materials on the island (Sato 1997), an upland component of Kellogg Island was created. A mixture of introduced and native plant and tree species rapidly colonized the 7-ha (17-ac) island.

Remnants of natural intertidal habitat occur on the northern portion of Kellogg Island and in occasional patches throughout the LDW (Map 2-10). The majority of the LDW shoreline is composed of riprap, pier aprons, or sheet piling (Tanner 1991). These hard surfaces support populations of encrusting organisms, such as barnacles, and burrowing organisms, such as shipworms (Leon 1980). Shoreline armoring is usually present at the top of most of the intertidal zone, but areas of sloping mud and sandflats can exist below (Battelle et al. 2001). However, due to shoreline armoring, inputs of sediment, nutrients, and organic matter (i.e. woody debris) from upland riparian vegetation zones are decreased relative to inputs received by sandflats in non-urban estuaries, resulting in relatively diminished habitat quality in these flats (Battelle et al. 2001). In addition, overwater structures (e.g., docks and piers), which are common throughout the LDW, shade shallow and intertidal habitats, alter microclimates, and inhibit growth of plant communities, thus further degrading nearshore habitats for native fauna (Battelle et al. 2001).

Small intertidal areas of marsh and unvegetated marsh habitat in the LDW have become the focus of habitat restoration activities (www.darcnw.noaa.gov/eb.htm). The objectives of these projects include the removal of rock riprap and over-water wharf structures, restoration of natural tidal flow, and natural colonization by native wetland plants (Cordell et al. 1996).

2.4.2 Benthic invertebrates

Benthic invertebrate species are important components of the LDW ecosystem because they serve as a major food resource for commercially and recreationally important fish and wildlife, and they serve a critical role in overall nutrient cycling. This section presents a summary of studies that have investigated site usage by benthic invertebrates (Section 2.4.2.1) and a summary of results from these studies (Section 2.4.2.2). Details regarding life history characteristics and dietary preferences are presented in Section A.2.2.2 in Appendix A.

2.4.2.1 LDW studies summary

Nine studies have been conducted in the LDW investigating site usage by benthic invertebrates (Table 2-6). Map 2-12 lists the benthic invertebrate community and sediment toxicity sampling locations in the LDW. Most of the sampling has been conducted in a very limited area around Kellogg Island and is associated with restoration sites (Cordell et al. 1996, 1997, 1998) or as part of reconnaissance surveys. Benthic invertebrate samples have been collected from nine other locations (King County 1999a; Ecology 2000).[21]

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[21] Studies that have evaluated the toxicity of LDW sediments to benthic macroinvertebrates are summarized in Table A-3-10 in Appendix A.

Table 2-6. Benthic macroinvertebrate datasets collected in the LDW

REPORT TITLE	YEAR CONDUCTED	CITATION	STUDY DETAILS
Results of second phase of LDW clam reconnaissance survey	2000	Windward (2000)	Clam reconnaissance
Waterway Sediment Operable Unit, Harbor Island Superfund site	1999	ESG (1999)	Crab reconnaissance
Sediment Quality in the Puget Sound	1998	Ecology (2000)	3 BCA samples
King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay - Benthic Task	1997	King County (1999a)	6 BCA samples
Duwamish Coastal America Restoration and Reference Sites: Results from 1997 monitoring studies (KI)	1997	Cordell et al. (1998)	21 BCA samples
Duwamish Coastal America Restoration and Reference Sites: Results from 1996 monitoring studies (KI)	1996	Cordell et al. (1997)	21 BCA samples
Duwamish Coastal America Restoration and Reference Sites: Results from 1995 monitoring studies (KI)	1995	Cordell et al. (1996)	6 BCA samples
Terminal 107 (Kellogg Island) biological assessment, 1989	1989	Williams (1990)	investigated intertidal and subtidal near KI
Benthic community impact study for Terminal 107 (Kellogg Island) and vicinity	1976, 1977	Leon (1980)	investigated intertidal and subtidal near KI

BCA – Benthic Community Analysis

KI – Kellogg Island

2.4.2.2 Summary of site usage

Based on results of these studies, benthic invertebrates observed in the LDW comprise 187 taxa, representing 46 families in 10 phyla (Table 2-7). Typical of estuarine environments, the invertebrate community is dominated by annelid worms, mollusks, and arthropods. Annelids are the most diverse of these three groups in the LDW, comprising 75 taxa of polychaete worms. Mollusks present include various bivalves and a lesser representation of snails. Amphipods were the most diverse group of arthropods documented.

The invertebrates present in the LDW form two distinct communities. The infaunal community is typified by burrowing polychaetes and bivalves. King County (1999a) found that at most stations, the infaunal community was dominated by surface detrital/surface-deposit feeding organisms. The epibenthic community (invertebrates living on top of the sediment), which consists mainly of larger crustaceans and mussels, is dominated by surface detrital and surface filter-feeding organisms.

Table 2-7. Species list of benthic invertebrates in the LDW

PHYLUM	CLASS	ORDER	FAMILY	GENUS AND SPECIES
Bryozoa				
Cnidaria				
	Hydrozoa			
		Hydroida		
	Anthozoa (sea anemones)			
		Actiniaria		
			Edwardsiidae	
				Edwardsia sp.
				Edwardsia californica
				Edwardsia callimorpha
				Edwardsia leidya
				Edwardsia sipunculoids
Platyhelminthes				
	Turbellaria (flatworms)			
		Polycladida		
			Stylochidae	
				Kaburakia excelsa
Nemertea (proboscis worms)				
	Anopla			
		Heteronemertea		
			Lineidae	
				Cerebratulus californiensis
				Cerebratulus sp.
		Palaeonemertea		
			Tubulanidae	
				Tubulanus sp.
	Enopla			
		Hoplonemertea		
Nematoda				
Annelida (segmented worms)				
	Archianellida			
	Oligochaeta			
			Megascolecidae	
				Enchytraeus sp.
			Naididae	
				Paranais sp.
	Polychaeta			
			Ampharetidae	
				Ampharete lobrops
				Amphicteis sp.
				Amphicteis scaphobranchiata
				Asabellides lineata
				Pseudoamphicteis sp.
				Hobsonia florida
			Arabellidae	
			Arenicolidae	
				Abarenicola pacifica
			Capitellidae	
				Capitella capitata
				Heteromastus filiformis
				Heteromastus filobranchus
				Heteromastus sp.
				Mediomastus sp
				Nodomastus sp.
			Cirratulidae	
				Aphelochaeta sp.
				Aphelochaeta monilaris
				Chaetozone setosa
				Chaetozone sp.
				Cirratulus sp.
				Tharyx multifilis
			Cossuridae	
				Cossura sp.
				Cossura pygodactylata
			Dorvilleidae	
			Eunicidae	
			Glyceridae	
				Glycera americana
				Glycera nana
				Glycera capitata
			Goniadidae	
				Glycinde picta
				Glycinde polygnatha
				Goniada sp.
				Goniada maculate
			Hesionidae	
				Podarkeopsis glabra
			Lumbrineridae	
				Lumbrineris luti
				Scoletoma luti
			Maldanidae	
				Euclymene zonalis
				Euclymeninae sp.
			Nephtyidae	
				Nephtys sp.
				Nephtys cornuta
				Nephtys ferruginea
			Nereidae	
				Neanthes sp.
				Nereis sp.
				Platyneris bicanaliculata
			Onuphidae	
				Onuphis iridescens
			Opheliidae	
				Ammotrypane sp.

Phylum	Class	Order	Family	Genus and Species
				Ammotrypane aulogaster
				Armandia brevis
				Ophelina acuminata
			Orbiniidae	
				Levinsenia gracilis
				Scoloplos sp.
			Paraonidae	
				Aricidea lopezi
			Pectinariidae	
				Pectinaria californiensis
			Phyllodocidae	
				Anaitides sp.
				Eteone longa
				Eteone sp.
				Phyllodoce sp.
			Pilargiidae	
				Pilargus maculata
			Polynoidae	
				Tenonia priops
			Sabellidae	
				Sabella sp.
				Manayunkia aestuarina
				Fabricia pacifica
				Fabricia sp.
			Sigalionidae	
				Pholoe sp.
				Pholoe minuta
			Sphaerodoridae	
				Sphaerodoropsis sphaerulifer
			Spionidae	
				Dipolydora caulleryi
				Laonice sp.
				Polydora uncata
				Polydora cornuta
				Polydora cardilia
				Polydora quadrilobata
				Polydora sp.
				Prionospio sp.
				Prionospio jubata
				Paraprionospio pinnata
				Pseudopolydora kempi japonica
				Pseudopolydora paucibranchiata
				Pygospio elegans
				Pygospio sp.
			Syllidae	
				Exogone lourei
			Terebellidae	
				Amphitrite cirrata
				Artacama coniferi

Phylum	Class	Order	Family	Genus and Species
				Lanassa venusta venustai
				Polycirrus sp.
Mollusca				
	Bivalvia			
		Myoida		
			Hiatellidae	
				Hiatella arctica
			Myidae	
				Cryptomya californica
				Mya arenaria
		Mytiloida		
			Mytilidae	
				Megacrenella columbiana
				Mytilus edulis
		Nuculoidea		
			Nuculidae	
				Nucula tenuis
			Nuculanidae	
				Nuculana minuta
		Ostreoida		
			Anomiidae	
				Pododesmus cepio
		Pholadomyoida		
			Lyonsiidae	
				Lyonsia californica
			Pandoridae	
				Pandora filosa
				Pandora sp.
			Thraciidae	
				Thracia trapezoides
		Veneroida		
			Cardiidae	
				Clinocardium sp.
				Clinocardium nuttali
			Kelliidae	
				Odontogena borealis
			Lucinidae	
				Lucinoma acutlineata
				Parvilucina tenuisculpta
			Montacutidae	
				Mysella tumida
				Mysella sp.
			Solenidae	
				Solen sicarius
			Tellinidae	
				Macoma balthica
				Macoma carlottensis
				Macoma elimata
				Macoma expansa

Phylum	Class	Order	Family	Genus and Species
				Macoma incongrua
				Macoma nasuta
				Macoma yoldiformis
				Macoma sp.
				Tellina sp.
			Thyasirdae	
				Axinopsida serricata
			Veneridae	
				Psephidia lordii
				Saxidomus giganteus
				Transennella tantilla
	Gastropoda (snails)			
		Mesogastropoda		
			Epitoniidae	
				Epitonium sp.
			Melanellidae	
				Melanella sp.
			Rissoidae	
				Alvania compacta
				Barleeia sp.
			Turritellidae	
				Tachyrhynchus sp.
		Neogastropoda		
			Nassinae	
				Nassarius sp.
			Columbellidae	
				Alia carinata
				Mitrella gouldii
				Nitidella gouldi
	Opisthobranchia (subclass)			
			Pyramidellidae	
				Odostomia sp.
		Nudibranchia		
			Aeolidacea	
		Cephalaspidea		
			Gastropteridae	
				Gastropteron pacificum
			Doridiidae	
				Melanochlamys diomedea
		Pteropoda		
	Aplacaphora			
			Chaetodermatidae	
				Chaetoderma sp.
Arthropoda				
	Arachnida			
		Acari		
			Halacaridae	
	Crustacea			
		Amphipoda		

Phylum	Class	Order	Family	Genus and Species
				Tritella pilimana
				Incisocalliope sp.
				Eochelidium miraculum
				Chromopleustes oculatus
			Aoridae	
				Aoroides sp.
			Ampithoidae	
				Ampithoe sp.
			Anisogammaridae	
				Eogammarus confervicolus
				Anisogammarus confervicolus
				Anisogammarus sp.
			Caprellidae	
			Corophiidae	
				Corophium acherrusicum
				Corophium salmonis
				Corophium spinicorne
				Corophium insidiosum
				Corophium sp.
			Eusiridae	
				Paramoera sp.
			Ischyroceridae	
				Protomedeia sp.
			Melitidae	
				Melita desdichada
			Oedicerotidae	
				Americhelidium shoemakeri
				Monoculoides sp.
				Westwoodilla caecula
			Podoceridae	
				Dyopedos sp.
		Cladocera		
			Podonidae	
				Podon leuckarti
		Euphausiacea		
			Euphausid	
		Isopoda		
			Paramunnidae	
				Munnogonium sp.
				Munnogonium tillerae
			Pleurogoniidae	
				Pleurogonium rubricundum
			Sphaeromatidae	
				Gnorimosphaeroma oregonesis
			Epicaridea	
		Cumacea		
			Diastylidae	
				Diastylis santamariensis
			Lampropidae	

Phylum	Class	Order	Family	Genus and Species
				Lamprops quadriplicata
			Nannastacidae	
				Cumella vulgaris
			Leuconidae	
				Eudorella pacifica
				Nippoleucon hinumensis
		Tanaidacea		
				Leptochelia sp.
				Leptochelia savignyi
				Sinelobus stanfordi
				Tanais sp.
		Mysidacea		
			Mysidae	
				Neomysis mercedis
				Alienacanthomysis macropsis
		Decapoda		
			Cancridae	
				Cancer oregonensis
			Crangonidae	
				Crangon sp.
				Crangon alaskensis
			Hippolytidae	
				Eualus pusiolus
			Pinnotheridae	
				Pinnixa schmitti
		Thoracica		
			Balanomorpha (suborder)	
			Balanidae	
				Balanus crenatus
	Copepoda (subclass)			
		Harpacticoida		
			Ancorabolidae	
			Ameiridae	
				Ameira sp.
				Nitocra sp.
			Canthocamptidae	
				Leimia vaga
				Cletocamptus sp.
				Mesochra sp.
				Mesochra rapines
			Canuellidae	
				Coullana canadensis
			Cletodidae	
				Acrenhydrosoma sp.
				Enhydrosoma sp.
			Cylindropsyllidae	
			Darcythompsoniidae	
			Diosaccidae	
				Amphiascopsis cinctus

Phylum	Class	Order	Family	Genus and Species
				Amphiascopsis sp.
				Amphiascoides sp.
				Amonardia perturbata
				Amonardia normani
				Diosaccus sp.
				Diosaccus spinatus
				Bulbamphiascus sp.
				Robertsonia sp.
				Typhlamphiascus pectinifer
				Typhlamphiascus sp.
				Stenhelia asetosa
				Stenhelia peniculata
				Stenhelia sp.
				Schizopera knabi
				Schizopera sp.
			Ectinosomatidae	
				Pseudobradya sp.
			Harpacticidae	
				Harpacticus uniremis
				Harpacticus sp.
				Harpacticus compressus
				Harpacticus obscurus
				Harpacticus spinulosus
				Harpacticus arcticus
				Zaus sp.
			Huntemanniidea	
				Nannopus palustris
				Huntemannia jadensis
			Laophontidae	
				Heterolaophonte discophora
				Heterolaophonte longisetigera
				Heterolaophonte hamondi
				Laophonte sp.
				Laophonte cornuta
				Laophonte elongata
				Echinolaophontes sp.
				Onychocamptus mohammed
				Paralaophonte sp.
				Paralaophonte pacifica
				Paralaophonte perplexa
				Pseudonychocamptus sp.
			Longipediidae	
				Longipedia sp.
			Normanellidae	
				Normanella sp.
			Orthopsyllidae	
				Orthopsyllus illgi
			Paramesochridae	
				Apodopsyllus sp.

Phylum	Class	Order	Family	Genus and Species
			Parastenheliidae	
				Parastenhelia hornelli
				Parastenhelia spinosa
			Peltidiidae	
			Tachidiidae	
				Microarthridion littorale
				Tachidius disciples
				Tachidius triangularis
			Tegastidae	
			Thalestridae	
				Dactylopodia crassipes
				Dactylopodia vulgaris
				Dactylopodia tisboides
				Dactylopodia paratisboides
				Dactylopodia glacialis
				Diarthrodes sp.
				Idomene sp.
				Paradactylopodia sp.
				Parathalestris sp.
				Rhynchothalestris helgolandica
			Tisbidae	
				Scutellidium sp.
				Tisbe sp.
		Cyclopoida		
			Cyclopoidae	
				Halicyclops sp.
			Oithonidae	
				Oithona similis
				Oithona longirastris
		Calanoida		
			Temoridae	
				Eurytemora sp.
				Eurytemora americana
			Centropagidae	
				Centropages abdominalis
			Pseudodiaptomidae	
				Pseudodiaptomus marinus
			Stephidae	
				Stephos sp.
			Calanidae	
				Calanus sp.
			Paracalanidae	
				Paracalanidae sp.
			Clausocalanidae	
				Microcalanus sp.
				Pseudocalanus sp.
			Acartiidae	
				Acartia sp.
				Acartia longiremis

Phylum	Class	Order	Family	Genus and Species
		Poecilostomatoida		
			Corycaeidae	
				Corycaeus anglicus
			Clausidiidae	
				Hemicyclops sp.
			Ergasilidae	
			Oncaeidae	
				Oncaea sp.
	Ostracoda			
		Myodocopida		
			Cylindroleberididae	
			Philomedidae	
				Euphilomedes carcharodonta
		Podocopida		
	Insecta (larvae)			
		Ceratopogonidae		
		Coleoptera		
		Diptera (pupa)		
			Dolichopodidae (larvae)	
			Chironomidae (larvae)	
		Empididae		
		Collembola		
		Trichoptera		
		Thysanoptera		
Echinodermata				
	Stelleroidea			
		Ophiurida		
			Amphiuridae	
				Amphiodia sp.
				Amphiodia digitata
	Holothuroidea			
		Dendrochirotida		
			Cucumariidae	
				Pentamera sp.
Cephalorhyncha				
	Priapulida			
			Priapuloidae	
				Priapulus caudatus
Rhizopoda				
	Rhizopodea			
		Foraminiferida		
Rotifera				

Sources: Bingham (1978); Leon (1980); Williams (1990); Cordell et al. (1996, 1997); Taylor et al. (1999); Striplin (1998)

Intertidal Community

The key physical factors influencing infaunal benthic invertebrate species distribution and abundance are salinity, water depth, percent fines (silt and clay), and organic carbon content (Leon 1980; Cordell et al. 2001; Striplin 1998). The intertidal community has been sampled at various locations throughout the LDW. Leon (1980) identified 43 different benthic taxa in sediment cores from the intertidal mudflats at Kellogg Island. Most organisms occurred infrequently; nine types accounted for 97% of all individuals. Small marine worms of the genus *Manayunkia*, oligochaetes, and harpacticoid copepods made up nearly 80% of all individuals (Leon 1980). In comparison, very few organisms were found at a mudflat site with anoxic sediments near the Duwamish Shipyards. A greater degree of seasonal variability in the benthic community was observed at a mudflat site in the marina near Kellogg Island compared to sediments from Duwamish Shipyards. Williams (1990) identified 80 invertebrate taxa inhabiting intertidal habitats at Kellogg Island. Nematodes, oligochaetes, small harpacticoid copepods, ostracods, and sabellid polychaetes were the dominant forms.

Cordell et al. (2001) conducted epibenthic and infaunal surveys at 14 restoration and reference sites throughout the LDW from 1993 through 1999. They found diversity and abundance of intertidal organisms varied seasonally and among locations in the LDW. The greatest diversity of organisms (i.e., species richness) occurred in the lower LDW; diversity was comparatively lower in Turning Basin 3. Seasonally, species diversity and abundance increased from winter through summer as primary productivity increased. In spring, community composition was generally dominated by two to three species. By summer, the species composition was generally more evenly distributed among a greater number of species. At all sites sampled, the macrofauna (>0.5 mm) were generally numerically dominated by nematodes, oligochaetes, polychaete worms of the genus *Manayunkia*, and gammarid amphipods of the genus *Corophium*. The meiofauna (0.045 – 0.5 mm) at all sites sampled were generally dominated by nematodes and harpacticoid copepods. The authors attribute the differences in diversity and abundance among sites to differences in sediment grain size, intertidal vegetation, disturbance from boat traffic and dredging, and greater fluctuations in salinity at the upstream sites.

Subtidal Community

The subtidal community is less well characterized than the intertidal community in that surveys have only taken place below RM 1.5. Diversity and abundance in the upper LDW (above RM 1.5) is unknown. Because there is less fluctuation in salinity in the subtidal than in the intertidal zone, subtidal diversity and abundance may vary less between the upper and lower LDW than do intertidal abundance and diversity. Leon (1980) used van Veen grab samplers to characterize the subtidal epibenthic and infaunal sediment biota at five locations below RM 1.5. They found more than 60 different taxa, greater than the number found in the intertidal habitat from the same survey. The most abundant taxon was deposit-feeding Cirratulid polychaete worms. Most subtidal species were deposit-feeding polychaete worms characteristic of deeper, turbid waters of the LDW. Small deposit-feeding clams (*Macoma* sp., *Axinopsida* sp., and *Psephidia* sp.) and the amphipod *Anisogammarus* sp., which feeds on diatoms and green algae, were also present.

Williams (1990) sampled epibenthic biota to a depth of –8 ft MLLW near Kellogg Island and found that nematodes, oligochaetes, small harpacticoids, and cumaceans dominated the subtidal epibenthos. As with the intertidal benthos, stations with finer sediments generally had a greater abundance of epibenthic biota.

King County evaluated risks to benthic infauna and epibenthos as a component of their assessment of CSO discharges to the LDW and Elliott Bay (Striplin 1998). Subtidal samples were collected with a 0.1-m^2 van Veen grab sampler and organisms were retained using a 1.0-mm mesh sieve. Sampling sites included transects located at Kellogg Island and downgradient from the Diagonal CSO/SD and Duwamish CSO. Polychaeta were abundant in all samples and were the dominant organisms at all locations except at two stations downstream of the Diagonal CSO/SD and Duwamish CSO, where Oligochaeta and Mollusca were dominant. A Kellogg Island station also had relatively abundant Mollusca. Arthropoda tended to be more abundant in deeper waters.

Macroinvertebrate Species

The Puget Sound Ambient Monitoring Program (PSAMP) has conducted otter trawls in the LDW near Kellogg Island annually from 1992 to 1998 as part of the fish monitoring component of the program. Large invertebrates were captured in addition to the target fish species (English sole and salmon). Larger benthic invertebrates in the LDW include various mollusks, crustaceans, arthropods, and echinoderms (Table 2-8). The species abundance in Table 2-8 is based on the results of otter trawls along the navigation channel, and thus may be biased away from benthic invertebrates associated with subtidal structures or rocks.

Dungeness and several other crab species are found in the LDW; their distribution is generally limited to the lower part of the estuary where salinity is greater. During a reconnaissance study conducted by Environmental Solutions Group (1999), Dungeness and red rock crabs were found at multiple locations near Kellogg Island, but adults could not be located upstream of this point, whereas juveniles were found up to the 1st Avenue Bridge.[22]

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[22] In this reconnaissance study, baited crab pots were deployed for at least 1.5 hours prior to checking for crabs. Pots were placed at approximately 20 locations from just south of Harbor Island to south of Boeing Plant 2.

Table 2-8. Average abundance per trawl of invertebrate species collected in PSAMP otter trawls from vicinity of Kellogg Island [a]

NAME	AVERAGE ABUNDANCE PER TRAWL
Graceful crab	16.7
Crangonid shrimp unidentified	11.5
Gigantic anemone	6.2
False ochre star	3.8
Dungeness crab	2.5
Coonstripe shrimp	2.3
Pink short-spined seastar	1.8
Dock shrimp	0.8
California arminid	0.7
Basket cockle	0.5
Leather star	0.3
Porcelain crab	0.3
Sunflower star	0.3
Oregon cancer crab	0.2
Chiton (unidentified)	0.2
Rose sea star	0.2
Scarlet anemone	0.2

Source: West (2001)

[a] A total of six otter trawls were conducted on 18 May 1992, 29 May 1993, 19 May 1995, and 14 April 1997 (three trawls) at depths of 5.5-11 m near Kellogg Island.

Shellfish

Windward (2000) conducted a reconnaissance survey to document the presence or absence of bivalves in the intertidal zone of several areas[23] within the LDW. This survey was an initial effort to understand more about the abundance and distribution of clams. Samples were collected by shovel using randomly placed transects and directed sampling. Only one clam was found using randomly placed transects; most of the clams were found when siphon holes in probable places were investigated. Abundance was highest at Kellogg Island, but one or more clams were found at each sampling site. Five different species were identified: butter clam (*Saxidomis giganteus*), softshell clam (*Mya arenaria*) sand clam (*Macoma secta*), bent-nose clam (*Macoma nasuta*), and the inconspicuous macoma (*Macoma inconspicua*). Mussels were also observed in large numbers on pilings and other structures in the lower, more saline end of the LDW, although they have also been reported to occur up to and slightly above Turning Basin 3 in the LDW.

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[23] Terminal 105, Kellogg Island, Slip 2, Slip 4, and Duwamish Yacht Club

2.4.3 Fish

A diverse population of fish use the LDW as habitat. This section presents a summary of studies that have investigated fish site usage (Section 2.4.3.1) and a summary of the results of these studies (Section 2.4.3.2). Details regarding life history characteristics and dietary preferences are presented in Section A.2.2 in Appendix A.

2.4.3.1 Summary of LDW fish studies

Data are available for eight studies conducted or ongoing in the LDW investigating site usage by fish (Table 2-9). The majority of these studies used active capture techniques such as beach seining and otter trawls. These techniques are biased against capture of highly mobile species and are not effective for rough substrates or near structures. One study (Weitkamp and Campbell 1980) used a passive technique (gill net). No additional species were observed by Weitkamp and Campbell (1980) beyond those observed using beach seines or otter trawls. Additionally, five of the eight studies were conducted prior to the diversion of the Renton Sewage Treatment Plant effluent in 1986. Because the diversion of the sewage treatment plant effluent decreased summer flows by as much as 25% (~1.6 m^3/s [56 cfs]) (see Section 2.2.3), the diversity and abundance of fish in the LDW may have changed somewhat since these studies were conducted. Because the LDW has not been comprehensively surveyed, additional fish species beyond those presented in Table 2-10 may be present.

Table 2-9. Summary of studies assessing fish community in the LDW [a]

Survey Citation	Year Surveyed	Sampling Frequency	Gear	Number of Locations Sampled	Locations
PSAMP (West 2001)	1992-1997	6 samples over entire survey	otter trawl	1	Kellogg Island
Taylor et al. (1999)[b]	Apr-Aug 1998	biweekly	beach seine	7 (2 in LDW)	Kellogg Island and Harbor Island area
Warner and Fritz (1995)	Feb-Sep 1994	biweekly, but weekly Apr and May	beach seine	9	Kellogg Island to above rapids
Meyer et al. (1981)	Apr-Jul 1980	biweekly, but weekly mid Apr-Jun	purse seine	2	Kellogg Island and at S Kenyon St (RM 3)
Meyer et al. (1981)	Apr-Jul 1980	biweekly, but weekly mid Apr-Jun	beach seine	2	Kellogg Island and at S Kenyon St (RM 3)
Weitkamp and Campbell (1980)	Oct 1977-Aug 1978	quarterly	gill net (surface and bottom)	1	South end of Kellogg Island
Weitkamp and Campbell (1980)	Oct 1977 - Aug 1978	monthly Oct-Feb plus Jul and Aug; more frequently Mar-Jun	purse seine	5	Kellogg Island and adjacent channel
Weitkamp and Campbell (1980)	Oct 1977 - Aug 1978	monthly Oct-Feb plus Jul and Aug; more frequently Mar-Jun	beach seine	5	Kellogg Island and adjacent channel
Malins et al. (1980)	1979	quarterly	7.5-m otter trawl	1 in LDW	South end of Harbor Island
Miller et al. (1975, 1977a)	1974-1975	monthly	5-m otter trawl	8 (7 in LDW)	West Waterway to Turning Basin 3
Matsuda et al. (1968)	1964-1966	weekly	beach seine	2	upper and lower LDW (exact locations unknown)

[a] ACOE conducted beach seine and fyke net sampling in the LDW in 2002, but data are not yet available (Goetz 2002). PSEP conducted otter trawls in the LDW in 1985, but data are only available in summary form combined with Elliott Bay data; raw data are not available.

[b] additional sampling occurred in 2001 and 2002

2.4.3.2 Summary of site usage by fish

The LDW is home to numerous anadromous and resident fish species (Table 2-10). Warner and Fritz (1995) recorded 33 resident and seasonal species of fish in the LDW. Miller et al. (1977a) observed a total of 29 species and Matsuda et al. (1968) recorded a total of 28 species. Of the species reported in the LDW, shiner surfperch, snake prickleback, Pacific sandlance, Pacific staghorn sculpin, English sole, and starry flounder were particularly abundant, as were chinook, chum, and coho salmon. This section briefly summarizes the fish observed in the LDW, including anadromous salmonids, other salmonids, and non-salmonid fish. For additional details regarding their life history characteristics and dietary preferences, see Section A.2.2.3 in Appendix A.

Table 2-10. Fish species in the LDW

COMMON NAME	SCIENTIFIC NAME	FAMILY	ABUNDANCE	CITATION	ENVIRONMENT	HABITAT	CITATION	DIET	CITATION
Bay goby	*Lepidogobius lepidus*	Gobiidae	r	2, 3, 6	marine (estuary)	benthic (mud bottom)	9	benthic organisms	25
Bay pipefish	*Syngnathus grisiolineatum*	Syngnathidae	r	6	marine	demersal (associated with eel grass in the intertidal areas)	11	isopods, amphipods	10
Big skate	*Raja binoculata*	Rajidae	r	7	marine	benthic (sandy and gravelly bottoms)	12	crustaceans, fish	10
Buffalo sculpin	*Enophrys bison*	Cottidae	r	1, 2, 3, 4, 7	marine (estuary)	benthic (inshore rocky and sandy areas)	9	mainly algae, also amphipods, small fishes, crabs, polychaetes, nudibranchs, isopods	9, 26
Bull trout	*Salvelinus confluentes*	Salmonidae	r	6	anadromous	benthopelagic (near shore)	17	mainly fish, plus zooplankton	28
Butter sole	*Isopsetta isolepis*	Pleuronectidae	c, (r)	6, (7)	marine (estuary)	benthic (sandy bottom)	9	worms, fish, shrimps	10
Chinook salmon [a]	*Oncorhynchus tshawytscha*	Salmonidae	a, (r)	1, 4, 5, 6, (2)	anadromous	benthopelagic	24	juveniles: insects, epibenthic crustaceans, pelagic organisms	27
Chum salmon [a]	*Oncorhynchus keta*	Salmonidae	r (a)	1, 4, (5, 6)	anadromous	benthopelagic	24	juveniles: copepods, amphipods, cumaceans, euphausiids	26
C-O sole	*Pleuronichthys coenosus*	Pleuronectidae	r	7	marine	benthic (flat bottoms, rocky areas)	9	isopods, fish, polychaetes, amphipods, turbellarians, bivalves	26
Coho salmon [a]	*Oncorhynchus kisutch*	Salmonidae	r, (c), [a]	1, 2, (4), [6]	anadromous	benthopelagic	24	juveniles: insects, epibenthic crustaceans, pelagic organisms, small fish	26
Cresent gunnel	*Pholis laeta*	Pholidae	r	6	marine (estuary)	demersal (intertidal areas, under rocks)	9	gammarid amphipods, copepods, tanaids, isopods	26
Cutthroat trout	*Oncorhynchus clarki*	Salmonidae	r	1, 4, 5, 6	anadromous	benthopelagic	18	fish, epibenthic crustaceans, pelagic organisms, insects	14
Dolly Varden	*Salvelinus malma*	Salmonidae	r	1, 4	fresh water	benthopelagic	17	fish, epibenthic crustaceans, pelagic organisms, insects	10

COMMON NAME	SCIENTIFIC NAME	FAMILY	ABUNDANCE	CITATION	ENVIRONMENT	HABITAT	CITATION	DIET	CITATION
Dover sole	*Microstomus pacificus*	Pleuronectidae	c, (r)	2, (3)	marine	benthic (mud bottom)	9	benthic invertebrates, echinoderms, mollusks, polychaetes	20
English sole	*Parophrys vetulus*	Pleuronectidae	a, (r)	2, 3, 4, 7 (1,6)	marine (estuary)	benthic (sand and mud bottoms)	14	cumaceans, gammarid amphipods, polychaetes, tanaids, crabs, bivalves	26
Eulachon	*Thaleichthys pacificus*	Osmeridae	i	3	anadromous	pelagic	9	plankton (only feeds while at sea)	16
Flathead sole	*Hippoglossoides elassodon*	Pleuronectidae	i	2	marine	benthic (soft mud bottom, adults below 180m)	9	polychaetes, cumaceans, gammarid amphipods, isopods, bivalves	26
Hybrid sole	*Inopsetta Isopsetta ischyra*	Pleuronectidae	r	1	marine (estuary)	benthic	9	benthic organisms	10
Largescale sucker	*Catostomus macrocheilus*	Catostomidae	i (r)	1, 2, 4, (6)	fresh water	demersal	17	algae, diatoms, insects, amphipods, and mollusks	16
Longfin smelt	*Spirinchus thaleichthys*	Osmeridae	a, (r)	1, 2, (7)	anadromous	benthopelagic (close to shore, in bays and estuaries)	17	crab larvae, copepods, mysid shrimp	26
Longnose dace	*Rhinichthys cataractae*	Cyprinidae	i	6	fresh water	demersal	17	mayflies, blackflies, and midges	16
Mountain whitefish	*Prosopium williamsoni*	Salmonidae	i	1, 6	fresh water	benthopelagic	10	insects, inverts, eggs, small fish	10
Northern pikeminnow	*Ptychocheilus oregonensus*	Cyprinidae	i	1, 6	fresh water	benthopelagic	16	insects, fish	16
Northern sculpin	*Icelinus borealis*	Cottidae	r	6	marine	demersal	9	benthic crustaceans, shrimps/prawns	10, 26
Pacific cod	*Gadus macrocephalus*	Gadidae	r	2, 3, 4	marine	(demersal, continental shelf and upper slopes)	19	fish, octopi, large crustaceans, worms, amphipods	22, 26
Pacific herring	*Clupea pallasi*	Clupeidae	c, (a), [r]	1, 2, 7, (4), [6]	marine	benthopelagic (coastal, 1st yr in bays)	10	planktonic crustaceans, fish larvae	10, 26
Pacific sandlance	*Ammodytes hexapterus*	Ammodytidae	c, (r), [a]	4, (1), [6]	marine (brackish)	benthopelagic (surface or burrowed in sand)	9	zooplankton	13, 26

COMMON NAME	SCIENTIFIC NAME	FAMILY	ABUNDANCE	CITATION	ENVIRONMENT	HABITAT	CITATION	DIET	CITATION
Pacific staghorn sculpin	*Leptocottus armatus*	Cottidae	a, (c)	1, 2, 3, 4, 6, (7)	marine (lower estuary, offshore)	benthic (sandy bottom)	9	isopods, bivalve siphons, polychaetes, crabs, fish, tanaids, shrimp	15
Pacific tomcod	*Microgadus proximus*	Gadidae	r, (c), [a juvi]	1, 4, (2, 3), [7]	marine (brackish)	benthic (over sand)	19	shrimps, amphipods, isopods, gastropods, mussels, fishes	20
Padded sculpin	*Artedius fennestralis*	Cottidae	c, (r)	2, 3, (7)	marine	benthic	9	gammarid amphipods, isopods, tanaids, shrimp, copepods, small fish	14, 26
Penpoint gunnel	*Apodichthys flavidus*	Pholidae	r	5, 6	marine (estuary)	demersal (intertidal-tidepools)	9	isopods, amphipods, shrimp, gastropods, other epibenthic crustaceans	26
Pile perch	*Rhacochilus vacca*	Embiotocidae	r, (c)	1, 2, 3, 6, (4, 7)	marine	demersal (rocky shores; near kelp, pilings, underwater structures)	9	isopods, bivalves, crabs, amphipods	26
Pink salmon [a]	*Oncorhynchus gorbuscha*	Salmonidae	r	6	anadromous	benthopelagic	24	juveniles: copepods, amphipods, barnacle larvae, cumaceans	23, 25
Plainfin midshipman	*Porichthys notatus*	Batrachoididae	i	2	marine	benthic (nearshore shelf, sand/mud bottom)	14	crustaceans, fish	10
Prickly sculpin	*Cottus asper*	Cottidae	r	1, 2, 3, 4, 6	marine	benthic	9	benthic organisms	16
Pygmy poacher	*Odontopyxis trispinosa*	Agonidae	i, (r)	2, 3, (7)	marine	demersal (soft bottoms)	9	epibenthic invertebrates	10
Ratfish	*Hydrolagus colliei*	Chimeridae	r	2, 7	marine	demersal (sandy bottom)	9	worms, bivalves, crustaceans, fishes	13, 26
Redsided shiner	*Richardsonius balteatus*	Cyprinidae	c	6	fresh water	demersal	16	zooplankton, algae, insects	16
River lamprey	*Lampetra ayresi*	Petromyzontidae	r	1, 4, 6	anadromous	demersal	10	adult: fish juveniles: detritus, algae	16
Rock sole	*Lepidopsetta bilineata*	Pleuronectidae	c, (a)	2, 3, (7)	marine (estuary)	benthic (more pebbly bottom than most other flatfish)	9	isopods, gammarid amphipods, polychaetes, cumaceans, bivalves, crabs, fish	26

COMMON NAME	SCIENTIFIC NAME	FAMILY	ABUNDANCE	CITATION	ENVIRONMENT	HABITAT	CITATION	DIET	CITATION
Rockfish	*Sebastes* spp.	Scorpaenidae	r	1, 8	marine	demersal (near structure)	21	crabs, gammarid amphipods, mysids, shrimp, fish	22
Roughback sculpin	*Chitonotus pugeteneis*	Cottidae	i, (r)	2, (3, 7)	marine	benthic (sand/mud bottom)	9	shrimps and other crustaceans	14
Saddleback gunnel	*Pholis ornata*	Pholidae	r	3, 5, 6	marine (estuary)	demersal (sandy bottom)	9	amphipods, isopods, polychaete, copepods, cumaceans	26
Sand sole	*Psettichthys melanostictus*	Pleuronectidae	c, (r)	1, 2, 3, 7, (1)	marine, estuary	benthic (sandy bottom)	10	fishes, worms, crustaceans and mollusks	10, 26
Sharpnose sculpin	*Clinocottus acuticeps*	Cottidae	i	6	marine	benthic (sand/vegetation)	9	benthic organisms	18
Shiner surfperch	*Cymatogaster aggregata*	Embiotocidae	a, (c)	1, 4, 5, 6, 7, (2, 3)	marine (estuary)	demersal (in shallow water, around eelgrass beds, piers and pilings commonly in bays and quiet back waters)	9	amphipods, cumaceans, polychaetes, copepods, isopods, algae	18, 26
Slender sole	*Lyopsetta exilis*	Pleuronectidae	i	3	marine	benthic (>200m depth)	9	carnivore	20
Snake prickleback	*Lumpenus saggita*	Stichaeidae	a, (r)	1, 2, 3, 4, 6, (7)	marine	benthopelagic (shallow bays and offshore waters)	9	bivalves, marine worms, amphipods	26
Sockeye salmon [a]	*Oncorhynchus nerka*	Salmonidae	i		anadromous	benthopelagic	24	juveniles: insects, epibenthic crustaceans, pelagic organisms	25
Soft sculpin	*Gilbertidia sigalutes*	Cottidae	r	4	marine	demersal	9	epibenthic crustaceans, phytoplankton, fish eggs/larvae	10
Speckled sanddab	*Citharichthys stigmaeus*	Bothidae	r	7	marine	benthic (sandy bottom)	9	crustaceans, fish	15
Spiny dogfish	*Squalus acanthias*	Squalidae	i	2	marine	benthopelagic	22	primarily fish	24
Starry flounder	*Platichthys stellatus*	Pleuronectidae	a, (c)	1, 2, 3, 4, 6, 7, (5)	marine (estuary, brackish)	benthic	18	isopods, fish, gammarid amphipods, polychaetes, gastropods, worms	10

COMMON NAME	SCIENTIFIC NAME	FAMILY	ABUNDANCE	CITATION	ENVIRONMENT	HABITAT	CITATION	DIET	CITATION
Steelhead [a]	*Oncorhynchus mykiss*	Salmonidae	r	1, 4, 5, 6	anadromous	benthopelagic		juveniles: insects, epibenthic crustaceans, pelagic organisms	26
Striped seaperch	*Embiotoca lateralis*	Embiotocidae	r, (c)	2, 3, 5, 6, 7, (1, 4)	marine	demersal	9	amphipods, isopods, crabs, shrimp	26
Sturgeon poacher	*Podothecus acipenserinus*	Agonidae	i	3	marine	demersal (soft bottom)	9	cumaceans, gammarid amphipods, shrimp, copepods, polychaetes, tanaids	26
Surf smelt	*Hypomesus pretiosus*	Osmeridae	c	1, 4, 6, 7	marine (brackish)	benthopelagic	18	isopods, cumaceans, larvaceans, copepods, amphipods	26
Three-spine stickleback	*Gasterosteus aculeatus*	Gasterosteidae	c, (r)	1, 5, 6 (4)	marine, anadromous	benthopelagic (in/near vegetation)	17	worms, crustaceans, insects/larvae, small fish	16, 26
Tubesnout poacher	*Pallasina barbata*	Agonidae	i	3	marine	demersal (eelgrass & seaweeds)	9	amphipods, polychaetes, copepods, mysids	26
Walleye pollock	*Theragra chalcogramma*	Gadidae	r	1, 2, 4	fresh water	benthopelagic	19	insects, midge larvae, fish	10
Whitespotted greenling	*Hexagrammos stelleri*	Hexagrammidae	i, (c)	2, (7)	marine (intertidal)	demersal (nearshore, near rocks, pilings and eelgrass beds)	19	gammarid amphipods, shrimp, crabs, fish, polychaetes	26

[a] Adults are found in the LDW only as they migrate to spawning ground upstream of the LDW

Abundance: a-abundant (numerically dominant), c-common (occurs in most samples), r-rare (occurs regularly in a few samples), i-incidental (not usually found in LDW). Letters in parentheses relate distinct abundance classification to citation; numbers in parentheses indicate the source of the distinct data. Abundance characterizations reflect data collected by authors in the cited study. These data may reflect sampling gear bias for the species identified.

Abundance citations: 1-Matsuda et al. (1968), 2-Miller et al. (1975), 3-Miller et al. (1977a), 4-Weitkamp and Campbell (1980), 5-Taylor et al. (1999), 6-Warner and Fritz (1995), 7–West et al. (2001); 8–Malins et al. (1980)

Biology citations: 9-Eschmeyer et al. (1983), 10-Hart (1973), 11-Dawson (1985), 12-McEachran and Dunn (1998), 13-Armstrong (1996), 14-Clemens and Wilbey (1961), 15-Fitch and Lavenberg (1975), 16-Scott and Crossman (1973), 17-Page and Burr (1991), 18-Morrow (1980), 19-Cohen et al. (1990), 20-Pearcy and Hancock (1978), 21-Lamb and Edgel (1986), 22-Cox and Francis (1997), 23- 24-Groot and Margolis (1991), 25-Grossman (1979), 26 Miller et al. (1977b), 27-Cordell et al. (2001), 28-Rieman and McIntyre (1993)

Anadromous Salmonids – Pacific Salmon

All species of Pacific salmon (coho, chinook, chum, sockeye, and pink[24]) have been found in the LDW (King County 2000b). These anadromous fish use the estuary for rearing and as a migration corridor for adults and juveniles. Among numerous beneficial uses of the LDW identified by METRO (now King County), use as habitat for outmigrating juvenile salmonids was listed as the most important (Harper-Owes 1983). Salmonid residence time in the LDW is species-specific. Salmon found in the LDW spawn mainly in the middle reaches of the Green River and its tributaries (Grette and Salo 1986). Of the salmon species, chinook salmon have been studied the most extensively in the Green-Duwamish system. Puget Sound chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) on March 24, 1999. The decline of chinook salmon has been attributed primarily to habitat degradation and fragmentation, blockage of migratory corridors, hatchery fish, and harvest practices (Meyers et al. 1998).

Other Salmonids

Bull trout were historically found in the LDW because it originally included a much larger upper elevation drainage area, including the White River that still contains a bull trout run. Current stock status in the Green / Duwamish system is unknown (WDFW 2000). Because bull trout are morphologically similar to other char, positive identification of bull trout requires genetic testing. Thus from a regulatory perspective, any char are to assumed to be bull trout. Muckleshoot tribal biologists captured one char positively identified as an adult bull trout during beach seining in the LDW on May 24, 1994. However, it is unknown whether the fish reared in the Green River or was an opportunistic resident (Warner and Fritz 1995). Eight sub-adult bull trout ranging in length from 271 to 373 mm (10.7-14.7 in.) were captured in beach seines in Turning Basin 3 during two sampling events in August and September 2000 (Shannon 2001). Bull trout typically spawn in the upper headwaters of a river system, generally requiring high oxygen concentrations and water colder than 10°C. Tissue samples were collected from these fish for genetic sampling; however, identification has not yet been confirmed (Shannon 2001). Peak numbers of juvenile shiner surfperch were captured at the same site the previous week, and near peak numbers of shiner surfperch were captured in the same sampling that the bull trout were caught, indicating that these bull trout may also have been opportunistic residents (Shannon 2001). There is no evidence that bull trout are spawned or reared within the LDW. Bull trout juveniles typically remain in the upper tributaries for a period of two to three years prior to migrating to saltwater during spring. Adults typically return to their native streams in summer and fall (Grette and Salo 1986). The Coastal-Puget Sound population of bull trout was proposed for listing under ESA in June 1998 and was formally listed as threatened on November 1, 1999. The Coastal-Puget Sound wide decline of bull trout has been attributed primarily to

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[24] Sockeye and pink salmon are relatively rare in the LDW.

habitat degradation and fragmentation, blockage of migratory corridors, poor water quality, past fisheries management practices, and introduction of non-native species (64FR 210: 58910-58933).

Summer steelhead (*Oncorhynchus mykiss*) is a non-native stock sustained by wild production of hatchery origin fish (WDFW 1993). The run size is unknown, but approximated at a few hundred fish (WDFW 1993). Winter steelhead consists of wild and hatchery fish with annual returns ranging from 944 to 2,378 fish (WDFW 1993). Grette and Salo (1986) report that repeat spawners make up approximately 19% or fewer of returning wild adults in the Green River (1976/77 to 1983/84). Winter steelhead outmigrate from the Green River as subyearling smolts and do not have an extensive residence time in the LDW. Summer steelhead outmigrate after rearing for two years in the upper watershed and also do not have as extensive residence time in the LDW (Grette and Salo 1986).

Sea-run cutthroat trout exist in the LDW, but little is known about this population. They are found throughout Puget Sound, and thus it is reasonable that they would be found in the Green/Duwamish River. A total of 11 cutthroat trout were captured in beach seines at nine stations sampled approximately 30 times each throughout the LDW from February through June 1994 (Warner and Fritz 1995). The Green/Duwamish sea-run cutthroat trout are believed to be a native stock maintained through wild production (WDFW 1993).

Non-salmonid Fishes

The most abundant non-salmonid fish in the LDW are snake prickleback, shiner surfperch, English sole, Pacific staghorn sculpin, starry flounder, and longfin smelt (Matsuda et al. 1968; Miller et al. 1975; Miller et al. 1977a, Weitkamp and Campbell 1980; Meyer et al. 1981; Warner and Fritz 1995; Taylor 1999; West 2001). Based on trawl data, English sole are reported to be most abundant in the lower portion of the estuary (approximately below Kellogg Island), and starry flounder most abundant in the upper estuary (Miller et al. 1977a; Matsuda et al. 1968). Shiner surfperch and Pacific staghorn sculpin are also reported to be more abundant in the lower estuary (Miller et al. 1975, 1977a). Longfin smelt and snake prickleback are seasonally abundant in the LDW. English sole, Pacific staghorn sculpin, and starry flounder are abundant year-round. Adult English sole migrate to their spawning grounds in Puget Sound in winter (Forrester 1969). Data from Malins et al. (1982) show that during the winter and spring, greater than 50% of the English sole in the LDW are juveniles (<150 mm [<5.9 in.]), and adult English sole are very rare upstream of the 1st Avenue Bridge. Species composition exhibited similar relative abundances among the seven studies noted above. Seasonal trends in total abundance for the LDW have summer and early fall peaks compared to the fall peak for Elliott Bay (Dexter et al. 1981). Shiner surfperch abundance peaks in summer during the bearing of young (Miller et al. 1977a).

2.4.4 Wildlife

The aquatic and semi-aquatic habitats of the LDW support a diversity of wildlife species. Formal studies, field observations, and anecdotal reports indicate that up to 87 species of birds and six species of mammals utilize the LDW at least part of the year to feed, rest, or reproduce. This section provides a brief overview of these bird and mammal species. More detailed information regarding their life history characteristics and dietary preferences is in Section A.2.2.4 in Appendix A.

2.4.4.1 LDW studies summary

Table 2-11 presents a summary of the wildlife studies conducted in the LDW. These studies surveyed avifauna, seals, and sea lions.

Table 2-11. Studies investigating the wildlife community of the LDW

TYPE OF SURVEY	CITATION
Monitored bird populations monthly from June 1995 to September 1997 and March 1999 to September 2000 at four sites[a]	Cordell et al. (1996,1997, 1998, 1999, 2001)
Conducted extensive surveys of avifauna near Kellogg Island and occasional surveys of the entire LDW in 1977/1978	Canning et al. (1979)
The presence of sea lions and harbor seals in the LDW was observed for 52 days from December 1998 to June 1999	WDFW (1999)

[a] Two in Turning Basin 3, one on Kellogg Island, and one at Terminal 105

2.4.4.2 Site usage by birds

The bird species associated with the LDW are presented in Table 2-12. This section discusses site usage by the following five guilds of birds:

- passerine / upland birds
- raptors
- shorebirds / waders
- waterfowl
- seabirds

Canning et al. (1979) recorded a total of 70 species: 26 passerines / upland birds, 3 raptors, 11 shorebirds / waders, 17 waterfowl, and 13 seabirds. They report Kellogg Island had a much higher diversity of birds than the rest of the LDW due to its seclusion and greater variety of habitats. Cordell et al. (2001) reported 75 species of birds: 32 passerine / upland birds, 7 raptors, 8 shorebirds / waders, 16 waterfowl, and 12 seabirds. Diversity and abundance were highest at the Kellogg Island site, but other areas of the LDW were also consistently used by a wide variety of birds. Birds were most abundant in the spring and least abundant in the summer.

Table 2-12. Bird species using the LDW

COMMON NAME	LATIN NAME	COMMON NAME	LATIN NAME
Passerine/Upland species		**Raptors**	
Blackbird, red-winged	*Agelaius phoeniceus*	Eagle, bald	*Haliaeetus leucocephalus*
Bushtit, common	*Psaltriparus minimus*	Falcon, peregrine	*Falco peregrinus*
Chickadee, black-capped	*Poecile atricapillus*	Hawk, Cooper’s	*Accipter cooperii*
Cowbird, brown-headed	*Molothrus ater*	Hawk, red-tailed	*Buteo jamaicensis*
Crow, northwestern	*Corvus corrinus*	Hawk, sharp-shinned	*Accipiter striatus*
Dove, rock	*Columba livia*	Hawk, Swainson’s	*Buteo swainsoni*
Finch, house	*Carpodacus mexicanus*	Merlin	*Falco columbarius*
Flicker, northern	*Colaptes auratus*	Osprey	*Pandion haliaetus*
Goldfinch, American	*Spinus tristis*	**Waterfowl**	
Hummingbird, Anna’s	*Calypte anna*	Bufflehead	*Bucephala albeola*
Junco, dark-eyed	*Junco hyemalis.*	Canvasback	*Aythya valisineria*
Kingfisher, belted	*Ceryle alcyon*	Coot, American	*Fulica americana*
Kinglet, ruby-crowned	*Regulus calendula*	Duck, domestic	*Anas domesticus*
Siskin, pine	*Spinus pinus*	Gadwall	*Anas strepera*
Quail, California	*Lophortyx californicus*	Goldeneye, Barrow’s	*Bucephala islandica*
Robin, American	*Turdus migratorius*	Goldeneye, common	*Bucephala clangula*
Sparrow, English (house)	*Passer domesticus*	Goose, cackling Canada	*Branta canadensis minima*
Sparrow, fox	*Passerella iliaca*	Goose, Aleutian	*Branta canadensis*
Sparrow, golden-crowned	*Zonotrichia atricapilla*	Goose, domestic	*Branta domesticus*
Sparrow, savannah	*Passerculus sandwichensis*	Mallard	*Anas platyrhynchos*
Sparrow, song	*Melospiza melodia*	Merganser, common	*Mergus merganser*
Sparrow, white-crowned	*Zonotrichia leucophrys*	Merganser, hooded	*Lophodytes cucullatus*
Starling, European	*Sturnus vulgaris*	Merganser, red-breasted	*Mergus serrator*
Swallow, barn	*Hirundo rustica*	Scoter, surf	*Melanitta perspicillata*
Swallow, cliff	*Petrochelidon pyrronota*	Teal, greenwinged	*Anas carolinensis*
Swallow, tree	*Iridoprocne bicolor*	Wigeon, American	*Mareca americana*
Swallow, violet-green	*Tachycineta thalassina*	**Seabirds**	
Thrush, Swainson’s	*Hylocichla ustulata*	Cormorant, double-crested	*Phalacrocorax auritus*
Towhee, rufous-sided	*Pipilo erythrophthlamus*	Cormorant, pelagic	*Phalacrocorax pelagicus*
Warbler, orange-crowned	*Vermivora celata*	Grebe, eared	*Podiceps capsicus*
Wren, Bewick’s	*Thryomanes bewickii*	Grebe, horned	*Podiceps auritus*
Wren, house	*Troglodytes aedon*	Grebe, pied-billed	*Podilymbus podiceps*
Shorebirds/Waders		Grebe, red-necked	*Podiceps grisegena*
Dowitcher	*Limnodromus sp.*	Grebe, western	*Aechmophorus occidentalis*
Dunlin	*Erolia alpina*	Guillemot, pigeon	*Cepphus columba*
Heron, great blue	*Ardea herodias*	Gull, glaucous-winged	*Larus glaucescens*
Heron, green	*Butorides virescens*	Gull, mew	*Larus canus*
Killdeer	*Charadrius vociferus*	Gull, ring-billed	*Larus delawarensis*
Sanderling	*Crocethia alba*	Loon, common	Gavia immer
Sandpiper, least	*Calidris minutilla*	Loon, Pacific	Gavia Pacifica
Sandpiper, spotted	*Actitis macularia*	Loon, red-throated	Gavia stellata
Sandpiper, western	*Calidris mauri*	Murre, common	*Uria aalge*
Yellowlegs, lesser	*Totanus flavipes*	Tern, Caspian	*Hydroprogne caspia*

Passerines/Upland Birds

Thirty-two species of passerine/upland birds have been documented along the LDW (Canning et al. 1979; Cordell et al. 1999; Table 2-12). These birds, while generally associated with upland habitats, occasionally forage in the exposed mudflats or use freshwater habitats along the river for bathing (Canning et al. 1979).

Raptors

Eight species of raptors have been reported to use the LDW (Cordell et al. 1999), including bald eagle. The bald eagle is listed under ESA as a threatened species, but is currently under review for delisting. In Washington, it is also listed as a state threatened species (WDFW 2001). There are five bald eagle nests within 8 km (5 mi) of the LDW that were occupied in 1999 (King County 1999a). The closest nest is located in West Seattle within 1.6 km (1 mi) of the LDW. One or two pairs of resident eagles may be found in the LDW vicinity during the summer (King County 1999a). Overwintering migrant eagles are routinely observed in the vicinity of the LDW from the beginning of October through late March.

Cooper’s hawks and sharp-shinned hawks have been observed to overwinter in the LDW. Red-tailed hawks are a resident species commonly observed along grassland/woodland margins along the LDW. Swainson’s hawks and merlin are rare in the LDW (Canning et al. 1979; Cordell et al. 1998). Cordell et al. (1994) report osprey using Kellogg Island and the restored turning basin sites. An osprey nest is located on a utility pole near Terminal 105 (Matt Luxon personal observation June 2000). A female peregrine falcon recently attempted but failed to nest at the West Seattle Bridge and mate with the male falcon inhabiting the Washington Mutual Tower in downtown Seattle (Anderson 2002). Peregrine falcon is listed as a species of concern under ESA. WDFW currently lists peregrine falcon as a state endangered species, although they are recommending changing the listing to a state sensitive species due to increased breeding success. (WDFW 2001).

Shorebirds/Waders

Ten species of shorebirds and wading birds have been documented in the LDW (Cordell et al. 1999), including green heron and great blue heron. Of these species, great blue heron make up the only sizeable or consistent population and were the most abundant shore/wading bird recorded by Cordell et al. (1996) on the Duwamish River, and are year-round residents. Great blue heron nest in colonies of up to several hundred pairs, preferably on islands or wooded swamps (Butler 1992). Two nesting colonies can be found in the vicinity of the LDW: one is located 11 km (6.8 mi) to the northwest (the Kiwanis Ravine colony), and the other is located 12 km (7.5 mi) to the southeast, in Renton (the Black River colony). A colony of up to 37 active nests was located in West Seattle a few hundred meters from Kellogg Island until 1999, but no successful nesting occurred there in 2000 or 2001 (Norman 2002).

The two most common shorebirds observed in the LDW are the sandpipers and killdeer. The spotted, least, and western sandpipers are reported to use the LDW in substantive numbers. Sandpipers have been observed feeding in the intertidal mudflats along the LDW. Least and western sandpipers occur in mixed flocks and are difficult to distinguish. These species nest primarily in northern Canada and Alaska in the summer months, but are reported to frequent Kellogg Island from September through May. Most are thought to be migrants, though some may reside in the LDW throughout the winter.

Spotted sandpipers are a common bird in western Washington, and are known to nest along the LDW. They have been observed in the LDW from late June through September (Cordell et al. 1996) but have been known to overwinter locally (Paulson 1993). Nesting birds arrive in May and June. Canning et al. (1979) recorded seven spotted sandpiper nests located on Kellogg Island, and at least three additional nest sites were suspected. Spotted sandpipers breed in open habitats along the margins of water bodies (Oring and Lank 1986).

Killdeer are a common bird that uses the LDW year-round, with 20 to 60 birds recorded to use the area in the winter and approximately 10 in the area in the fall and spring. They are recorded to nest along the LDW, though few are recorded outside the Kellogg Island area (Canning et al. 1979).

Waterfowl

Cordell et al. (1999) reported 16 species of waterfowl utilizing the LDW, including nine species of dabbling ducks. All species are migratory, though some non-migratory populations exist. In general, these birds overwinter in the Puget Sound area (and further south) and migrate north in the summer. A resident population of approximately 25 mallards lives year-round in the LDW, and an additional population of approximately 15 mallards overwinters in the LDW. As many as 290 migratory mallards have been reported to move through the LDW (Canning et al. 1979). The other dabbling duck species use the LDW for nesting and migration. The most significant of these are gadwalls. Approximately ten gadwall nests have been observed along the LDW in the vicinity of Kellogg Island (Canning et al. 1979).

Canvasback, greater scaup, bufflehead, and common and Barrow’s goldeneye are reported to use the LDW. A peak population of approximately 60 canvasbacks arrives in the LDW in November and departs in late February, using Kellogg Island as a primary feeding area. Greater scaup and common and Barrow’s goldeneyes arrive in the study area late November and depart by early May. A small population of approximately eight buffleheads is reported to overwinter in the LDW from December to May. Feeding by all diving duck species is centered around Kellogg Island (Canning et al. 1979).

All three species of North American mergansers have been recorded to use the LDW, two substantively. Migratory common mergansers are reported to use the LDW as they migrate through the area from September to March, though none overwinter in the area. Approximately 30 red-breasted mergansers are reported to overwinter in LDW from December to March.

A resident population of approximately 1,000 Canada geese resides in the vicinity of Lake Washington. The Duwamish population is thought to be a part of the Lake Washington population. Migratory Canada geese arrive in the LDW in January and February and remain until the end of July as a spring nesting population. In the LDW, 40 to 50 birds overwinter from September to April along Kellogg Island and the west bank of the LDW along the South Park district and in Turning Basin 3 (Canning et al. 1979).

Seabirds

Sixteen species of seabirds were recorded in the LDW during surveys conducted by Canning et al. (1979) and Cordell et al. (1999), including two species of cormorants (pelagic and double-crested). Wintering cormorants use the LDW November-May, with large numbers present December-April (Canning et al. 1979; Cordell et al. 1996).

Several species of gulls are reported to use the LDW. Glaucous-winged gulls and mew gulls are the only species reported to use the area in large numbers. Glaucous-winged gulls are reported to use the area throughout the year. Mew gulls frequent the area, occasionally in large numbers, from September through May (Canning et al.1979).

Caspian terns have been seen using Kellogg Island (M. Luxon personal observation). Pigeon guillemots and common murres have been reported in the LDW, however, their use of the LDW is infrequent.

Common loons are a state sensitive species (WDFW 2001). They are present in Puget Sound in winter and use local waters for resting during migrations to and from wintering areas further south. Annual winter counts indicate 10 to 30 birds in the Seattle area, although they are reported to be a rare visitor to the LDW (Canning et al. 1979).

Five species of grebes are reported in the LDW. Of these, only western grebes are found in substantive numbers. Grebes and other marine bird species have been declining in recent years (Nysewander et al. 2001). The LDW population is estimated to comprise about 90 birds (Canning et al. 1979). Grebes arrive in the LDW October-November and depart by early May.

2.4.4.3 Site usage by mammals

Three species of semi-aquatic terrestrial mammals use the LDW (raccoons, muskrats, and river otters) and three marine mammalian species may occasionally enter the LDW (harbor seal, California sea lion, and harbor porpoise) (Tanner 1991). Site usage by these species is discussed briefly below and in more detail in Section A.2.2.4 in Appendix A.

Anecdotal information indicates that a river otter family lives year-round on Kellogg Island in the LDW, although otters have not been observed by Cordell during wildlife surveys (Cordell 2001). River otters are almost exclusively aquatic and prefer food-rich habitats such as the lower portions of streams and rivers, estuaries, and lakes and tributaries that feed rivers (Tabor and Wight 1977; Mowbray et al. 1979). Raccoons are reported to be common along the forested ridge slopes to the west of the LDW. Muskrat populations are reported to exist at Terminal 107 and at Turning Basin 3 (Canning et al. 1979).

Harbor seals and sea lions are commonly seen in Elliott Bay and have been observed in the LDW. During a survey conducted by WDFW from December 1998 to June 1999, over 307 hours on 52 days, sea lions were observed on 16 occasions and seals on 17 occasions (WDFW 1999), with most observations for both species occurring below the 1st Avenue South Bridge. Harbor seals have been shown to forage over large distances ranging from 5 km (3.1 mi) (Stewart et al. 1989) to 55 km (34.2 mi) (Beach et al. 1985). Recent information on use of the LDW by harbor porpoises was not available, although it has been noted that they occasionally enter the LDW (Dexter et al. 1981).

2.4.5 Plants

Few studies have investigated the plant communities present in the LDW (Table 2-13). The methods used to assess plant communities ranged from analysis of aerial photos to field surveys. Most recently, Cordell et al. (2001) monitored the vegetation of wetland restoration and reference sites in the Duwamish River estuary by conducting surveys during the growing season at each site from 1993-1999.

Table 2-13. Summary of studies assessing plant communities in the LDW

TYPE OF SURVEY	CITATION
Vegetation surveys of restoration and reference sites within LDW and vicinity	Cordell et al. 2001
Aerial photo interpretation of intertidal and shoreline habitats and riparian vegetation in LDW	USFWS 2000
Aerial photo interpretation of habitat areas in LDW and vicinity	Tanner 1991
Field survey of wildlife habitat areas in vicinity of Terminal 107 on west bank of LDW	Canning et al. 1979

Tidal elevation and salinity gradients determine the potential distribution for estuarine plants. In Puget Sound, intertidal elevation gradients between MLLW and MHHW create habitats such as mid-, and high-elevation tidal marshes. Salinity gradients range from saline to brackish to fresh tidal waters. The most productive areas for estuarine plant communities are found in tidal marshes. Marsh soils are generally fine-textured and nutrient-rich, and support grasses, sedges, rushes, and various other types of plants associated with maritime and estuarine habitats. In the LDW, there is a total of 0.0175 km^2 (0.0068 mi^2) of habitat with macrophytes, primarily limited to portions of Kellogg Island and other small intertidal areas with vegetated intertidal habitat (USFWS 2000).

Carex (sedges) and *Scirpus* (bulrushes) are the predominant marsh vegetation type between the Turning Basin and Kellogg Island. *Carex* requires freshwater near its roots. Downstream from Kellogg Island are more marine plants such as *Salicornia* (grassworts), *Distichlis* (salt grass), and *Atriplex* (salt bush). The interior high marsh plant community of Kellogg Island, which is flooded only by higher spring tides, includes *Carex lyngbyei*, *Distichlis spicata*, *Juncus balticus* (Baltic rush), and *Phragmites* sp., a non-native species (Battelle et al. 2001). The naturally occurring *Carex* patches surveyed in 1993 occurred between elevations of 1.6 to 3.0 m (5.2 to 9.8 ft) above MLLW, and the single patch of naturally occurring *Scirpus* was at 3.7 m (12 ft) above MLLW (Cordell et al. 2001). Thus, these plants are seldom under water.

2.4.6 Threatened and endangered species

This section summarizes site usage by the 14 species reported in the LDW that are listed under either the federal Endangered Species Act (ESA), or by the Washington State Department of Fish and Wildlife, as candidate species, threatened species, or species of concern (Table 2-14).

Table 2-14. LDW species listed under ESA or by Washington State Department of Fish and Wildlife[a]

COMMON NAME	SCIENTIFIC NAME	STATUS	ABUNDANCE IN LDW[d]
Chinook salmon	*Oncorhynchus tshawytscha*	FT, SC	abundant (1, 2, 3, 4)
Coho salmon	*Oncorhynchus kisutch*	FC	rare to abundant (1, 2, 3, 4)
River lamprey	*Lampetra ayresi*	FSC, SC	rare (1, 2, 3)
Bull trout	*Salvelinus confluentes*	FT, SC	incidental (2)
Pacific herring	*Clupea herengus pallasi*	SC	rare to abundant (1, 2, 3, 5, 6)
Pacific cod	*Gadus macrocephalus*	SC	rare (3, 5)
Walleye pollock	*Theragra chalcogrammus*	SC	rare (1, 3, 5)
Rockfish species	*Sebastes spp.*	SC	rare (1); present (9)
Bald eagle	*Haliaeetus leucocephalus*	FT[b], ST	common (7)
Peregrine falcon	*Falco peregrinus*	FSC, SS[c]	anecdotal (8)
Merlin	*Falco columbarius*	SC	rare (7)
Common murre	*Uria aalge*	SC	believed to be rare
Common loon	*Gavia immer*	SS	rare (1)
Western grebe	*Aechmophorus occidentalis*	SC	common (7)

FT – Federal threatened species
FC – Federal candidate species
FSC – Federal species of concern
ST – State threatened species
SC – State candidate species
SS – State sensitive species
[a] Source for status: WDFW (2003)
[b] Listing currently under review for removal
[c] Downlisted from state endangered to state sensitive April 2002
[d] Abundance characterizations reflect data collected by the authors in the cited study. These data may reflect sampling gear bias for the species identified.

References for abundance:

1. Matsuda et al. (1968)
2. Warner and Fritz (1995)
3. Weitkamp and Campbell (1980)
4. Taylor et al. (1999)
5. Miller et al. (1975)
6. West (2001)
7. Cordell et al. (1997)
8. Anderson (2002)
9. Malins et al. (1980)

Eight of these fourteen listed species are fish and six are birds. With the exception of chinook salmon, coho salmon, bald eagle, western grebe, and perhaps Pacific herring, use of the LDW by these species is considered rare or incidental, based on the available data. Reports of these species in the LDW are from the following documents: loons, (Canning et al. 1979, rare), merlin (Cordell et al. 1997, rare), western grebe (Cordell 1997, common), common murre (believed to be rare), rockfish (Matsuda et al. 1968, rare; Malins et al. 1980, present[25]), river lamprey (Warner and Fritz 1995, rare; Matsuda et al. 1968, rare), Pacific herring (Matsuda et al. 1968, common; Miller et al. 1977a, rare; Warner and Fritz 1995, rare), walleye pollock (Matsuda et al. 1968, rare; Miller et al. 1977a, rare). Reports of peregrine falcon are anecdotal (Anderson 2002). NMFS ruled on November 22, 2000 that listing of Pacific cod and walleye pollock under the ESA is not warranted (65 FR 227, Friday,

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[25] Abundance relative to other species not presented in paper

November 24, 2000) and they also ruled on April 3, 2001 (66 FR 64) that listing of Pacific herring, brown rockfish, copper rockfish, and quillback rockfish is not warranted. Use of the LDW by chinook salmon, coho salmon, and bull trout is described in Section 2.4.3.2. Use of the LDW by bald eagle is described in Section 2.4.4.2.

2.5 HUMAN CHARACTERISTICS

This section provides site usage information for people. Included is information on demography, land use, and specific site usage activities.

2.5.1 Demography

Although the LDW is often viewed as an industrial corridor, two residential neighborhoods are adjacent to the LDW (Map 1-1). The population density within the LDW corridor is lower than in many other Seattle neighborhoods, reflecting the mixed land use of the area. The racial diversity among the 21,409 people within the City of Seattle living in these two neighborhoods is higher than the racial diversity within the Seattle and Tukwila city limits (Table 2-15).

Table 2-15. Population and racial background data for Duwamish neighborhoods, City of Seattle, and City of Tukwila

RACE	DUWAMISH NEIGHBORHOODS [a]	CITY OF SEATTLE [b]	CITY OF TUKWILA [b]
White	9,404 (43.9%)	394,889 (70.1%)	10,074 (58.6%)
Black or African-American	2,882 (13.5%)	47,541 (8.4%)	2,198 (12.8%)
American Indian and Alaska Native	349 (1.6%)	5,659 (1.0%)	223 (1.3%)
Asian	5,527 (25.8%)	73,910 (13.1%)	1,870 (10.9%)
Native Hawaiian and other Pacific islander	315 (1.5%)	2,804 (0.5%)	312 (1.8%)
Other single race	1,653 (7.7%)	13,423 (2.4%)	1,385 (8.1%)
Two or more races	1,279 (6.0%)	25,148 (4.5%)	1,119 (6.5%)
Total	21,409	563,374	17,181

Note: Percentage of total population in column given in parentheses

[a] Population estimates from City of Seattle boundaries only. Data from 2000 US census for tract numbers 9300, 9900, 10800, 10900, 11200, 11700, 26400, 26500 obtained from City of Seattle website (http://www.cityofseattle.net/planning/comprehensive/demog/info.htm)

[b] Data from 2000 US census obtained from Washington State website (http://www.ofm.wa.gov/census2000/pl/tables/ctable02.htm)

Socioeconomic data from the 2000 census have yet to be released, but the City of Seattle (1993) summarized salient facts for the Duwamish sub-area[26] from the 1990 census.

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[26] Defined by Jackson and Dearborn streets on the north, the Duwamish River on the west, Rainier Avenue on the east, and the city limits on the south

- Residents of the Duwamish area tend to have less formal education than is the case for other areas of the city – 31.4% of the residents 25 years and older have less than a high school education compared to 13.6% citywide
- The unemployment rate in the Duwamish area was higher than the city as a whole – 7.4% of the labor force was unemployed in 1990 compared to 4.9% citywide
- Incomes in the Duwamish area tend to be less than incomes citywide
    - median household income was $25,448 compared to $29,353 citywide
    - median family income was $30,458 compared to $39,860 citywide
    - per capita income was $11,309 compared to $18,308 citywide

2.5.2 Land use

Land use within the LDW drainage basin has changed considerably since the construction of Harbor Island approximately 100 years ago. Approximately 98% (5.7 km^2) of the Duwamish River's historic floodplain marshes and intertidal mudflats have been replaced with fill, overwater structures, commercial and industrial facilities, and other development (King County 2000b). The LDW, which covers only a small part of the LDW drainage basin, is primarily an industrial waterway today, but other land uses exist within the drainage basin (Table 2-16). Approximately 15% of the current land cover is vegetated[27] or open water; the remainder is bare ground or impervious surfaces (Table 2-16). The current vegetative cover, as a percentage of the total area, is greater than the percentage area designated for parks and open space, which is only 4.2% (Table 2-17).

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[27] Deciduous, grass, mixed forest, scrub/shrub

Table 2-16. Current land cover/land use for Green/Duwamish estuary sub-watershed

LAND COVER DESCRIPTION	AREA (Sq. Mi.)	AREA (Acres)	%OF SUB-WATERSHED
Industrial and commercial	5.93	3,796	26.67%
Bare rock/concrete	0.25	163	1.15%
Conifer – early	0.00	0.62	0.00%
Conifer – mature	0.00	0.00	0.00%
Conifer – middle	0.00	0.00	0.00%
Deciduous	1.57	1,004	7.05%
City center, industrial and mining	3.52	2,253	15.83
Low and medium density residential	3.48	2,227	15.65
High density residential	5.64	3,611	25.37%
Grass – brown	0.71	457	3.21%
Grass – green	0.39	247	1.74%
Mixed forest	0.14	92	0.65%
Open water	0.43	276	1.94%
Recently cleared	0.03	16	0.12%
Scrub/shrub	0.14	87	0.61%
Shadow	0.00	0.00	0.00%
Sub-watershed total	**22.23**	**14,230**	**100%**

Source: King County (2000b); categories assigned according to US Geological Survey conventions

Table 2-17. Designated land use for Green/Duwamish sub-watershed

COMP PLAN DESCRIPTION	AREA (Sq. Mi.)	AREA (Acres)	% OF SUB-WATERSHED
Designated agriculture	0.00	0.00	0.00%
Commercial	0.24	153	1.08%
Designated commercial forestry	0.00	0.00	0.00%
Industrial	9.63	6,163	43.31%
Mixed Use (incl. residential)	0.52	336	2.35%
Parks and open space	0.93	597	4.20%
Residential	8.68	5,558	39.06%
Utility and transportation	1.63	1,040	7.31%
Right of way	0.00	0.00	0.00%
Mineral resource lands	0.00	0.00	0.00%
Tribal, governmental, military	0.20	129	0.90%
Unknown designation	0.06	36	0.25%
Water	0.34	218	1.54%
Sub-watershed total	**22.23**	**14,230**	**100%**

Source: King County (2000b)

2.5.3 Human site use

Predominant human uses within the LDW and immediately adjacent areas are for commercial, industrial, and residential purposes. Recreational uses also occur, but on a more limited scale. Although recreational use may increase somewhat in the future, this area is anticipated to remain primarily commercial, industrial, and residential. Each use category is described below.

2.5.3.1 Commercial and industrial site use

Land use, zoning, and land ownership within the LDW corridor are consistent with an active industrial waterway. The LDW provides a critical navigational corridor for moving material associated with these facilities. Most of the industrial and commercial facilities on the LDW operate year-round vessel schedules. For example:

- Shipping companies move container-laden barges in both directions
- Cement companies bring raw materials in and ship products out
- Boats move in and out of shipyards

Although the LDW is heavily used for commercial and industrial purposes, little of the occupational exposure is related to sediments because the majority of the human activities take place above water. One exception is the commercial netfishing operations conducted by the Muckleshoot Tribe. Nets used by these fishers may come into contact with the sediment while they are deployed and retrieved. Appendix B provides further discussion on the exposure scenario created to characterize this exposure. The Muckleshoot Tribe's fishing operation operates seasonally on the LDW, although it is not associated with a permanent facility within the LDW. The LDW is part of the Muckleshoot Tribe's Usual and Accustomed fishing grounds; consequently, they are permitted by federal law to harvest salmon in commercial quantities from this area. Other tribes may also fish occasionally in the LDW, but much less frequently than the Muckleshoot Tribe (Ruggerone 2001).

2.5.3.2 Recreational site use

The LDW is not a major area for recreational use compared to other water bodies in and around Seattle (King County 1999a). However, there are several public access points where people may enter the LDW for recreational purposes (Map 1-1). Two motorboat launches, three hand boat launches, and nine shoreline public access sites existed in the LDW as of 1998 (Green-Duwamish Watershed Alliance 1998). Beach play has been observed at Duwamish Waterway Park in the South Park neighborhood. This park is the most likely access point in the LDW for direct contact with sediment. Many other access points are elevated above the water surface and separated from the sediment by steep banks covered by riprap or blackberry bushes. The number and type of public access points in the LDW will be enumerated in the Phase 2 RI.

Recreational boating in the LDW occurs on a limited basis. There are three marinas located in the LDW, as shown on Map 1-1. Few data have been located quantifying the frequency with which people use the river for recreational purposes. King County (1999a) discussed the human site use of both the Duwamish River and Elliott Bay, but presented quantitative data only for fishing. They suggested that few, if any, people engage in water activities such as swimming, SCUBA diving, and windsurfing within the LDW. The frequency of these recreational activities may increase in the future as ongoing remedial efforts and habitat restoration projects are completed, but such uses are likely to continue to be limited by the active commercial use of the river and the availability of nearby areas that provide superior recreational opportunities.

The recreational population most likely to be directly or indirectly exposed to contaminated sediments is human anglers. These individuals consume seafood from the LDW that may have been in direct contact with LDW sediments. King County (1999a) conducted a survey of fishing and seafood consumption practices and identified three sites where recreational fishing occurred in the LDW, (Duwamish Waterway Park, Diagonal Avenue, and a Boeing parking lot) ; the fishing frequency at these sites was very low compared to sites in Elliott Bay. Individuals (adults only) interviewed at these sites indicate they fish from one to four days per year within the LDW (Simmonds 2001). There will be additional evaluation of recreational seafood consumption from the LDW in Phase 2. This will include contact with the Washington State Department of Health.

Although available surveys (see Environmental Solutions Group [ESG 1999] for summary) indicate fishing within the LDW is infrequent relative to other fishing areas in the region, several recent surveys have documented relatively high seafood consumption for several Puget Sound populations, some of which may fish within the LDW for recreational or subsistence purposes (Toy et al. 1996; Suquamish Tribe 2000; EPA 1999a). ESG (1999) presented a review of seafood consumption surveys previously conducted in this area. Many individuals within these groups consume more seafood than do individuals from the general US population (EPA 1997b). Seafood consumption rates reviewed and those identified as the most representative for the Phase 1 HHRA are discussed further in Appendix B.

2.5.3.3 Residential/commercial site use

There are two mixed residential/commercial neighborhoods adjacent to the LDW. The South Park neighborhood is at the southern edge of Seattle city limits and borders the west bank of the LDW (Map 1-1). The neighborhood includes approximately 300 m (984 ft) of residential shoreline (Green-Duwamish Watershed Alliance 1998). Several houses in the South Park neighborhood abut the LDW; residents of these houses may visit shoreline areas and come into contact with intertidal sediments adjacent to their property. The Georgetown neighborhood is east of the LDW and East Marginal Way South (Map 1-1). This neighborhood is separated from the LDW by several commercial facilities between the LDW and East Marginal Way South, although access to the river by foot from this neighborhood is possible. Appendix B describes a beach play scenario that was evaluated in the Phase 1 HHRA to consider risks for residents and recreational visitors who might contact sediments in the intertidal zone of the LDW.

2.5.3.4 Miscellaneous site use

There are some human activities in the LDW that do not clearly fall within any of the three use categories discussed above. For example, shoreline restoration projects have been conducted along the LDW in the last 10 years and many more are planned (Green-Duwamish Watershed Alliance 1998). Many of these projects rely on volunteers who may be exposed to potentially contaminated sediments in the shallow subtidal or intertidal zones during work parties. Potential exposure for these individuals is expected to be episodic and of relatively short duration. Because of the nature of these activities, the scenario described above for evaluation of residential exposure is expected to provide a conservative means to evaluate potential exposure and risks associated with these less frequent activities.

3.0 Potential Applicable or Relevant and Appropriate Requirements

3.1 INTRODUCTION

This section presents potential applicable or relevant and appropriate requirements (ARARs) identified for the LDW site.[28] Because the LDW RI/FS is being conducted under a joint order of Washington's Model Toxics Control Act (MTCA) and the federal Comprehensive Environmental Resource Conservation and Liability Act (CERCLA), ARARs for both programs apply. The identification of ARARs is an iterative process. The list of ARARs is expected to change during the various phases of the remedial process and will be updated as appropriate. The ARARs could change due to identification of additional COCs during the RI or due to changes in remedial actions during the feasibility study. Final ARAR determinations will be made during the preparation of the Record of Decision (ROD).

3.1.1 Applicable requirements

State and federal requirements can be either *applicable* or *relevant and appropriate*. Applicable requirements, as defined in 40 Code of Federal Regulations (CFR) 300.5, are

> those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal

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[28] Most of the text and tables in this section were excerpted from EPA's Harbor Island RI prepared by Weston (1993).

> environmental or state environmental or facility siting laws that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance found at a CERCLA site. Only those state standards that are identified by a state in a timely manner and that are more stringent than federal requirements may be applicable.

In other words, an applicable requirement is one that a private party would have to comply with by law if the situation/action was not undertaken under CERCLA or MTCA. MTCA, the state equivalent to the federal CERCLA program, has a similar definition of applicable or relevant and appropriate requirements at WAC 173-340-710.

3.1.2 Relevant and appropriate requirements

If a requirement is not applicable, it may still be relevant and appropriate. Relevant and appropriate requirements, also defined in 40 CFR 300.5, are

> those cleanup standards, standards of control, and other substantive requirements, criteria, or limitations promulgated under federal environmental or state environmental or facility siting laws, that, while not "applicable" to a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well suited to the particular site. Only those state standards that are identified in a timely manner and are more stringent than federal requirements may be relevant and appropriate.

While the determination of "applicability" is a legal one, the determination of "relevant and appropriate" relies on professional judgment, taking into account the circumstances of the site, the chemicals, the actions, and the location. A relevant and appropriate requirement should cover situations similar to those at the site (relevancy) and be suitable for the conditions at the site (appropriateness). Both conditions must exist in order for a requirement to be relevant and appropriate. MTCA has a similar definition of applicable or relevant and appropriate requirements at WAC 173-340-710.

3.1.3 Items to be considered

Unenforceable standards or guidelines may be used as items to be considered (TBCs) in developing and evaluating remedial alternatives. Proposed standards, guidance documents, and health advisories are examples of potential items to be considered. Not all items to be considered need be reported [40 CFR 300.4(g)(3)]; a small number of items to be considered are presented at the end of this section.

3.2 ARAR CATEGORIES

ARARs may be divided into the following categories: chemical-specific, action-specific, or location-specific. These different categories are defined in the sections below; potential ARARS for the LDW are listed in Table 3-1 (chemical-specific ARARs), Table 3-2 (action-specific ARARs) and Table 3-3 (location-specific ARARs). These tables present both federal and state ARARs, because the LDW RI/FS is being conducted under both CERCLA and MTCA.

Table 3-1. Potential chemical-specific ARARs for the LDW[29]

MEDIUM/REQUIREMENT	STANDARD/CRITERIA	PREREQUISITE	CITATION	COMMENTS
Clean Air Act (42 USC 7401 et seq.; 40 CFR 50-69)	National primary and secondary ambient air quality standards	Site located in nonattainment area for National Ambient Air Quality Standards; treatment unit would be "significant source"	Clean Air Act (Sec.109; 40 CFR 50)	Not anticipated as ARAR; in general, emissions from site not expected to qualify as significant source.
Washington State Clean Air Act (70.94 RCW)	State implementation of ambient air quality standards		General Requirements for Air Pollution Sources (WAC 173-400)	Potential ARAR for investigative or remedial actions; site located in nonattainment zone for CO and ozone.
	Puget Sound Clean Air Agency (PSCAA) ambient and emission standards		PSCAA Regulations I and III	
Resource Conservation and Recovery Act (42 USCA 7401-7642) (40CFR 260-280)	Lists and characteristics for identifying hazardous wastes	Meets listing or characteristic definitions (includes threshold levels for Toxic Characteristic Leaching Procedure [TCLP])	Criteria for Identifying the Characteristics of Hazardous Waste and for Listing Hazardous Waste (40 CFR 261.24.10-11, Subpart B)	Using appropriate analytical methods or knowledge of the source of contamination, determination should be made whether sediments (including investigation-derived waste [IDW]) contain hazardous waste characteristic; certain requirements for management of hazardous wastes may be applicable or relevant and appropriate. Dredged sediments are excluded from RCRA Subtitle C if they are managed under the CWA Section 404 program (63 FR 65874)
Washington Dangerous Waste Regulations (WAC 173-303)	State criteria for dangerous waste which are broader than federal criteria	Meets listing or characteristic definitions, or concentrations exceed defined threshold criteria	Section -070, Designation procedures	The appropriate waste designation for state-listed or characteristic waste should be made in order to determine the applicability or relevance and appropriateness of state requirements for the management of IDW. Dredged sediments are excluded as a designated dangerous waste if they are managed under the CWA Section 404 program (WAC 173-303-071.
Federal Water Pollution Control Act/Clean Water Act (CWA) (33 USCA 1251-1376; 40 CFR 100-149)	Ambient water quality criteria for the protection of aquatic organisms and human health	Discharges to surface waterbody that are sources of contamination of LDW sediments.	40 CFR 131	CERCLA requires the attainment of water quality criteria where relevant and appropriate under the circumstances of the release or threatened release. Requirements are implemented differently depending on whether discharges are subject to NPDES permits. Also anticipated to be relevant and appropriate for remedial measures involving any discharges.
Toxic Substances Control Act (TSCA) (40 CFR 761)	Because PCBs are a COC at this site, regulations pertaining to "PCB remediation waste" may be a potential ARAR		40 CFR 761.61	Cleanup levels may be determined based on expected exposure and proximity to sensitive environments.

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[29] Tables 3-1, 3-2, and 3-3 provide a menu of requirements that might be ARARs and from which ARARs will be selected in the Record of Decision or, for Early Action Areas, in the Action Memorandum.

Medium/Requirement	Standard/Criteria	Prerequisite	Citation	Comments
Washington State Public Water Supplies (WAC 246-290)	Includes Maximum Contaminant Levels (MCLs) for drinking water	Public drinking water supply	WAC 173-290-310 Federal MCLs (40 CFR 141)	Depending on the scope of any remedial action, MCLs could be a potential ARAR for groundwater if it were a localized source of public drinking water, which is highly unlikely. MCLs are also potentially relevant and appropriate to groundwater, even if it is not a public source of drinking water, until and unless EPA determines the groundwater is Class III.
Washington State Water Quality Standards for Surface Waters (WAC 173-201a)	State Water Quality Standards; conventional water quality parameters and toxic criteria	Discharges to surface waterbody that are sources of contamination of LDW sediments.	WAC 173-201a-040	Implementation of federal requirement to develop state water quality control plan. Narrative and quantitative limitations for surface water protection. Requirements are implemented differently depending on whether discharges are subject to NPDES permits. Anticipated as relevant and appropriate to control releases that create concentrations of concern in the sediment. LDW has been classified as “Class B” water.
Model Toxics Control Act (WAC 173-340)	Requirements for establishing numeric or risk-based standards and selecting cleanup actions	State hazardous waste site and any contaminated site in Washington being cleaned up under Superfund	Section 760: Sediment	Sediment cleanup must comply with the requirements of MTCA as well as the Washington Sediment Management Standards. If the remedy involves media other than sediment, other sections of MTCA will also be ARARs.
Washington Sediment Management Standards (WAC 173-204)	Numerical and narrative criteria for sediment quality standards, cleanup screening levels, and minimum cleanup levels	Sediment remediation and source control	WAC 173-204	Anticipated to be applicable to site remediation. Anticipated as relevant and appropriate to control releases that create concentrations of concern in the sediment.

Table 3-2. Potential action-specific ARARs for LDW

Actions	Requirement	Prerequisite	Citation	Comments
General Remediation	Requirement for use of all known available and reasonable technologies for treating wastewater prior to discharge to waters of the state	Industrial sources	State Water Pollution Control Act (RCW 90.48), Water Resources Act (RCW 90.54)	Anticipated to be applicable to remedial technologies involving discharges to surface or groundwater. See also MTCA under Pump and Treat.
Construction in state waters	Requirements for construction and development projects for the protection of fish and shellfish	State waters	Construction in State Waters, Hydraulic Code Rules (RCW 75.20; WAC 220-110) Rivers and Harbors Appropriation Act (33 USC 401 et seq.) DMMP (2000) guidelines	Substantive requirements of Army Corps of Engineers permit anticipated to be relevant and appropriate to construction, dredging, and filling below the mean high-water line. (See also Dredging/Disposal under soil action-specific ARARs.) Substantive requirements of State Hydraulic Code may apply.

ACTIONS	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Source control	Requirements for protecting sediment and surface water quality	Ongoing sources of chemicals to LDW sediments.	State Water Pollution Control Act (RCW 90.48) Clean Water Act (40 CFR 100-149) Sediment Management Standards (WAC 173-204) Model Toxics Control Act (WAC 173-340)	Applicable to chemical sources that create concentrations of concern in LDW sediments. Requirements are implemented differently depending on whether discharges are subject to NPDES permits.
Discharge to POTW (Publicly Owned Treatment Works)	Contaminated water must be pretreated to certain limits prior to discharge	Nonhazardous waste	National Pretreatment Standards (40 CFR 403); Metro District Wastewater Discharge Ordinance	Discharges to POTWs are considered off-site activities; pretreatment and permitting requirements would be applicable.
Discharge to surface waters	Point-source standards for discharges into surface water bodies	Point-source discharge or site runoff directed to surface water body when the discharges are subject to an NPDES Permit	National Pollutant Discharge Elimination System (40 CFR 122, 125) State Discharge Permit Program; NPDES Program (WAC 173-216, 220)	Anticipated to be applicable to some discharges.
	Federal criteria for water quality to protect human health and aquatic life	Discharges to surface water bodies.	Federal Water Quality Criteria (40 CFR 131)	CERCLA requires the attainment of water quality criteria where relevant and appropriate to the circumstances of the release. Requirements are implemented differently depending on whether discharges are subject to NPDES permits. Anticipated to be relevant and appropriate for remedial measures involving this activity.
	State Water Quality Standards for Surface Water	Discharges to surface water bodies.	WAC 173-201-045, -047	Implementation of federal requirement to develop state water quality control plan. Narrative and quantitative limitations for surface and groundwater protection, based upon beneficial uses. Requirements are implemented differently depending on whether discharges are subject to NPDES permits. Anticipated as relevant and appropriate.
Containment - Capping - Vertical barriers	(see Capping and General Excavations under Action-specific ARARS for soil)			
Air stripping	Meet ambient air quality requirements for significant sources	Site located in nonattainment area for National Ambient Air Quality Standards; treatment unit would be major source	National Ambient Air Quality Standards (40 CFR 50)	Not anticipated as ARAR, not anticipated to qualify as major source.
Granular-activated carbon treatment	Meet design and operating standards for treatment and storage units	Treatment and storage of RCRA hazardous waste	40 CFR 264, Subpart I-Containers 40 CFR 264, Subpart J-Tanks 40 CFR 264, Subpart X-Misc. units	Anticipated to be relevant and appropriate if technology is implemented.

ACTIONS	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Treatment, storage, or disposal of hazardous wastes	Disposal of contaminated soil or debris is subject to land disposal prohibitions or treatment standards	Dangerous or hazardous waste	40 CFR 268 Federal Land Disposal Restrictions WAC 173-303-140, -141 Land Disposal Restrictions	May be ARAR if placement of hazardous or dangerous waste occurs during remediation.
Storage or disposal of solid wastes	Requirements for solid waste management	Solid waste (nonhazardous)	Solid Waste Disposal (Act 42 USC Sec. 3251-3259, 6901-6991) as administered under 40 CFR 257, 258 Solid Waste Handling Standards (WAC 173-350)	Potentially ARAR to nonhazardous waste generated during remedial activities
Noise control	Maximum noise levels		Noise Control Act of 1974 (RCW 80.107; WAC 173-60)	Potentially relevant and appropriate depending upon remedial activities selected.
Air				
Air emissions	National Primary and Secondary Ambient Air Quality Standards for carbon monoxide, lead, nitrogen dioxide, particulate matter (PM_{10}), ozone, and sulfur dioxides	Emissions from a "major" source	Clean Air Act (Sec. 109; 40 CFR 50)	Emissions from site not expected to qualify as major source unless activities will result in emissions of ≥100 tons/year or of a specified air contaminant.
	Regional ambient air quality standards	Emission of regulated air contaminant	Puget Sound Clean Air Agency (PSCAA) Regulation I	Not anticipated as ARAR
	National Emissions Standards for Hazardous Air Pollutants (NESHAPs)	Industrial emissions	Clean Air Act, National Emissions Standards for Hazardous Air Pollutants (NESHAPs) (40 CFR 61) State Emission Standards for Hazardous Air Pollutants (WAC 173-400-075)	Emission standards would need to be converted to area source standards for use at Harbor Island, if determined to be relevant and appropriate to releases of hazardous air pollutants from remedial actions.
	New Source Pretreatment Standards	New source of hazardous air pollutants	40 CFR 60	Potentially applicable to releases from remedial actions.
	Controls for New Sources of Toxic Air Pollutants	Emission of any Class A or Class B toxic air pollutant (identified in WAC 173-460-150 through -160) into ambient air	WAC 173-460	Potentially applicable to releases from remedial actions.
	Regional Emission Standards for Toxic Air Pollutants	Source of toxic air contaminant requires a notice of construction	PSCAA Regulation III	Potentially applicable depending upon remedial technology used.

ACTIONS	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Soil/Sediment/Fill				
General remediation of hazardous waste	RCRA hazardous waste management requirements	RCRA hazardous waste management in treatment, storage, or disposal facility	Resource Conservation and Recovery Act [RCRA as amended by the Hazardous and Solid Waste Amendments (HSWA) (42 USCA 6901 et seq.)]; 40 CFR 264 for permitted TSDFs	Need to determine waste designation for IDW and remediation waste. In general, RCRA requirements are anticipated to be applicable or relevant and appropriate depending upon designation of waste, if generated. Dredged sediments are excluded from RCRA Subtitle C if they are managed under the CWA Section 404 program (63 FR 65874)
	State hazardous waste management requirements	Management of wastes that pass criteria for WA hazardous waste as specified in WAC 173-303-070	General Facility Standards (WAC 173-303-280-395)	In general, state hazardous waste requirements are broader and more stringent than federal requirements; anticipated to be relevant and appropriate. . Dredged sediments are excluded as a designated dangerous waste if they are managed under the CWA Section 404 program (WAC 173-303-071).
Closure with waste in place (capping)	RCRA design and operational requirements for closures with waste in place require the minimization of need for further maintenance and control, installation of long-term cover, elimination of free liquids, stabilization of remaining waste, post-closure care, etc.	RCRA waste in landfill placed after 19 November 1980	Federal: 40 CFR 264-110 through 117 State: WAC 173-303-610	Potentially ARAR for placement of RCRA wastes, or wastes sufficiently similar to RCRA wastes in on-site upland facility.
Clean closure	RCRA clean closure requirements; complete removal of RCRA hazardous waste	Any unit that is not closing as landfill	40 CFR 264.110 et seq.	Potentially relevant and appropriate depending upon remedial action. Clean closure requires minimization of need for further maintenance and control.
Post-closure care	Post-closure monitoring and maintenance requirements	RCRA TSD Unit	Federal: 40 CFR 264.110 et seq. State: WAC 173-303-665(6)	Requirements provided under each action or storage method (e.g., landfill, waste piles, etc.). Anticipated to be relevant and appropriate.
Remediation of PCB-contaminated waste	Regulations pertain to PCB remediation waste	PCBs as chemical of concern	Toxic Substances Control Act (TSCA) (40 CFR 761.61)	Cleanup levels may be determined based on expected exposure and proximity to sensitive environments.
Surface impoundments	Requirements for containment system, emergency repair, contingency plans, design, etc.	New RCRA surface impoundment	Federal: 40 CFR 264.220 et seq. State: WAC 173-303-650	Not anticipated to be relevant and appropriate unless this technology is used during remediation.
Waste piles	Requirements for noncontainerized solid, non-flowing material	RCRA hazardous waste stored in pile	Federal: 40 CFR 264.254 et seq.	Potentially relevant and appropriate if employed during investigation or remediation.
		State dangerous waste stored in pile	State: WAC 173-303-660	

Actions	Requirement	Prerequisite	Citation	Comments
Landfills	Requirements for design, operation, and maintenance	New or replacement on-site landfill units for disposal of RCRA hazardous waste	Federal: 40 CFR 264.300 et seq. State: WAC 173-303-665	Potentially relevant and appropriate to extensions of existing landfill.
	Landfill design, construction, and closure standards developed to protect the water of the state	Hazardous, designated, or nonhazardous wastes and closed landfills	Federal: 40 CFR 257, 258, 264 State: WAC 173-304, 173-303-665, 173-350	Should this technology be used, anticipated to be relevant and appropriate.
Land treatment	Operating, monitoring, and closure requirements; hazardous chemicals must be degraded, transformed, or immobilized within the treatment zone; treatment efficiency must be demonstrated, design criteria must be met, and monitoring must be established. Develop fugitive and odor emission control plan for the treatment activities.	RCRA hazardous waste treatment in land farming unit	40 CFR 264, Subpart M	May be ARAR if technology is selected for remediation.
Chemical, physical, and biological treatment	Operating, monitoring, and closure requirements	RCRA hazardous waste	Federal: 40 CFR 264 State: WAC 173-303	Potentially applicable if hazardous or state dangerous wastes are treated using any of these methods. Otherwise, anticipated to be relevant and appropriate for the treatment of nonhazardous waste.
Incineration	Requirements include monitoring and analysis of waste feed and residuals, and disposal of treatment residuals. Performance standards include: - Destruction removal efficiency of 99.99% for each principal organic hazardous chemical - Reduction of hydrogen chloride emissions to 1.8 kg/hr or 1% HCl in the stack gases prior to entering any pollution control devices - Limit maximum particulate matter to 180 mg in stack gases	RCRA hazardous waste	Federal: 40 CFR 264.340 et seq.	Anticipated to be relevant and appropriate should this technology be implemented. On-site operations would need to meet substantive requirements of the operating permit. State requirements would be applicable for non-RCRA hazardous wastes.
		State dangerous waste	State: WAC 173-303-670	
	Performance standards for incinerators	Incinerator with charging rates of more than 45 metric tons per day	Federal: CAA 42 USCA 7401-7642 State: WAC 173-303-670; PSCAA emission and ambient standards	Anticipated to be relevant and appropriate if this technology is employed.

ACTIONS	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Thermal treatment (other than incineration)	Operating, monitoring, and closure requirements	Treatment using technologies other than controlled flame combustion	Federal: 40 CFR 265, Subpart P State: WAC 173-303-680	Potentially applicable if wastes are treated using this method. Otherwise, anticipated to be relevant and appropriate for wastes sufficiently similar to hazardous or dangerous waste.
Excavation and disposal of hazardous wastes	Disposal of contaminated soil or debris is subject to land disposal prohibitions of treatment standards	RCRA hazardous waste	Federal: 40 CFR 268 federal land disposal restrictions	May be ARAR if placement of hazardous or dangerous waste occurs during remediation.
		State dangerous waste	State: Land Disposal Restrictions (WAC 173-303-140, -141)	
Excavation and disposal of solid wastes	Requirements for solid waste management	Solid waste (nonhazardous)	Federal: Solid Waste Disposal Act (42 USC Sec. 325103259, 6901-6991), as administered under 40 CFR 257, 258 State: Solid Waste Handling Standards (WAC 173-350)	Potentially applicable to the disposal of nonhazardous waste generated during remedial activities.
Treatment of non-RCRA hazardous or state dangerous waste	Treatment requirements for non-RCRA hazardous or state dangerous wastes	Non-RCRA hazardous waste	Federal: 40 CFR 257, 258, 761	Standards for non-RCRA hazardous or non-RCRA state dangerous waste, including PCB waste, incinerator treatment residuals, etc. Anticipated to be applicable to non-RCRA hazardous and dangerous wastes, or relevant and appropriate to sufficiently similar wastes.
		Non-RCRA state-only dangerous waste	State: WAC 173-303-141	
Sediment remediation	Methods for determining allowable levels of chemicals and/or biological effects in sediment	Marine/estuarine environment	WAC 173-204; WAC 173-340-760	Marine sediment. Anticipated as ARAR.
Dredging/disposal	Requirements for the discharge of dredged/fill material into navigable waters or wetlands	Waters of the US	CWA 33 USC 401 et seq.; 33 USC 1413; 33 USC 1251-1316; 40 CFR 230, 231, 404; 33 CFR 320-330 Hydraulic Code Rules on Dredging (WAC 220-110-130, -320) Aquatic Land Management Open Water Disposal Sites (WAC 332-30-166) PSDDA (1988a,b; 1989)	Potential ARAR. Deposited materials could be considered point-source discharges under NPDES. (See also General excavation activities and Construction in state waters under Action-specific ARARs for waters.)
Noise control	Maximum noise levels	Activities which may result in exceedance of maximum noise levels	Noise Control Act of 1974 (RCW 70.107; WAC 173-60)	Potentially relevant and appropriate depending upon remedial activities selected.

Table 3-3. Potential location-specific ARARs for LDW

LOCATION	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Within 61 m of a fault displaced in Holocene time	New treatment, storage, or disposal facilities of hazardous waste are prohibited in these areas	RCRA hazardous waste; treatment, storage, or disposal	40 CFR 264.18(a)	Not potential ARAR. Not within 61 m of Holocene fault.
Within 61 m of shoreline	Requirements for construction and development near shorelines	Shorelines of statewide significance, including marine waters and wetlands	Shoreline Management Act (RCW 90.58); Coastal Zone Management Act (16 USC 1451 et seq.)	Anticipated to be relevant and appropriate.
Within 100-year floodplain	Facility must be designed, operated, and maintained to avoid washout	RCRA hazardous waste	40 CFR 264.18(b); 40 CFR 761.75	None
Within floodplain	Actions must be performed so as to avoid adverse impacts, minimize potential harm, restore and preserve natural and beneficial values of the floodplain	Actions that will occur in a floodplain (i.e., lowlands) and relatively flat areas adjoining inland and coastal waters and other flood-prone areas	Executive Order 11988, Protection of Floodplains (40 CFR 6, Appendix A)	None
Within/adjacent to wetlands	Action must be performed so as to minimize the destruction, loss, or degradation of wetlands. Requirement for no net loss of remaining wetlands.	Wetland as defined by Executive Order 11990, Section 7	Executive Order 11990, Protection of Wetlands (40 CFR 6, Appendix A).	None
Critical habitat upon which endangered or threatened species depend	Actions must be performed so as to conserve endangered or threatened species, including consultation with the Department of the Interior and National Marine Fisheries Service.	Determination of endangered or threatened species and the essential fish habitat on which they depend	Endangered Species Act of 1973 (16 USC 1531 et seq.); 50 CFR Part 200, 50 CFR Part 402 Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act (50 CFR 600)	LDW is used as a salmon migratory route
State waters	Dredging and other construction must meet specific standards.	Applies to any construction activity in or near state waters	Hydraulic Code (RCW 77-55-100) Hydraulic Code Rules (WAC 220-110)	Substantive standards potentially applicable. No Hydraulic Project Approval required on-site. Dredging is explicitly considered as a construction activity
Oceans or waters of the US	Permit requirements for activities that may obstruct or alter a navigable waterway	Obstruction or alteration of a navigable waterway	Section 10 of the Rivers and Harbors Appropriations Act (33 USC 403)	None
Within state siting criteria locations for dangerous waste facilities	Siting criteria to be used as initial screen for consideration of dangerous waste facility sites	New dangerous waste facilities	WAC 173-303-282(2)(b)(iii)	Not ARAR. Does not apply to facilities conducting CERCLA remediation.

LOCATION	REQUIREMENT	PREREQUISITE	CITATION	COMMENTS
Habitat for fish, plants, or birds subject to WDFW oversight	Prohibits water pollution with any substance deleterious to fish, plant life, or bird life	Discharges of chemicals to LDW sediment	US Fish and Wildlife Coordination Act. 16 USC 661-667e	LDW is used as a salmon migratory route and provides habitat for other species of fish and wildlife. Requirements are implemented differently depending on whether discharges are subject to NPDES permits.
Harbors, tidelands, shorelines, or beds of navigable rivers	Siting criteria and requirements for fill operations		Constitution of the State of Washington (RCW 79.90.020; WAC 332-300-117, -118)	Potentially relevant and appropriate to remedial actions.
Native American graves	Excavation must cease if Native American burials or cultural items are inadvertently discovered	Potentially applicable to sediment removal	Native American Graves Protection and Repatriation Act (25 USC 3001 et seq.; 43 CFR Part 10)	None
Sacred Native American sites	Work must stop if sacred religious sites are discovered	Potentially applicable to sediment removal	American Indian Religious Freedom Act (42 USC 1996 et seq.)	None
Historic sites or structures	Alternatives must be evaluated to avoid, minimize, or mitigate the impact on historic sites or structures	Activities that could disturb historical sites or structures	National Historic Preservation Act (16 USC 470f; 36 CFR Parts 60, 63, and 800)	None
Archaeological Resources on public and Indian lands	Removal of archaeological resources is prohibited without a permit	Potentially applicable to sediment removal	Archaeological Resources Protection Act (16 USC 470 aa et seq.; 43 CFR Part 7)	None

3.2.1 Chemical-specific ARARs

Chemical-specific requirements set concentration limits or ranges in various types of environmental media. Such ARARs may set protective cleanup levels for the chemicals of concern in the designated media. Chemical-specific ARARs may also indicate an appropriate level of discharge.[30]

Chemical-specific requirements are health- or risk-based concentration limits such as ambient water quality criteria. Table 3-1 presents a list of potential federal and state chemical-specific ARARs identified for the various media at the LDW site. These ARARs are based on current, publicly available information and do not reflect administrative discretion that may be exercised in the future by federal or state authorities.

EPA (2002b) states the following:

> "Generally, under CERCLA, cleanup levels are not set at concentrations below natural background levels. Similarly, for anthropogenic contaminant concentrations, the CERCLA program normally does not set cleanup levels below anthropogenic background concentrations (EPA 1996, 1997c, 2000b). The reasons for this approach include cost-effectiveness, technical practicability, and the potential for recontamination of remediated areas by surrounding areas with elevated background concentrations."

Therefore, when background concentrations for contaminants are above the ARAR for that contaminant, the ARAR may not be achievable and alternative ARARs or risk-based standards may dictate the appropriate action. This scenario could occur in the LDW for some chemicals, such as arsenic, but a detailed comparison of site-specific chemical concentrations with background chemical concentrations will not be made until the Phase 2 RI. Additional discussion of this issue is provided in Section 4.2.2 and in the Phase 1 risk assessments (see Appendices A and B).

3.2.2 Action-specific ARARs

Action-specific ARARs are typically technology- or activity-based requirements or limitations on actions. These requirements are not triggered by the specific contaminants identified, but by activities related to management of these contaminants. Table 3-2 presents the potential action-specific ARARs for soil, surface water, groundwater, and air that have been identified for a preliminary list of remedial actions. The final list of remedial actions will be developed during the feasibility study phase of the RI/FS. Requirements such as Occupational Safety and Health Act (OSHA) standards are excluded as action-specific ARARs because they must be adhered to under all circumstances, regardless of whether the activity is related to a CERCLA or MTCA action.

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[30] In this instance an ARAR can be considered both chemical-specific and action-specific.

Because one activity may trigger several requirements, descriptions of the potential ARARs are provided under each activity category. In general, activities may be subject to certain limitations depending upon 1) the type of activity performed (e.g., incineration), 2) the type of waste being managed, and 3) whether the activity is conducted on-site. A discussion of the second and third limitations is provided below.

3.2.2.1 Waste type

Requirements for treatment, storage, and disposal of hazardous wastes are provided under the federal Resource Conservation and Recovery Act (RCRA) and the Washington State Dangerous Waste Regulations. Activities may be subject to RCRA or state hazardous waste ARARs depending upon the type of waste generated at the LDW site.

RCRA requirements are generally applicable for actions involving RCRA hazardous waste. RCRA hazardous waste must be a 1) solid waste or contaminated environmental media and 2) RCRA-characteristic or RCRA-listed waste. RCRA characteristic wastes exhibit at least one of four characteristics: ignitability, reactivity, corrosivity, or toxicity. Toxicity is determined by the toxicity characteristic leaching procedure (TCLP), which has threshold values for various contaminants above which a waste would be regulated. RCRA-listed wastes are listed in 40 CFR 261, Subpart D.

State dangerous waste requirements are generally applicable for activities involving either a RCRA or non-RCRA state hazardous waste. State dangerous wastes are defined in WAC 173-303-070 and include RCRA plus state-defined “criteria” waste.

Solid wastes are subject to the federal Solid Waste Disposal Act storage and disposal requirements as administered under 40 CFR 257-258 and the state Solid Waste Handling Standards in WAC 173-350.

3.2.2.2 On-site permit exemptions

CERCLA §121(e) provides an exemption from federal, state, or local permits for the portion of any removal/remedial action conducted entirely on-site. On-site is interpreted by the EPA to mean “the areal extent of contamination and all suitable areas in very close proximity to the contamination necessary for implementation of the response action.”

Although a permit would not be required for on-site activities, substantive, non-administrative requirements of the permit must be met. For example, on-site discharges to the LDW via a pipe, ditch, conduit, or other means of discrete conveyance would be subject to the substantive requirements of an NPDES permit issued by the state, but in itself would not require a National Pollutant Discharge Elimination System (NPDES) permit. However, discharges directly off-site (e.g., into a conveyance system leading to a Publicly Owned Treatment Works [POTW]) would be subject to both substantive and administrative permitting requirements.

3.2.3 Location-specific ARARs

Location-specific ARARs are restrictions placed on either the concentration of hazardous substances or the conduct of activities performed in certain locations. They may restrict or preclude certain remedial actions or may apply only to certain portions of the area of contamination. Potential LDW-specific ARARs are presented in Table 3-3.

3.3 PROCEDURES FOR DETERMINING ARARS

Compliance with other laws may be either applicable or relevant and appropriate, but not both, based on cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under federal or state law. Thus, each evaluation of a potential ARAR will consist of a determination as to whether the requirement is applicable, relevant and appropriate, or neither.

The determination of ARARs will be ongoing throughout the RI/FS process, and will progress from the identification of regulatory programs that may impose requirements, to a determination of specific criteria and standards that will become part of the response objectives. In general, potential chemical-specific and location-specific ARARs will be identified during the Phase 2 RI. Later, as remedial alternatives are developed as part of the feasibility study, activity-specific ARARs will be more definitive. Final ARAR determinations will be made during preparation of the ROD.

3.4 ARAR WAIVERS OR VARIANCES

An ARAR waiver or variance may be obtained if an ARAR(s) cannot be met. Typically, the justification for these waivers must be one of the following items:

1. The measure/action that will not attain all ARARs is an interim measure, which will be followed by a complete measure that will attain ARARs.
2. Equivalent or better results can be obtained using a design or method different from that specified in the ARAR.
3. Compliance with an ARAR will cause greater risk to human health and the environment than noncompliance.
4. Achieving an ARAR(s) is technically impracticable.
5. The costs associated with meeting an ARAR in order to obtain an added degree of protection or reduction of risk would jeopardize the funds for remedial actions at other sites. This waiver is available for Fund-financed actions only.

3.5 STATE REQUIREMENTS AS POTENTIAL ARARS

The LDW RI is being conducted jointly under both federal (i.e., CERCLA) and state (i.e., MTCA) regulations. For actions conducted only under CERCLA in the LDW, an analysis of state ARARs is required. CERCLA §121 states that in order for a state requirement to be eligible to be an ARAR, it must be both promulgated and more stringent than federal requirements. A state requirement is promulgated if it is legally enforceable (i.e., it must be issued in accordance with state procedural requirements and contain specific enforcement provisions or be otherwise enforceable under state law), and it is generally applicable. The evaluation of stringency considers two types of regulations: 1) those for which there is a federal counterpart (or program), and 2) those for which there is no federal counterpart (or program).

For most federally authorized state programs (e.g., RCRA, Clean Water Act [CWA]), state requirements are at least as stringent as federal requirements. Therefore, state requirements under these programs do not require a comparison of stringency. It must be determined, however, that the state has been authorized to administer the program and to develop regulations under the authorized program. For non-authorized state programs, the investigator must prepare a side-by-side analysis of requirements to show that the state requirement is more stringent than federal requirements. Regulations promulgated under state programs that do not have a federal counterpart, but address specific conditions within that state, represent ARARs because they are more stringent than federal law and add new or specific requirements to the body of federal environmental regulations.

In addition, state requirements must be substantive; that is, they must not impose only administrative or procedural requirements, or requirements that can be substituted effectively by established CERCLA administrative procedures. Further, EPA will consider state requirements to be an ARAR only if they are “of general applicability.” That is, state requirements that apply only to one or more Superfund sites are not to be considered an ARAR. For a state requirement to be a potential ARAR it must be applicable to all remedial situations described in the requirement, not just to Superfund sites. Also, the requirement must be consistently applied to all sites. Local laws are generally not promulgated state requirements and therefore may or may not be ARARs. If the local requirement is developed under explicit state authority or if compliance is a requirement of a promulgated state statute, the local requirement may be an ARAR.

To support the inclusion of state requirements as ARARs, the following information should be provided. First, evidence should be provided that the proposed ARAR is a promulgated standard, including the statute or regulation, the date of enactment, or the effective date. Second, evidence should be provided that the proposed ARAR is broader or that it imposes a more restrictive standard of performance than federal requirements.

If a state disputes the determination by the EPA that a state requirement is not an ARAR, the state may submit its argument to the EPA Assistant Administrator for Solid and Hazardous Waste. Other dispute resolution mechanisms may be developed and presented in a State/Superfund Memorandum of Agreement. If the state’s requirement is still not determined to be an ARAR after completing the dispute resolution process, the requirement may nevertheless be applied to the remedy if the state demonstrates an ability and willingness to pay for the additional incremental expense associated with its application. In this circumstance, the state may be required to take the lead in the remedial design and remedial action.

3.6 ITEMS TO BE CONSIDERED (TBCS)

State and local ordinances, advisories, and other requirements that are not ARARs may be used in determining the appropriate extent and manner of cleanup. These requirements can be TBC requirements. Generally, TBC requirements are used when no federal or state requirements exist for a particular situation. Some TBC items are presented in Table 3-4.

Table 3-4. Potential items to be considered (TBCs) for the LDW

Federal, State, and Local Criteria, Advisories, and Procedures	
Guidelines developed by the Elliott Bay/Duwamish Restoration Program	
Sediment Cleanup Standards Users Manual, Washington Department of Ecology (December 1991)	
Dredged Material Management Program (DMMP) Guidelines (DMMP 2000)	
Puget Sound Water Quality Management Plan	
EPA Total Maximum Daily Load (TMDL) regulations (40 CFR 130)	
Guidance Document for Discharging CERCLA Aqueous Wastes to POTWs, EPA/540/G-90/005	
FDA Maximum Concentrations of Contaminants in Fish Tissues (49 CFR 10372-10442)	
Water Quality Guidance Documents:	
	Water Quality Criteria and Standards Plan (EPA, June 1998)
	Water-Related Environmental Fate of 129 Priority Pollutants (1979)
	Water Quality Standards Handbook, Second Edition (August 1994)
	Technical Support Document for Water Quality-based Toxics Control (1994)
Local Shoreline Substantial Development Permits	
EPA Wetlands Action Plan (Jan 1989, OWWP)	

4.0 Summary of Nature and Extent of Contamination

This section uses existing data collected after 1990 to summarize chemical concentrations found in various LDW environmental media. Spatial and temporal trends are presented, as appropriate.

4.1 DATA USABILITY

There are several factors to consider in assessing the suitability of environmental data for risk assessments (EPA 1989, 1992a). These factors are also relevant for determining the adequacy of existing data for nature and extent considerations. Of primary importance is the degree to which the data adequately represent site-related chemical concentrations. Also important to consider are the data quality criteria goals, and the source, documentation, analytical methods / detection limits,[31] and level of review associated with the data. Because data from many different investigations were available for the LDW, the factors described above had to be evaluated for each data set to determine whether it was reasonable to combine all data for use in the RI.

4.1.1 Representativeness to site-related contamination

4.1.1.1 Sediment

Many environmental sampling events have included the collection of potentially contaminated sediment (Table 2-1). These studies were designed for both reconnaissance (e.g., Boeing SiteChar, EPA SI, and NOAA SiteChar) and focused investigations on suspected areas of contamination (e.g., Boeing RFI, Rhône-Poulenc RFI). Most events focused on subtidal sediments, although intertidal sediments have also been collected. The extensive coverage of the reconnaissance surveys and the focused intensity of the facility investigations indicate that the available sediment chemistry data are representative of the general range of environmental conditions within the LDW. Far more samples have been collected in areas where chemical concentrations were high (near known sources). Standard statistical measures (e.g., mean, median) may therefore not be representative of the overall distribution of chemicals in the LDW. Most chemicals, however, have been analyzed in surface sediment samples collected throughout the LDW, so spatially weighted averages are likely to be fairly representative of overall conditions. Additional sediment quality characterization will take place during the Phase 2 RI.

4.1.1.2 Tissue

Representativeness of the tissue data was evaluated by assessing the migratory behavior of selected receptor species and by reviewing the collection locations with respect to the location of the study area. The tissue samples analyzed since 1990 and summarized in Table 2-6 were collected during the spring and fall.

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[31] An explanation of what is meant by the generic term "detection limit" is provided in Appendix Section C.3.1.

Although site-specific studies of migration behavior are not available for English sole and crab, available data on the life history of these species in other regions suggest that during the spring and fall, the individuals are residents of the waterbody in which they were captured (Lassay 1989; Miller et al. 1975; Pauley et al. 1988). Shiner surfperch were captured only in the fall, when they are abundant in nearshore environments (Fritzsche and Hassler 1989), although they are also present during other seasons. Amphipods, while present year-round in areas captured, were only collected in one location in the study area (KI), and thus their tissue burdens do not reflect site-wide contamination, but may reflect localized contamination. Mussels also occupy fixed sites within the LDW. Although mussel samples are available from more sites than amphipod samples, concentrations in mussel tissue are still only reflective of a subset of LDW locations. Thus, each of the resident species from the studies summarized in Table 2-6 were apparently exposed to the chemical environment in the vicinity of where they were captured for at least several months of the year.

Salmon reside in the LDW only during their downstream migration from their spawning grounds to Puget Sound (Section A.2.2.3.1; Warner and Fritz 1995). Juveniles accumulate chemicals from ingesting prey items within the LDW during their downstream migration. Other possible chemical sources are hatchery feed[32] and transfer from the mother to the eggs (Niimi 1983). Salmon grow to adulthood outside the LDW, where they pick up additional chemicals from various sources in the ocean, including atmospheric deposition (O'Neill et al. 1998). During their upstream migration as adults, they eat little or no food (Healy 1991). O'Neill et al. (1998) estimated that less than 1% of the total PCB body burden in an adult salmon can be attributed to sources within the LDW.

The size of the home range of each resident species (i.e., shiner surfperch, English sole, and crab) to the entire LDW is unclear, because no site-specific research on home ranges has been conducted. Home range estimates have been developed using best professional judgment. The unconstrained average home range of English sole, as reported by PSDDA (1988c) is 9 km^2. The spatial variability of certain fish tissue abnormalities observed in the Hylebos Waterway of Commencement Bay in Tacoma, Washington, is consistent with this value (Myers et al. 1998). Similarly, the unconstrained home range of Dungeness crab has been reported to range from 0.1 to 1 km per day (Breen 1985; Waldron 1958), and Ecology has used an area of 10 km^2 in crab-based risk assessments performed elsewhere in Puget Sound (e.g., Bellingham Bay). The resident species to be characterized in this HHRA are mobile but they also demonstrate some site fidelity (Lassay 1989; Pauley et al. 1988; Fritzsche and Hassler 1989), indicating they may have spent more time in the LDW than outside the LDW.

Within the LDW, samples of shiner surfperch, crab, and English sole were collected from several locations. Given the variety of collection locations, the individuals within

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[32] Recent data indicate that salmon raised in hatcheries have significant amounts of PCBs that likely come from the pellets they are fed (Gina Ylitalo, NMFS, pers comm., as cited in Meador et al. 2002).

each composite sample likely represent exposure to a relatively wide range of chemical regimes.

4.1.2 Quality Assurance/Quality Control (QA/QC) results

All data sets used in the RI and Phase 1 RAs have been validated by the original authors of the individual studies or by outside third parties, although the documentation of such data validation is sometimes minimal (Table 4-1). No additional data validation was conducted for this RI. The data validation results were summarized in Windward (2001b). Some results were qualified as unusable[33] by the data validators. Data qualified as unusable are not being used in the RI and RAs. A summary of the data qualified as unusable is provided in Appendix D.

Some sample results were qualified as estimates. Many of the data qualifiers reflect a directional bias (i.e., overestimate or underestimate), although the direction of the bias was not explicitly included in any quantitative analyses. Estimated data were considered usable for RI and RA purposes, although the uncertainty associated with risk assessments made from estimated data is slightly higher than that of assessments made from unqualified data. The data CD[34] attached to this RI report includes definitions of all qualifiers used in the LDWG database.

Many other results were qualified with a “U” flag indicating that the chemical was not detected at the reporting limit specified. Reporting limits were variously defined by the different laboratories responsible for historical data analyses (See Appendix C.3.1). Some reporting limits were above risk-based guidelines, which creates uncertainty in risk estimates, as described in the uncertainty assessments of the ERA (Appendix Section A.7) and HHRA (Appendix Section B.6).

EPA and ACOE have conducted a preliminary review of the available QA/QC information for the chemistry data sets used in Phase 1 and have agreed that these data sets are acceptable for use in Phase 1 (EPA/ACOE 2003). Additional data validation has occurred for some of these sampling events (EPA/ACOE 2003) since the original validation occurred, and more data validation may be conducted during Phase 2. Based on the data review conducted by EPA, some changes will be made to data qualifiers for several King County sampling events prior to the use of these data sets in Phase 2. Specifically, additional qualification will be necessary for some data associated with method blanks contaminated with chemicals such as bis(2-ethylhexyl)phthalate (BEHP). LDWG and the agencies will continue to consult with each other on the suitability of historical data for use in Phase 2.

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[33] A total of 158 results were qualified as unusable out of more than 80,000 analytical results.

[34] The data CD includes Access database tables (and pdf files that contain the same information as the database tables) containing all the sediment and tissue chemistry data in this RI.

Table 4-1. Summary of data validations conducted for historical sediment and tissue chemistry sampling events

Sampling Event	Event Code	Reference	Data Validation Performed By	Level [a]	Data Validation Report
Sediment					
Norfolk CSO five-year monitoring program, Year Two, April 2001	Norfolk-monit4	King County (2001a)	King County Environmental Lab	QA1	Yes
Norfolk CSO five-year monitoring program – Twelve-month post construction	Norfolk-monit3	King County (2000c)	King County Environmental Lab	QA1	Yes
Norfolk CSO five-year monitoring program – Supplemental nearshore sampling	Norfolk-monit2b	King County (2000c)	King County Environmental Lab	QA1	Yes
Norfolk CSO five-year monitoring program – Six-month post construction	Norfolk-monit2a	King County (2000d)	King County Environmental Lab	QA1	Yes
Norfolk CSO five-year monitoring program – Post backfill	Norfolk-monit1	King County (1999b)	King County Environmental Lab	QA1	Yes
Dredge material characterization Duwamish Yacht Club	Duwam Yacht Club	Hart Crowser (1999)	Hart Crowser	QA1	Yes
Sediment sampling and analysis James Hardie Gypsum Inc. – Round 1	Hardie Gypsum-1	Spearman (1999)	Spearman	QA1	Yes
Sediment sampling and analysis James Hardie Gypsum Inc. – Round 2	Hardie Gypsum-2	Spearman (1999)	Spearman	QA1	Yes
Dredge material characterization Hurlen Construction Company & Boyer Alaska Barge Lines berthing areas	Hurlen-Boyer	Hart Crowser (1998)	Hart Crowser	QA1	Yes
Sediment quality in Puget Sound. Year 2 – Central Puget Sound	PSAMP	Ecology (2000)	Unknown	Unknown	No
EPA Site Inspection: Lower Duwamish River [b]	EPA SI	Weston (1999)	Weston	QA2	Yes
King County combined sewer overflow water quality assessment for the Duwamish River and Elliott Bay	KC WQA	King County (1999a)	King County Environmental Lab	QA1	Yes

Sampling Event	Event Code	Reference	Data Validation Performed By	Level [a]	Data Validation Report
Duwamish Waterway Phase 1 site characterization	Boeing SiteChar	Exponent (1998)	Exponent	QA2	Yes
Duwamish Waterway sediment characterization study	NOAA SiteChar	NOAA (1997, 1998)	EcoChem	QA2	Yes
Seaboard Lumber site, Phase 2 site investigation	Seaboard	Herrera (1997)	Herrera	QA1	Yes
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 2b	Plant 2 RFI-2b	Weston (1998)	Weston	QA2	Yes
Proposed dredging of Slip No. 4, Duwamish River, Seattle, WA	Slip4-Crowley	PTI (1996)	PTI	QA1	Yes
Duwamish/Diagonal cleanup Study – Phase 2	Duw/Diag-2	King County (2000a)	King County Environmental Lab	QA1	Yes
1996 USACE Duwamish O&M	ACOE96	Striplin (1996)	Striplin	QA1	Yes
Duwamish/Diagonal cleanup Study – Phase 1.5	Duw/Diag-1.5	King County (2000a)	King County Environmental Lab	QA1	Yes
Lone Star Northwest and James Hardie Gypsum – Kaiser dock upgrade	Lone Star-Hardie Gypsum	Hartman Associates (1995)	Hartman Associates	QA1	No
Norfolk CSO sediment cleanup study – Phase 3	Norfolk-cleanup3	King County (1996)	King County Environmental Lab	QA1	Yes
Norfolk CSO sediment cleanup study – Phase 2	Norfolk-cleanup2	King County (1996)	King County Environmental Lab	QA1	Yes
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 2a	Plant 2 RFI-2a	Weston (1998)	Weston	QA2	Yes
RCRA Facility Investigation Duwamish Waterway sediment investigation, Plant 2 – Phase 1	Plant 2 RFI-1	Weston (1998)	Weston	QA2	Yes
Duwamish/Diagonal cleanup Study – Phase 1	Duw/Diag-1	King County (2000a)	King County Environmental Lab	QA1	Yes
Norfolk CSO sediment cleanup study – Phase 1	Norfolk-cleanup1	King County (1996)	King County Environmental Lab	QA1	Yes
Rhône-Poulenc RCRA Facility Investigation for the Marginal Way facility – Round 1	Rhône-Poulenc RFI-1	Rhône-Poulenc (1995)	CH2M Hill	QA2	No

SAMPLING EVENT	EVENT CODE	REFERENCE	DATA VALIDATION PERFORMED BY	LEVEL [a]	DATA VALIDATION REPORT
Rhône-Poulenc RCRA Facility Investigation for the Marginal Way facility – Round 2	Rhône-Poulenc RFI-2	Rhône-Poulenc (1995)	CH2M Hill	QA2	No
Lone Star Northwest – West Terminal US ACOE – Seattle	Lone Star 92	Hartman Associates (1992)	Hartman Associates	QA1	No
Harbor Island Remedial Investigation	Harbor Island RI	Weston (1993)	Weston	QA2	Yes
Tissue					
Waterway Sediment Operable Unit Harbor Island Superfund Site - Assessing human health risks from the consumption of seafood	WSOU	Environmental Solutions Group (1999)	Quality By Design	QA2	Yes
King County combined sewer overflow water quality assessment for the Duwamish River and Elliott Bay	KC WQA	King County (1999a)	King County Environmental Lab	QA1	Yes
Puget Sound Ambient Monitoring Program – annual sampling (1992-1998)	PSAMP-fish	West et al. (2001)	Manchester Laboratory (Ecology/EPA)	Unknown	No
Elliott Bay/Duwamish River Fish Tissue Investigation	EVS 95	Battelle Marine Research Laboratory (1996), EVS (1995), Frontier Geosciences (1996)	EVS	QA1	No
NMFS Duwamish injury assessment project	NOAA-salmon2	NMFS (2002)	NMFS Seattle (Montlake) Lab	Unknown	No
Contaminant exposure and associated biochemical effects in outmigrant juvenile chinook salmon from urban and non-urban estuaries of Puget Sound	NOAA-salmon	Varanasi et al. (1993)	NMFS Seattle (Montlake) Lab	Unknown	No

[a] QA1 includes a review of quality control data, such as matrix spike/matrix spike duplicates, laboratory control standards, surrogate standards, and method blanks. QA2 includes all the elements of a QA1 review, plus additional review of calibration, instrument performance, and calculation checks.

[b] This investigation also included the collection of porewater chemistry data

4.1.3 Other factors

Documenting field and laboratory procedures makes it possible to assess the impact of any deviation from these procedures on data usability. As described in Windward (2001a), such procedures were documented during the verification process that was conducted during database construction. A thorough review of the documentation (e.g., method descriptions, quality control results) provided for the various studies did not reveal any issues that would adversely affect the usability of the data for RI or RA purposes.

The level of analytical data review can also affect data usability. All data used in the Phase 1 RI and RAs were subjected to data reduction and validation processes. Other factors that could potentially impact data usability for specific data types are described below.

4.1.3.1 Sediment

The sediment surveys summarized in Table 2-1 used similar or identical analytical methods for most analytes, with one notable exception. PCB analyses for NOAA SiteChar were conducted by high performance liquid chromatography and a photodiode array detector (HPLC/PDA) in contrast to PCB analyses for all the other events, which were conducted using EPA's standard method of gas chromatography with an electron capture detector (GC/ECD). NOAA data for total PCBs are based on a nonstandard analytical method and may not be quantitatively comparable to other data generated using standard analytical techniques. The NOAA laboratory data for total PCBs reflect the difference between the results of one analysis for the sum of PCBs and polychlorinated terphenyls (PCTs) and the results of a separate analysis for PCTs alone.

Krahn et al. (1998) reported the results for 30 samples that were analyzed by both HPLC/PDA and GC/ECD methods by two different laboratories.[35] The two laboratories calculated total PCBs for each sample, which were then compared to each other. Total PCB concentrations varied between the two laboratories by as much as a factor of six (Krahn et al. 1998). Regression analyses conducted for the two sets of results indicate that the GC/ECD results were lower than the HPLC/PDA results at high PCB concentrations, and higher than the HPLC/PDA results at low PCB concentrations (Krahn et al. 1998). The regression coefficient (R^2) between the two sets of analyses was 0.92. The differences between the total PCB concentrations calculated by the two laboratories are not surprising given the differences between the two methods, including 1) different ranges of linear response for the two detectors, 2) differences in methods for calculating total PCBs, 3) differences in methods of quantifying and/or removing analytical interferences, and 4) differences in detection limits.

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[35] HPLC/PDA analyses were conducted by the NMFS laboratory in Seattle; GC/ECD analyses were conducted by Analytical Resources Inc., Seattle.

Despite the differences between the two analytical methods, data from both methods are used in the Phase 1 RI and RAs, although the uncertainty associated with total PCB concentrations may be significant in some areas.

4.1.3.2 Tissue

The source of analytical data can be an issue if data from different investigations are used. Although different laboratories and in some cases different methods were used for the various surveys, inter-survey consistency in sample types (e.g., skinless fillets) and species selection indicates that combining data from various sources is acceptable.

Detection limits can affect data usability if they are higher than risk-based screening concentrations. Elevated detection limits were noted for several chemicals (see Appendices A and B), which were subsequently identified as chemicals of potential concern (COPCs) solely on the basis of their detection limits.

Analytical methods were generally consistent among studies, but some variations were noted. PCBs were quantified in all studies except Environmental Solutions Group (1999) and NMFS (2002) using GC/ECD (i.e., EPA Method 8081). Environmental Solutions Group (1999) quantified PCBs using a low-resolution mass spectrometer (MS). NMFS (2002) quantified PCBs by HPLC/PDA. The three types of detectors should give similar results, although the comparability between PCB data collected using HPLC/PDA and PCB data collected using either GC/ECD or MS may be questionable depending on the concentrations in question (see Section 4.1.3.1). All analyses using GC/ECD and MS quantified individual Aroclors, which were then summed in an identical manner.[36] The NMFS data for total PCBs reflect the difference between the results of one analysis for the sum of PCBs and PCTs, and the results of a separate analysis for PCTs alone.

4.1.3.3 Porewater

All the porewater data used in the Phase 1 RI and RAs were collected during the EPA Site Inspection (Weston 1999). Porewater was extracted from sediment samples by centrifugation in the laboratory. Consequently, data usability issues such as data source and comparability of analytical methods are not applicable to porewater data.

4.2 NATURE AND EXTENT OF CONTAMINATION

This section presents a summary of the abundance and distribution of chemicals in potentially contaminated media in the LDW. Data are summarized in separate sections for the following media: surface sediment, subsurface sediment, porewater, surface water, groundwater, and fish and shellfish tissue. The information is presented mostly as GIS maps and summary tables.[37]

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[36] Total PCBs concentrations derived from Aroclor data are the sum of detected values only. In cases where all Aroclors were undetected, the total PCB concentration is equal to the highest detection limit of the individual Aroclor.

[37] Note that only data from sediment, porewater, and tissue have been compiled in the LDWG database.

4.2.1 Data selection and reduction

This section describes how data used in the rest of Section 4.2 were selected and provides details on various data manipulation techniques used to create maps and data tables. Additional details on specific data reduction methods are provided in Appendix C.

The data quality objective (DQO) process that was used to identify data for inclusion in the Phase 1 RI and risk assessments were documented in a SOW Task 2 deliverable (Windward 2001a) that was reviewed by EPA and Ecology and the various stakeholders, and subsequently approved by EPA and Ecology. The primary elements of the DQO process are summarized below.

DQOs were established for four categories, corresponding to the level at which each DQO would be applied: event, station, sample, or result. For example, a DQO applied at the result level could cause a result record to be qualified for a particular chemical, but not for other chemicals analyzed during a particular study. Table 4-2 lists the DQOs that had to be satisfied for data to be considered for inclusion in the RI.

Table 4-2. Data quality objectives applied to historical Duwamish chemistry data

Event Level
Hard copy or original electronic copy of data report must be available
Field coordinates must be available
Data must have been collected since 1990
Data must have been collected using appropriate sampling methods
Station Level
Stations located within dredge prisms or remediated areas should be identified
Station type (e.g., study site vs. reference site) must be clearly identified (applicable to toxicity test and benthic macroinvertebrate data only)
Sample Level
Sediment depth sampled should be identified
Sample type should be clearly identified
Number of replicates should be identified (applicable to benthic invertebrate and toxicity test data only)
Result Level
For non-detects, detection limits[a] and appropriate qualifiers must be given
Calculated values must be recalculated
Analytical methods must be identified
QA/QC information must be available

[a] An explanation of what is meant by the generic term “detection limit” is provided in Appendix Section C.3.1.

The data sets listed in Tables 2-1 (sediment chemistry) and 2-5 (tissue chemistry) satisfied the DQOs listed in Table 4-2 and are included in the RI and Phase 1 RAs. No sampling events were excluded in their entirety based on failure to satisfy project DQOs.

The LDWG environmental chemistry database contains data for sediment, porewater, and tissue chemistry. Chemistry data for surface water and groundwater are not included in the LDWG database because analysis and mapping of these data were not needed due to the sediment and tissue focus of this project. However, water quality data are available from the King County Water Quality Assessment (King County 1999a) and are summarized in Section 4.2.5. Available groundwater data are summarized in Appendix G.

As described in the sediment data quality objective memorandum (Windward 2001a), some of the sediment samples (see Section 2.3.1 for description of sediment sampling events) may not reflect current conditions because the sediment previously characterized has been remediated or dredged. Tables D-1 and D-2 in Appendix D list the surface and subsurface sediment samples, respectively, that are not included in the Phase 1 RI or RAs for this reason. The dredged areas were identified through review of ACOE files for dredging projects conducted since the time of sampling. Some additional sediments may have been removed from relatively small areas of the LDW (e.g., as part of interim removal actions at Boeing's Plant 2) since the time of sampling, but it is not believed that removal of those sediments substantially affects the analyses conducted as part of the Phase 1 RI.

Although sediment chemistry data associated with the dredged samples are not used in the RI or RAs, they are retained in the database in the event they are needed for future analysis. Such data could be useful for characterizing sources and identifying patterns of historical contamination.

Tissue samples were collected during several different sampling events (see Section 2.3.5). The nature and extent discussion presented in Section 4.2.7 includes data from all samples compiled in the database. Because the relevance of a particular sample for the Phase 1 RAs varies with sample type and species, additional data selection procedures were employed as described in Appendices A and B.

Data reduction refers to computational methods used to aggregate data. Data summarized in the rest of Section 4.2 are presented on a dry weight basis for sediment chemistry and on a wet weight basis for tissue chemistry. Concentrations generated by the laboratory through analyses of laboratory replicates or field duplicates were averaged for use in subsequent calculations and maps (see Appendix C for averaging rules).

Detection limits are shown separately from detected concentrations or treated as zero, depending on the map (see Appendix C for additional details on detection limits). Each map presented below clearly describes how detection limits were treated for display purposes.

Concentrations for several analyte sums were calculated as follows:

- **Total PCBs** were calculated using only detected values for 7 Aroclor mixtures[38] in accordance with Ecology's Sediment Management Standards (SMS). For individual samples in which none of the 7 Aroclor mixtures were detected, total PCBs were given a value equal to the highest detection limit of the seven Aroclors and assigned a "U" qualifier indicating the lack of detected concentrations.
- **Total LPAHs, HPAHs, and benzofluoranthenes** were also calculated in accordance with SMS. Total LPAHs are the sum of detected concentrations for naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, and anthracene. Total HPAHs are the sum of detected concentrations for fluoranthene, pyrene, benzo(a)anthracene, chrysene, total benzofluoranthenes, benzo(a)pyrene, indeno(1,2,3,-c,d)pyrene, dibenzo(a,h)anthracene, and benzo(g,h,i)perylene. Total benzofluoranthenes are the sum of the b (i.e., benzo(b)fluoranthene), j, and k isomers. Because the j isomer is rarely measured, this sum is typically calculated with only the b and k isomers. For samples in which all individual compounds within any of the three groups described above were undetected, the single highest detection limit for that sample represents the sum.
- **Total DDTs** were calculated from detected concentrations of three isomers: 4,4'-DDD, 4,4'-DDE, and 4,4'-DDT. Samples without detected concentrations for these three isomers were handled as described above for other sums.
- **Toxic equivalent quotients (TEQs) for 2,3,7,8-TCDD and carcinogenic PAHs (cPAHs)** were calculated by summing the products of concentrations and compound-specific toxic equivalent factors (TEFs), including TEFs for polychlorinated dibenzo-p-dioxins or furans (PCDD/Fs) or relative potency factors (RPFs) for cPAHs, as shown in Table 4-3. Compounds that were undetected for a given sample were assigned a value equal to one-half the sample-specific detection limit for use in the TEQ calculation.

All other sums included in the database (e.g., total xylenes, total butyltins) were reported by the laboratories and were not calculated specifically for this project.

Units are clearly specified in the maps and summary tables presented in Appendix D. Chemical concentrations in sediment are reported in dry weight units; concentrations in tissue are reported in wet weight units. TBT, which is reported in various units in the technical literature, is reported in units of TBT ion rather than as tin.[39]

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[38] Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260

[39] TBT ion concentrations were converted from the reported TBT compounds using conversion factors based on the molecular weight of the compound relative to the molecular weight of the TBT ion.

Table 4-3. Toxic equivalent factors for dioxins, furans, and carcinogenic PAHs

COMPOUND	TOXIC EQUIVALENT FACTOR
Dioxins and furans	
2,3,7,8-TCDD	1
1,2,3,7,8-PeCDD	1
1,2,3,6,7,8-HxCDD	0.1
1,2,3,4,7,8-HxCDD	0.1
1,2,3,7,8,9-HxCDD	0.1
1,2,3,4,6,7,8-HpCDD	0.01
OCDD	0.0001
2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDF	0.05
2,3,4,7,8-PeCDF	0.5
1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDF	0.1
1,2,3,4,7,8-HxCDF	0.1
2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDF	0.01
1,2,3,4,7,8,9-HpCDF	0.01
OCDF	0.0001
Carcinogenic PAHs	
Benzo[a]pyrene	1
Benz[a]anthracene	0.1
Benzo[b]fluoranthene	0.1
Benzo[k]fluoranthene	0.1
Chrysene	0.01
Dibenz[a,h]anthracene [a]	0.4
Indeno[1,2,3-cd]pyrene	0.1

Sources:

Dioxin/furan TEFs – World Health Organization (Van den Berg et al. 1998)

Carcinogenic PAHs – California EPA, Office of Environmental Health Hazard Assessment (OEHHA 1999); TEFs for PAHs that have not been measured in the LDW are not shown

[a] The TEF shown was determined by OEHHA by dividing the inhalation unit risk factor for this compound by that for benzo[a]pyrene

Many of the SQS and CSL values to which chemical concentrations in surface sediment were compared are in units of mg/kg normalized to the organic carbon content in the sediment sample (mg/kg OC). Concentrations originally in units of µg/kg dry weight were converted to mg/kg OC using the following equation:

$$C_{mg/kg\_OC} = \frac{C_{\mu g/kg-dw}}{TOC \times 10}$$

Equation 1

where C is the chemical concentration and TOC is the percent total organic carbon. At very low TOC concentrations, normalization is not appropriate (Michelsen and Bragdon-Cook 1993). Concentrations of organic chemicals were not normalized to TOC for samples with TOC concentrations less than or equal to 0.2%. In these cases, dry weight chemical concentrations were compared to the lowest apparent effects threshold (AET), which is functionally equivalent to the SQS, or the second lowest AET, which is functionally equivalent to the CSL. The 0.2% threshold was suggested by DiToro et al (1991) in their paper describing the technical basis for sediment quality criteria for non-ionic organic chemicals. Thirty-three surface sediment samples, out of almost one thousand used for analysis, had TOC concentrations less than or equal to 0.2% (Table 4-4).

Table 4-4. LDW surface sediment samples with TOC concentrations less than or equal to 0.2%

EVENT NAME	LOCATION NAME	SAMPLE ID	CONCENTRATION (%)
Norfolk-cleanup3	NFK302	L7462-2	0.032
NOAA SiteChar	WIT268	WIT07-03	0.050
NOAA SiteChar	EIT094	EIT14-02	0.070
NOAA SiteChar	EST102	EST01-04	0.070
NOAA SiteChar	EST099	EST01-02	0.070
Norfolk-cleanup1	NFK014	L4321-15	0.070
Duw/Diag-1	DUD015	L4288-13	0.080
EPA SI	DR298	SD-DR298-0000	0.080
EPA SI	DR301	SD-DR301-0000	0.080
NOAA SiteChar	EST103	EST02-02	0.080
NOAA SiteChar	WIT297	WIT13-06	0.090
EPA SI	DR140	SD-DR140-0000	0.090
EPA SI	DR076	SD-DR076-0000	0.10
EPA SI	DR300	SD-DR300-0000	0.11
EPA SI	DR272	SD-DR272-0000	0.11
NOAA SiteChar	WIT298	WIT14-01	0.11
NOAA SiteChar	EST106	EST03-02	0.11
NOAA SiteChar	EST115	EST04-05	0.12
NOAA SiteChar	EIT044	EIT01-01	0.12
NOAA SiteChar	EST113	EST04-03	0.13
NOAA SiteChar	EST175	EST12-10	0.13
NOAA SiteChar	EIT088	EIT13-02	0.14
NOAA SiteChar	WIT299	WIT14-02	0.14
EPA SI	DR299	SD-DR299-0000	0.14
EPA SI	DR297	SD-DR297-0000	0.14
Norfolk-monit3	NFK502	L17647-4	0.14
Duw/Diag-1	DUD013	L4288-12	0.15

EVENT NAME	LOCATION NAME	SAMPLE ID	CONCENTRATION (%)
EPA SI	DR294	SD-DR294-0000	0.15
EPA SI	DR295	SD-DR295-0000	0.15
EPA SI	DR257	SD-DR257-0000	0.15
NOAA SiteChar	EST098	EST01-01	0.16
NOAA SiteChar	EST104	EST02-03	0.20
Norfolk-monit3	NFK503	L17647-6	0.20

4.2.2 Surface sediment

Sediment is the environmental medium of greatest concern in the LDW. Chemicals released to the water can accumulate in the sediments, particularly because many chemicals have an affinity for fine particles, such as silt and clay, and the organic material typically associated with these particles. Chemicals in the sediments can have adverse effects on animals that live in and on the sediment. Some of the sediment investigations described in Section 2.3.1 were conducted to characterize a particular location where contamination was previously identified or suspected. Other investigations were conducted for reconnaissance purposes to better understand the spatial trends in LDW sediment chemistry. There may be also be trends over time in sediment chemistry, but these trends are not explored in the Phase 1 RI. Temporal trend analysis may be conducted as part of the Phase 2 RI or other LDW early remedial actions to better understand contributions of historical versus ongoing sources of contamination.

For the purposes of the Phase 1 RI, the primary focus of the nature and extent of chemical contamination is on surface sediment, rather than subsurface sediment. In addition, the sediment portions of both the ecological and human health risk assessments are based on exposure to surface sediment only. Existing data on sediment fate and transport summarized in Section 4.4.2 suggest that erosive forces sufficient to expose sediment deeper than 15 cm may only occur episodically on a localized scale. The frequency and importance of these phenomena will be investigated further during Phase 2.

Data from the large number of historical LDW surface sediment chemistry samples are summarized in this section by individual chemical. Summary statistics for all chemicals are provided in Table D-3 in Appendix D. Narrative descriptions and maps are provided for a subset of chemicals measured in sediment. This subset is listed in Table 4-5, along with the rationale for each chemical's selection. Chemicals listed in Table 4-5 pose greater human health and ecological risks, according to the risk assessments presented in Appendices A and B, than chemicals that were not listed.

The primary criterion for selecting chemicals for mapping was detection frequency and the results of the Phase 1 risk assessments. For the ERA, all COPCs identified for fish, wildlife, and plants were also identified as COPCs for benthic invertebrates. Consequently, the benthic invertebrate component of the ERA was used as the primary screening method and the other ERA components were used for confirmation. Identification as a chemical of concern (COC) for the HHRA (see Appendix B) was also a primary method for selecting chemicals for mapping.

The benthic component of the ERA relies heavily on Ecology's Sediment Management Standards (SMS). The SMS include numeric chemical standards for 47 chemicals or groups of chemical. The lowest standard is called the Sediment Quality Standard (SQS). The Dredged Material Management Program (DMMP) includes similar criteria. The lowest guideline in that program is called the Screening Level (SL). There are 14 chemicals that have SLs but do not have an SQS value (Table 4-6).

Table 4-5. Chemicals selected for narrative description and GIS mapping

CHEMICAL	RATIONALE FOR SELECTION
1,2,4-Trichlorobenzene	Group 4 chemical for benthic invertebrate ERA, best example of semivolatile organic compound with elevated detection limits
1,2-Dichlorobenzene	Group 1 chemical for benthic invertebrate ERA
1,4-Dichlorobenzene	Group 1 chemical for benthic invertebrate ERA
2,3,7,8-TCDD TEQ	Human health COC for beach play scenario
4-Methylphenol	Group 1 chemical for benthic invertebrate ERA
Acenaphthene	Group 1 chemical for benthic invertebrate ERA
Arsenic	Human health COC (multiple scenarios), Group 2 chemical for benthic invertebrate ERA, COPC for English sole and otter
Benzoic acid	Group 1 chemical for benthic invertebrate ERA
Benzo(g,h,i)perylene	Group 2 chemical for benthic invertebrate ERA, representative HPAH
Bis(2-ethylhexyl)phthalate	Group 1 chemical for benthic invertebrate ERA
Butyl benzyl phthalate	Group 1 chemical for benthic invertebrate ERA
Cadmium	Group 2 chemical for benthic invertebrate ERA, representative metal
Carcinogenic PAHs	Human health COC for seafood consumption scenario
Copper	COPC for English sole, Group 2 chemical for benthic invertebrate ERA
DDTs (total-calculated)	Group 1 chemical for benthic invertebrate ERA
Dibenzofuran	Group 1 chemical for benthic invertebrate ERA
Ethylbenzene	Group 4 chemical for benthic invertebrate ERA, represents other volatile organics that were infrequently measured and rarely detected
Fluoranthene	Group 2 chemical for benthic invertebrate ERA, represents other individual HPAHs
Fluorene	Group 1 chemical for benthic invertebrate ERA
Hexachlorobenzene	Group 1 chemical for benthic invertebrate ERA
HPAHs	Group 2 chemical for benthic invertebrate ERA, represents individual HPAHs, COPC (PAHs) for juvenile salmon and English sole
Lead	Group 2 chemical for benthic ERA, chemical of interest for HHRA given recent investigations by Ecology of regional lead contamination in soil, COPC for sandpiper
LPAHs	Group 2 chemical for benthic invertebrate ERA, represents individual LPAHs
Mercury	Group 1 chemical for benthic invertebrate ERA, COPC for bull trout, great blue heron, and bald eagle

CHEMICAL	RATIONALE FOR SELECTION
PCBs (total-calculated)	Human health COC for seafood consumption scenario, Group 1 chemical for benthic invertebrate ERA, COPC for bull trout, English sole, great blue heron, bald eagle, and river otter
Phenol	Group 1 chemical for benthic invertebrate ERA
Tributyltin	COPC for benthic invertebrates, bull trout, and juvenile chinook salmon
Zinc	Group 2 chemical for benthic invertebrate ERA, representative metal

Group 1 – Detection frequency ≥ 5% and SQS/SL exceedance frequency ≥ 5%

Group 2 – Detection frequency ≥ 5%, SQS/SL exceedance frequency < 5%, 3 or more exceedances by detected concentrations

Group 4 – Detection frequency < 5%, but SQS/SL exceedance frequency for detection limits > 5%

COC – Chemical of concern (i.e., cancer risk > 10^{-6} or HQ > 1 in Phase 1 risk assessments)

COPC – Chemical of potential concern (i.e., HQ > 1) in Phase 1 ERA recommended for further evaluation in Phase 2 ERA. Note the COPCs listed above are not a complete list of chemicals to be evaluated in the Phase 2 ERA.

Table 4-6. Numeric chemical standards used in the benthic portion of the ERA

CHEMICAL	SQS	CSL	UNITS
1,2,4-Trichlorobenzene	0.81	1.8	mg/kg OC-dry
1,2-Dichlorobenzene	2.3	2.3	mg/kg OC-dry
1,3-Dichlorobenzene	170 [a]	na	µg/kg, dry wt.
1,4-Dichlorobenzene	3.1	9.0	mg/kg OC-dry
2,4-Dimethylphenol	29	29	µg/kg, dry wt.
2-Methylnaphthalene	38	64	mg/kg OC-dry
2-Methylphenol	63	63	µg/kg, dry wt.
4-Methylphenol	670	670	µg/kg, dry wt.
Acenaphthene	16	57	mg/kg OC-dry
Acenaphthylene	66	66	mg/kg OC-dry
Aldrin	10 [a]	na	µg/kg, dry wt.
alpha-Chlordane	10 [a]	na	µg/kg, dry wt.
Anthracene	220	1,200	mg/kg OC-dry
Antimony	150 [a]	200 [b]	mg/kg, dry wt.
Arsenic	57	93	mg/kg, dry wt.
Benzo(a)anthracene	110	270	mg/kg OC-dry
Benzo(a)pyrene	99	210	mg/kg OC-dry
Benzo(g,h,i)perylene	31	78	mg/kg OC-dry
Benzofluoranthenes (total-calc'd)	230	450	mg/kg OC-dry
Benzoic acid	650	650	µg/kg, dry wt.
Benzyl alcohol	57	73	µg/kg, dry wt.
bis(2-ethylhexyl)phthalate	47	78	mg/kg OC-dry
Butyl benzyl phthalate	4.9	64	mg/kg OC-dry
Cadmium	5.1	6.7	mg/kg, dry wt.
Chromium	260	270	mg/kg, dry wt.

CHEMICAL	SQS	CSL	UNITS
Chrysene	100	460	mg/kg OC-dry
Copper	390	390	mg/kg, dry wt.
DDTs (total-calc'd)	6.9 [a]	69 [b]	µg/kg, dry wt.
Dibenzo(a,h)anthracene	12	33	mg/kg OC-dry
Dibenzofuran	15	58	mg/kg OC-dry
Dieldrin	10 [a]	na	µg/kg, dry wt.
Diethyl phthalate	61	110	mg/kg OC-dry
Dimethyl phthalate	53	53	mg/kg OC-dry
Di-n-butyl phthalate	220	1,700	mg/kg OC-dry
Di-n-octyl phthalate	58	4,500	mg/kg OC-dry
Ethylbenzene	10 [a]	50 [b]	µg/kg, dry wt.
Fluoranthene	160	1,200	mg/kg OC-dry
Fluorene	23	79	mg/kg OC-dry
gamma-BHC	10 [a]	na	µg/kg, dry wt.
Heptachlor	10 [a]	na	µg/kg, dry wt.
Hexachlorobenzene	0.38	2.3	mg/kg OC-dry
Hexachlorobutadiene	3.9	6.2	mg/kg OC-dry
Hexachloroethane	1,400 [a]	14,000 [b]	µg/kg, dry wt.
Indeno(1,2,3-cd)pyrene	34	88	mg/kg OC-dry
Lead	450	530	mg/kg, dry wt.
Mercury	0.41	0.59	mg/kg, dry wt.
Naphthalene	99	170	mg/kg OC-dry
Nickel	140 [a]	370 [b]	mg/kg, dry wt.
N-Nitrosodiphenylamine	11	11	mg/kg OC-dry
PCBs (total-calc'd)	12	65	mg/kg OC-dry
Pentachlorophenol	360	690	µg/kg, dry wt.
Phenanthrene	100	480	mg/kg OC-dry
Phenol	420	1,200	µg/kg, dry wt.
Pyrene	1,000	1,400	mg/kg OC-dry
Silver	6.1	6.1	mg/kg, dry wt.
Tetrachloroethene	57 [a]	210 [b]	µg/kg, dry wt.
Total HPAH (calc'd)	960	5,300	mg/kg OC-dry
Total LPAH (calc'd)	370	780	mg/kg OC-dry
Trichloroethene	160 [a]	1,600 [b]	µg/kg, dry wt.
Xylene (total)	40 [a]	160 [b]	µg/kg, dry wt.
Zinc	410	960	mg/kg, dry wt.

[a] SQS not available; concentration is DMMP SL

[b] CSL not available; concentration is DMMP ML

na = not available

If the chemical concentrations in a sediment sample are all below their respective SQS/SL, that sediment is unlikely to cause significant adverse effects to benthic invertebrates. At concentrations above the SQS/SL, there is a possibility of adverse effects to benthic invertebrates. Consequently, the SQS/SL exceedance frequency is a reasonable criterion for identifying chemicals that warrant maps and discussion.

The exposure assessment for benthic invertebrates (see Appendix A) includes a grouping process that uses detection and SQS/SL exceedance frequencies to prioritize chemicals for discussion purposes. This process was also used here to identify chemicals for mapping. A group 1 chemical was detected in more than 5% of the samples and also exceeded the SQS/SL in 5% or more of the samples. Approximately half the chemicals in Table 4-5 are group 1 chemicals. Chemicals in other groups (see the Table 4-5 notes for additional definitions) are less likely to be risk drivers for benthic invertebrates, so fewer chemicals were mapped from the other groups.

Two maps are presented for each chemical listed in Table 4-5. Each map shows the distribution of sampling points for that chemical and the associated concentration ranges relative to the SQS and CSL (if available). The first map in each pair represents sampling locations as points and shows detected concentrations separately from undetected concentrations (i.e., detection limits). The second map in each pair represents each sampling location as a Thiessen polygon. The rationale and theory for using Thiessen polygons in this project is provided in Appendix C. Non-detects are presented as zero in the Thiessen polygon maps. The large-format (11” x 17”) maps are presented at the end of this document in a separate section.

Multiple samples were collected at some sampling locations, primarily for the King County Water Quality Assessment and the Norfolk CSO monitoring program. In these cases, concentrations associated with these locations represent means from multiple samples.[40]

The following sections discuss individual chemicals from Table D-3. All locations are designated as river miles (RM) upstream of the southern tip of Harbor Island. Maps showing multiple chemicals are provided in Section A.3 of Appendix A.

Concentrations discussed below are also presented in comparison to their respective SQS and CSL values, if available. These comparisons were made as a familiar reporting convention, not in an attempt to characterize risk to benthic invertebrates upon which the standards are based. The ecological and human health risks associated with the chemicals described below are described in Appendices A (ERA) and B (HHRA).

4.2.2.1 Semivolatile and volatile organic compounds

1,2-Dichlorobenzene

1,2-Dichlorobenzene was detected at 35 of 557 locations (Table D-3). The maximum detected concentration by location was 555 µg/kg dw (6.44 mg/kg OC), at station DUD027 (RM 0.6). The median detected concentration was 2.6 µg/kg dw. Throughout

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[40] See Appendix C for a detailed discussion of averaging rules.

the LDW, detected concentrations of 1,2-dichlorobenzene exceeded the SQS at only two locations (between RM 0.4 and 0.6) (Maps 4-1a and 4-1b).

Detection limits exceeding the SQS for 1,2-dichlorobenzene were found throughout the LDW (Map 4-1a). The majority of detection limits exceeding SQS were found on the east side of the LDW between RM 3.3 and 3.6.

1,2,4-Trichlorobenzene

1,2,4-Trichlorobenzene was detected at 7 of 557 locations (Table D-3). The maximum detected concentration by location was 191 µg/kg dw (2.21 mg/kg OC), at station DUD027 (RM 0.6). The median detected concentration was 2.8 µg/kg dw. Detected concentrations of 1,2,4-trichlorobenzene exceeded the CSL or the SQS only at station DUD027 (Maps 4-2a and 4-2b).

Detection limits exceeding the SQS and CSL standards for 1,2,4-trichlorobenzene occurred frequently throughout the LDW (Map 4-2a). Detection limits exceeding SQS exhibited a fairly even distribution throughout the LDW, while the majority of detection limits exceeding the CSL were found on the east side of the LDW between RM 3.3 and 3.6.

1,4-Dichlorobenzene

1,4-Dichlorobenzene was detected at 69of 557 locations (Table D-3). The maximum detected concentration by location was 1,900 µg/kg dw (21 mg/kg OC), at station DUD027 (RM 0.6). The median detected concentration was 6.5 µg/kg dw. Detected concentrations of 1,4-dichlorobenzene exceeded the CSL at two locations and the SQS at one other location in the LDW (Maps 4-3a and 4-3b).

Detection limits exceeding SQS and CSL standards for 1,4-dichlorobenzene were found throughout the LDW (Map 4-3a). The majority of detection limits exceeding the SQS and CSL were found on the east side of the LDW between RM 3.3 and 3.6.

2,3,7,8-TCDD TEQ

2,3,7,8-TCDD TEQ was detected at all 29 locations at which it was measured (Table D-3). The maximum detected concentration was 224 ng/kg dw, at station DR123 (RM 1.5). The median detected concentration was 2.6 ng/kg dw. No particular pattern of contamination was observed (Map 4-4).

4-Methylphenol

4-Methylphenol was detected t 36 of 281 locations (Table D-3). The maximum detected concentration by location was 6,250 µg/kg dw, at station 205 (RM 1.8). The median detected concentration was 43 µg/kg dw. Detected concentrations of 4-methylphenol exceeded the SQS or CSL only six times, with five of these between RM 0.3 and 0.6 (Maps 4-5a and 4-5b).

Detection limits exceeding the SQS/CSL for 4-methylphenol were found from RM 0.0 to 0.7 (Map 4-5a).

Acenaphthene

Acenaphthene was detected at 229 of 557 locations (Table D-3). The maximum detected concentration by location was 3,300 µg/kg dw (130 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 46 µg/kg dw. Detected concentrations of acenaphthene exceeded the CSL at three locations and the SQS at 20 additional locations (Maps 4-6a and 4-6b). These exceedances were found scattered throughout the LDW.

Detection limits exceeding the CSL were found at three locations between RM 0.0 and 0.7. Detection limits exceeding the SQS for acenaphthene were found infrequently throughout the LDW (Map 4-6a).

Bis(2-ethylhexyl)phthalate

Bis(2-ethylhexyl)phthalate (BEHP) was detected at 466 of 561 locations (Table D-3). The maximum detected concentration by location was 13,000 µg/kg dw (140 mg/kg OC), at station DUD027 (RM 0.6). The median detected concentration was 430 µg/kg dw. Exceedances of the SQS or CSL for BEHP were found in the majority of samples collected on the east side between RM 0.3 and 0.6 (Maps 4-7a and 4-7b). Less frequent exceedances were found between Slips 4 and 6 (between RM 3.3 and 3.9). A small number of other CSL exceedances were dispersed throughout the LDW.

One detection limit exceeding the CSL for BEHP was found at RM 1.8 (Map 4-7a).

Benzo(g,h,i)perylene

Benzo(g,h,i)perylene was detected at 489 of 557 locations (Table D-3). The maximum detected concentration by location was 14,000 µg/kg dw (540 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 150 µg/kg dw. Detected concentrations of benzo(g,h,i)perylene exceeded the CSL at 6 locations and the SQS at 8 other locations (Maps 4-8a and 4-8b). The SQS exceedances were found throughout the LDW, but the CSL exceedances are limited to RM 3.5 to 4.3.

Detection limits exceeding the SQS and CSL for benzo(g,h,i)perylene were found infrequently in the LDW (Map 4-8a).

Benzoic acid

Benzoic acid was detected at 30 of 549 locations (Table D-3). The maximum detected concentration by location was 5,930 µg/kg dw, at station 205 (RM 1.8). The median detected concentration was 252 µg/kg dw. Detected concentrations of benzoic acid exceeded SQS/CSL at 3 locations, two near RM 0.5 and one at RM 1.8 (Maps 4-9a and 4-9b).

Detection limits exceeding the SQS or CSL for benzoic acid were found infrequently in the LDW, with the exception of the east side of the LDW between RM 3.3 and 3.6 (Map 4-9a).

Butyl benzyl phthalate

Butyl benzyl phthalate was detected at 336 of 561 locations (Table D-3). The maximum detected concentration by location was 7,100 µg/kg dw (340 mg/kg OC), at station SD-04116 (RM 3.4). The median detected concentration was 41 µg/kg dw. The majority of butyl benzyl phthalate SQS exceedances were found in samples collected near the east side of the LDW between RM 0.3 and 0.6. (Maps 4-10a and 4-10b). Other SQS exceedances were found along the east side of the LDW between RM 3.3 and 3.6 as well as between RM 3.7 and 4.0. Only six CSL exceedances were found, five of which were located on the east side of the LDW between RM 3.4 and 3.6.

Detection limits exceeding the SQS for butyl benzyl phthalate were found scattered throughout the LDW (Map 4-10a). The majority of detection limits exceeding the SQS were found along the east side of the LDW from RM 3.3 to 3.6. Detection limits exceeding the CSL for butyl benzyl phthalate were found at seven locations from RM 0.0 to 0.7.

Carcinogenic PAHs

Carcinogenic PAHs, expressed as cPAH TEQs, were detected at 531 of 557 locations analyzed for PAHs (Table D-3). The maximum detected concentration by location was 30,900 µg/kg dw, at station R40 (east end of Slip 6). The median detected concentration was 327 µg/kg dw. Carcinogenic PAH concentrations were generally higher in the northern half of the LDW than in the southern half, but low and high concentrations were found to some degree throughout the LDW (Map 4-11).

Dibenzofuran

Dibenzofuran was detected at 188 of 556 locations (Table D-3). The maximum detected concentration by location was 2,300 µg/kg dw (88 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 40 µg/kg dw. Detected concentrations of dibenzofuran exceeded the CSL at two locations and the SQS at 10 other locations (Maps 4-12a and 4-12b). These exceedances were found scattered throughout the LDW.

Detection limits exceeding the SQS for dibenzofuran were found infrequently throughout the LDW (Map 4-12a). Three locations with detection limits exceeding the CSL for dibenzofuran were between RM 0.0 to 0.7.

Ethylbenzene

Ethylbenzene was detected at only 1 of 49 locations (Table D-3). The single detected ethylbenzene concentration (0.49 µg/kg dw) did not exceed the SL; however, detection limits for ethylbenzene did exceed the SL at 3 locations between RM 0.3 to 0.7 (Maps 4-13a and 4-13b).

Fluorene

Fluorene was detected at 299 of 557 locations (Table D-3). The maximum detected concentration by location was 4,400 µg/kg dw (170 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 48 µg/kg dw. Detected concentrations of fluorene exceeded the CSL at four locations and the SQS at 12 other locations (Maps 4-14a and 4-14b). These exceedances were found scattered throughout the LDW.

Detection limits exceeding the SQS for fluorene were found infrequently in the LDW; usually near other detection limits not exceeding the SQS (Map 4-14a). No detection limits exceeding the CSL were found in the LDW.

Fluoranthene

Fluoranthene was detected at 540 of 557 locations (Table D-3). The maximum detected concentration by location was 62,000 µg/kg dw (2,400 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 510 µg/kg dw. Fluoranthene concentrations exceeded the CSL at one location (Slip 6) and the SQS at 26 other locations throughout the LDW (Maps 4-15a and 4-15b).

No detection limits exceeded the SQS or CSL for fluoranthene (Map 4-15a).

Hexachlorobenzene

Hexachlorobenzene was detected at 41 of 557 locations (Table D-3). The maximum detected concentration by location was 690 µg/kg dw (45 mg/kg OC), at DR198 (RM 3.1). The median detected concentration was 1.3 µg/kg dw. Hexachlorobenzene exceeded the CSL at 1 location and the SQS at 4 other locations (Maps 4-16a and 4-16b).

Detection limits exceeding the SQS and CSL for hexachlorobenzene occurred frequently throughout the LDW (Map 4-16a). Detection limits exceeding the SQS were evenly distributed throughout the LDW, while the majority of detection limits exceeding the CSL were found on the east side of the LDW between RM 3.3 and 3.6.

Phenol

Phenol was detected at 197 of 557 locations (Table D-3). The maximum detected concentration by location was 3,600 µg/kg dw, at station K-07 (RM 0.1). The median detected concentration was 60 µg/kg dw. Phenol concentrations exceeded the CSL at four locations and the SQS at 10 other locations between RM 0.0 to 1.6 and 3.1 to 3.8 (Maps 4-17a and 4-17b).

Three detection limits exceeding the SQS for phenol were found on either side of the LDW at RM 0.6 (Map 4-17a). The phenol detection limit at one of these locations also exceeded the CSL for phenol.

Total HPAHs

Total HPAHs were detected at 544 of 557 locations (Table D-3). The maximum detected concentration by location was 241,000 µg/kg dw (9,280 mg/kg OC), at station R40 (east end of Slip 6). The median detected concentration was 2,610 µg/kg dw. The distribution of total HPAH exceedances is shown in Maps 4-18a and 4-18b. A single

CSL exceedance was found in Slip 6. SQS exceedances at 15 other locations were found scattered throughout the LDW.

No detection limits exceeded the SQS for total HPAHs (Map 4-18a).

Total LPAHs

Total LPAHs were detected at 522 of 557 locations (Table D-3). The maximum detected concentration by location was 60,200 µg/kg dw (2,320 mg/kg OC), at station R40 (RM 4.2/Slip 6). The median detected concentration was 330 µg/kg dw. Total LPAH concentrations exceeded the CSL at 3 locations and the SQS at 5 other locations scattered throughout the LDW (Maps 4-19a and 4-19b).

No detection limits exceeded the SQS for total LPAHs (Map 4-19a).

4.2.2.2 Pesticides and PCBs

Total DDTs

Total DDTs were detected at 42 of 101 locations (Table D-3). The maximum detected concentration by location was 2,880 µg/kg dw, at station DR178 (east end of Slip 4). The median detected concentration was 6.9 µg/kg dw. Total DDT concentrations exceeded the ML[41] at 6 locations and the SL at 15 other locations (Maps 4-20a and 4-20b). Detection limits exceeded the SL at 9 locations.

Total PCBs

Total PCBs[42] were detected at 905 of 957 locations (Table D-3). The maximum detected concentration by location was 222,600 µg/kg dw (10,600 mg/kg OC), at station NFK305 (RM 4.8). The median detected concentration was 139 µg/kg dw. Total PCB concentrations in excess of the SQS or the CSL were found at various locations scattered throughout the LDW (Maps 4-21a and 4-21b). Areas with the greatest number of CSL exceedances include the east side of the LDW from RM 0.3 to 0.6, and from Slip 4 down to RM 4.0 (primarily on the east side). Several CSL exceedances were found on the west side between RM 1.9 and 2.3, between RM 3.4 and 3.7, and near RM 4.9. SQS exceedances were found in areas similar to those described above for CSL exceedances, but were also found from RM 0.0 to 1.9, primarily on the west side of the LDW, and from RM 2.3 to 2.9.

Detection limits at only a single location exceeded the SQS for total PCBs (Map 4-21a). No detection limits exceeded the CSL.

4.2.2.3 Metals

Some metals are chemicals of potential concern in the LDW, but many are also detected in all soil and sediment samples regardless of the degree of contamination

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[41] SL and ML are used for total DDTs because SQS and CSL are not available.

[42] As described in Section 4.1.3.1, total PCBs refers to total Aroclors, as measured by standard EPA methods, and totals reported by NOAA (1998) in their Site Characterization study, which were measured by high pressure liquid chromatography/photodetector array (HPLC/PDA).

because they occur naturally as part of the earth's crust. Information on background concentrations is provided in the sections below that describe individual metals.

Arsenic

Arsenic was detected at 525 of 575 locations (Table D-3). The maximum detected concentration by location was 99 mg/kg dw, at station DR020 (head of Slip 1). The median detected concentration was 11.7 mg/kg dw. The arsenic concentration at DR020 exceeded the CSL; concentrations exceeded the arsenic SQS at three other locations scattered throughout the LDW (Maps 4-22a and 4-22b).

No detection limits exceeded the SQS for arsenic (Map 4-22a).

Cadmium

Cadmium was detected at 430 of 567 locations (Table D-3). The maximum detected concentration by location was 120 mg/kg dw, at station SS-SWY01 (RM 3.5). The median detected concentration was 48 mg/kg dw. Cadmium concentrations exceeded the CSL at nine locations and the SQS at one other location along the east side of the LDW from RM 3.3 to 3.6. The CSL at one other location on the east side between RM 0.5 and 0.6 (Maps 4-23a and 4-23b).

No detection limits exceeded the SQS or CSL for cadmium (Map 4-23a).

Copper

Copper was detected at all 575 locations at which it was analyzed (Table D-3). The maximum detected concentration by location was 12,000 mg/kg dw, which was found at both stations SS-SWY01 and SS-SWY02 (RM 3.5). The median detected concentration was 53 mg/kg dw. Copper concentrations exceeded the SQS (and the CSL, which is equal to the SQS) at 6 locations along the east side of the LDW between RM 3.4 and 3.6 (Maps 4-24a and 4-24b).

Lead

Lead was detected at all 575 locations at which it was analyzed (Table D-3). The maximum detected concentration by location was 23,000 mg/kg dw, at station SS-SWY02 (RM 3.5). The median detected concentration was 36 mg/kg dw. Lead concentrations exceeded the CSL at 11 locations and the SQS at 1 other location along the east side of the LDW from RM 3.2 to 3.7 (Maps 4-25a and 4-25b). One CSL exceedance was found on the east side at RM 4.8, and 1 other SQS exceedance was found on the east side of the LDW between RM 0.5 and 0.6.

Mercury

Mercury was detected at 501 of 572 locations (Table D-3). The maximum detected concentration by location was 4.6 mg/kg dw, at station SD-04408 (RM 3.4). The median detected concentration was 0.17 mg/kg dw. Mercury concentrations exceeded the CSL at 13 locations and the SQS at 14 other locations throughout the LDW (Maps 4-26a and 4-26b).

No detection limits exceeded the SQS or CSL for mercury (Map 4-26a).

Tributyltin

Tributyltin was detected at 88 of 94 locations (Table D-3). The maximum detected concentration by location was 358 µg/kg dw, at station K-07 (RM 0.0). The median detected concentration was 59 µg/kg dw. Tributyltin concentrations were highest overall from RM 0 to 2.2 (Maps 4-27a and 4-27b).

Zinc

Zinc was detected at 573 of 575 locations (Table D-3). The maximum detected concentration by location was 9,700 mg/kg dw, at station SS-SWY01 (RM 3.5). The median detected concentration was 115 mg/kg dw. Zinc concentrations exceeded the CSL at 10 locations and the SQS at 10 other locations along the east side of the LDW between RM 3.3 and 3.7 (Maps 4-28a and 4-28b). Six SQS exceedances were found scattered between RM 0.4 and 0.6. One CSL exceedance was found in Slip 1 (RM 1.0).

No detection limits exceeded the SQS for zinc (Map 4-28a).

4.2.3 Subsurface sediment

The following sections summarize the distribution of individual chemicals in subsurface sediment samples. The chemicals included in this section are a subset of the chemicals discussed in Section 4.2.2. Some chemicals are not discussed in this section because they were not analyzed or detected as frequently in subsurface sediments as in surface sediments, or were analyzed primarily in areas subject to early remedial actions (e.g., Duwamish/Diagonal CSO/SD site and Boeing Plant 2 RCRA correction action). A more detailed discussion of the nature and extent of subsurface sediment contamination will be provided in the Phase 2 RI, following collection of additional subsurface sediment chemistry data.

Summary statistics for all chemicals analyzed in subsurface sediment are provided in Table D-4 in Appendix D. The GIS maps referenced in this section present data from multiple depths, as shown on the inset tables on the maps. Some locations may have had one composite sample collected over a broad depth range, while other locations may have had multiple samples collected from strata of different thicknesses. It should be recognized that this presents a rather imprecise characterization of subsurface conditions, and comparison among stations should only be made with this caveat in mind. For the purposes of risk assessment and the identification of potential early remedial action areas, the focus of the Phase 1 RI is on surface sediments. Additional subsurface sediment characterization will be needed in Phase 2 as well as in the feasibility study.

Vertical trends in chemical contamination are a function of sources (historical vs. ongoing) and hydrodynamic environment. Age-dated cores collected in depositional environments in Puget Sound and some Washington lakes and rivers have demonstrated a general pattern of contamination that is consistent with the historical input trends (Bloom and Crecelius 1987; Lefkovitz et. al. 1997; Van Metre et. al. 2000). This pattern shows a historical maximum at depth relating to the time of maximum release into the environment and declining concentrations closer to the surface corresponding with lower releases as pollution controls took effect. The core collected at Station DUD006 (RM 0.4) demonstrates this pattern, particularly for PCBs (Map 4-32). Such patterns are only discernible in depositional environments, because active resuspension may mask the subsurface maximum due to vertical mixing.

Unfortunately there are very few sediment cores collected in the LDW that have been analyzed over multiple narrow depth intervals (30 cm [11.8 in.] or less) within a single core, and none that have been age-dated. Although the LDW is primarily a depositional environment with respect to sediment fate and transport (see Section 4.4.2), the lack of detailed cores makes it very difficult to identify site-wide vertical trends in contamination.

4.2.3.1 Bis(2-ethylhexyl)phthalate

BEHP was detected in 81 of 89 samples (Table D-4). The maximum detected concentration was 18,000 µg/kg dw (280 mg/kg OC), which was found at station DUD261 (RM 0.6; Location 1055 on Map 4-29). Thirty-two other samples had concentrations greater than 1,000 µg/kg dw; all but four of these samples were collected between RM 0.4 and 0.6.

4.2.3.2 Total HPAHs

Total HPAHs were detected in 84 of 87 samples (Table D-4). The maximum detected concentration was 15,800 µg/kg dw (376 mg/kg OC), which was found at station DUD254 (RM 0.4; Location 1049 on Map 4-30). Twenty-two samples from other locations had concentrations greater than 5,000 µg/kg dw; all but six of these samples were collected between RM 0.4 and 0.6.

4.2.3.3 Total LPAHs

Total LPAHs were detected in 75 of 87 samples (Table D-4). The maximum detected concentration was 5,607 µg/kg dw (1,078 mg/kg OC), which was found at station DUD006 (RM 0.4; Location 995 on Map 4-31). Fifteen samples from other locations had concentrations greater than 1,000 µg/kg dw. Concentrations were generally higher between RM 0.4 and 0.6 compared to other LDW regions.

4.2.3.4 Total PCBs

Total PCBs were detected in 111 of 150 samples (Table D-4). The maximum detected concentration was 890,000 µg/kg dw (29,000 mg/kg OC), which was found at station SD-04905 (RM 3.4; Location 399 on Map 4-32). The sediments in the immediate vicinity of the location where this sample was collected were subsequently removed during an interim remedial action at Boeing's Plant 2. Fourteen other samples from throughout the LDW had concentrations greater than 5,000 µg/kg dw. Concentrations at all depths were generally lower between RM 4 and 5 compared to other LDW regions, but concentrations below 100 µg/kg dw were found throughout the LDW (Map 4-32).

4.2.3.5 Mercury

Mercury was detected in 95 of 102 samples (Table D-4). The maximum detected concentration was 3.3 mg/kg dw, which was found at DUD006 (RM 0.4; Location 995 on Map 4-33). Eleven other samples had concentrations greater than 1 mg/kg dw. The highest mercury concentrations were in the surface segment of the core sample at some locations, but at other locations the maximum concentration was from a deeper stratum. Concentrations were consistently low between RM 4 and 5, but concentrations below 0.5 mg/kg dw were found throughout the LDW (Map 4-33).

4.2.4 Porewater

Porewater is the water found between sediment particles. It can be collected by centrifuging a sediment sample until the sediment and water fractions become separated. Porewater is analyzed because it may contain chemicals that are biologically available to animals that live in the sediment. In contrast, some of the chemicals found in sediment are probably not biologically available to these animals because the chemicals may be tightly bound to sediment particles.

Fifteen porewater samples from the EPA Site Inspection (Weston 1999) were analyzed for trace elements and butyltins (Map 2-8). Several elements (beryllium, chromium, cobalt, mercury, nickel, selenium, thallium, and tin) were never detected (Table D-5 in Appendix D). The maximum detected concentrations for the other elements were below applicable state marine water quality criteria with the exception of arsenic and copper.[43] Tributyltin was detected in eight of 15 samples. The maximum detected concentration was 0.080 µg/L, which is below the DMMP SL of 0.15 µg/L. Maximum concentrations were found at eight different locations for the various chemicals, suggesting that no single sample stood out from other samples with respect to general contamination.

4.2.5 Surface water

King County collected surface water chemistry data from October 1996 to June 1997 during their Water Quality Assessment (see Section 2.3.2). Grab samples were collected at least once a week at depths of 1 m (3.3 ft) below the surface and 1 m (3.3 ft) above the river bottom at three LDW locations near the Brandon (RM 1.1), SW Michigan (RM 2.0), and Norfolk (RM 4.9) CSOs.[44] Grab samples were analyzed for semivolatile organic compounds, dissolved and total concentrations of trace elements (arsenic, cadmium, copper, lead, nickel, and zinc), fecal coliform bacteria, and

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[43] Two of four detected copper concentrations were greater than the marine chronic criterion (5 µg/L vs 3.1 µg/L. Eight of 12 detected arsenic concentrations in porewater were greater than the marine chronic criterion (measured concentrations up to 114 µg/L vs. 36 µg/L).

[44] Eight other locations outside the LDW were also sampled.

conventional parameters. Grab samples were also collected during and shortly after four large rainstorms[45] that triggered CSO discharges to evaluate whether chemical concentrations were elevated above baseline during these events. These data are summarized in two groups, ambient and storm, in Table 4-7.

Ammonia and nitrate/nitrite concentrations were slightly higher in ambient samples compared to storm samples, suggesting that the additional wet weather discharges associated with storm samples had lower concentrations of these nutrients than ambient river water. Fecal coliform bacteria and suspended solids concentrations, however, were higher in storm samples, reflecting the contribution of the CSOs. Most metals were frequently detected, except beryllium, selenium, and silver, which were rarely detected. Concentrations of most metals were similar between ambient and storm samples, although concentrations of total metals (including solids) were higher for some metals (e.g., chromium, cobalt, zinc) in storm samples even though concentrations of dissolved metals (filtered) were higher in ambient samples. Concentrations of copper and nickel, two metals often associated with stormwater, were higher in storm samples than in ambient samples (Table 4-7). None of the dissolved metal concentrations, including all detection limits, exceeded the applicable Washington water quality criteria.[46]

Organic compounds were rarely detected in any samples (Table 4-7). Exceptions included benzoic acid (detected in 8 of 52 ambient samples), BEHP (detected in 44 of 52 ambient samples, and all 42 storm samples), di-n-butyl phthalate (detected in 5 of 52 ambient samples, and 6 of 42 storm samples). Phenol and butyl benzyl phthalate were also detected in a single storm sample. Phthalate concentrations, particularly BEHP, were much higher in storm samples, reflecting the common occurrence of these compounds in wet weather discharges.

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[45] Samples were collected on December 5, 6, and 7, 1996 (Storm 1); March 16, 17, and 18, 1997 (Storm 2); April 21 and 22, 1997 (Storm 3); and June 1, 2, and 3, 1997 (Storm 4).

[46] Based on the hardness data collected at the three sites, marine water quality criteria were applicable at the Brandon and SW Michigan sites (average hardness approximately 3,200 mg/L) and freshwater water quality criteria were applicable at the Norfolk site (average hardness of 60 mg/L).

Table 4-7. Summary of water chemistry data collected adjacent to Norfolk, Brandon, and SW Michigan CSOs during King County Water Quality Assessment

Chemical	Units	Ambient				Storm			
		Detection Frequency	Avg Detect	Max Detect	Max Detect Limit	Detection Frequency	Avg Detect	Max Detect	Max Detect Limit
Conventionals									
Ammonia Nitrogen	mg/L	260/308	0.0610	0.553	0.0200	115/142	0.0586	0.138	0.0200
Chemical Oxygen Demand	mg/L	27/56	134	790	3.0	17/22	7.9	25	3.0
Conductivity, Field	µmhos/cm	292/292	20,500	57,700	n/a	139/139	18,700	54,600	n/a
Dissolved Oxygen, Field	mg/L	156/156	9.1	12	n/a	84/84	8.9	10	n/a
Fecal Coliform	CFU/100ml	303/307	120	1100	0	141/141	430	5800	n/a
Hardness, Calculated	mg $CaCO_3$/L	56/56	743	5770	n/a	22/22	48	176	n/a
Nitrite + Nitrate Nitrogen	mg/L	210/210	0.345	0.634	n/a	100/100	0.307	0.551	n/a
pH, Field	pH	304/304	7.5	8.2	n/a	142/142	7.5	8.0	n/a
Total Suspended Solids	mg/L	308/308	14.0	69.0	n/a	142/142	18.0	70.2	n/a
Total Suspended Solids, 0.45 µm	mg/L	312/312	18.6	69.5	n/a	142/142	24.0	70.0	n/a
Volatile Suspended Solids	mg/L	209/210	2.2	7.3	0.50	99/100	2.6	6.2	0.50
Metals									
Antimony, Dissolved	µg/L	115/117	0.0458	0.116	0.010	42/42	0.0444	0.102	n/a
Antimony, Total	µg/L	200/243	0.0378	0.131	0.011	123/140	0.0356	0.0896	0.0110
Arsenic, Dissolved	µg/L	126/126	0.740	1.42	n/a	42/42	0.809	1.46	n/a
Arsenic, Total	µg/L	264/264	0.826	1.53	n/a	126/126	0.889	1.57	n/a
Beryllium, Dissolved	µg/L	0/111	n/a	n/a	0.016	0/42	n/a	n/a	0.016
Beryllium, Total	µg/L	38/249	0.0233	0.0370	0.016	41/128	0.0244	0.0530	0.016
Cadmium, Dissolved	µg/L	118/126	0.0419	0.0795	0.0073	38/40	0.0443	0.0755	0.0070
Cadmium, Total	µg/L	255/264	0.0422	0.391	0.0073	138/138	0.0402	0.0778	n/a
Chromium, Dissolved	µg/L	106/106	0.301	0.576	n/a	42/42	0.255	0.423	n/a
Chromium, Total	µg/L	240/240	0.613	2.27	n/a	140/140	0.788	2.37	n/a
Cobalt, Dissolved	µg/L	123/123	0.0580	0.163	n/a	42/42	0.0516	0.0794	n/a
Cobalt, Total	µg/L	221/221	0.208	0.771	n/a	138/138	0.270	1.33	n/a
Copper, Dissolved	µg/L	113/113	0.662	1.55	n/a	42/42	0.759	1.89	n/a
Copper, Total	µg/L	251/251	1.40	3.97	n/a	140/140	1.81	5.83	n/a
Lead, Dissolved	µg/L	118/118	0.0596	0.553	n/a	42/42	0.0554	0.241	n/a
Lead, Total	µg/L	256/256	0.396	2.81	n/a	140/140	0.495	1.62	n/a
Mercury, Dissolved	µg/L	14/15	0.000444	0.000710	0.00010	no data	n/a	n/a	n/a
Mercury, Total	µg/L	15/29	0.00219	0.00689	0.20	no data	n/a	n/a	n/a
Nickel, Dissolved	µg/L	104/104	0.365	0.628	n/a	42/42	0.427	1.50	n/a

CHEMICAL	UNITS	AMBIENT				STORM			
		DETECTION FREQUENCY	AVG DETECT	MAX DETECT	MAX DETECT LIMIT	DETECTION FREQUENCY	AVG DETECT	MAX DETECT	MAX DETECT LIMIT
Nickel, Total	µg/L	214/214	0.691	1.96	n/a	131/131	0.942	2.91	n/a
Selenium, Dissolved	µg/L	1/116	0.160	0.160	0.16	0/38	n/a	n/a	0.16
Selenium, Total	µg/L	3/238	0.193	0.270	0.16	0/122	n/a	n/a	0.16
Silver, Dissolved	µg/L	0/126	n/a	n/a	0.13	0/42	n/a	n/a	0.13
Silver, Total	µg/L	0/264	n/a	n/a	0.13	0/140	n/a	n/a	0.13
Thallium, Dissolved	µg/L	58/126	0.00967	0.0110	0.0053	20/42	0.00975	0.011	0.0053
Thallium, Total	µg/L	155/264	0.00929	0.0150	0.0053	85/140	0.00829	0.012	0.0053
Vanadium, Dissolved	µg/L	98/98	0.828	1.56	n/a	12/12	1.04	1.57	n/a
Vanadium, Total	µg/L	208/208	1.35	3.99	n/a	96/96	1.46	3.57	n/a
Zinc, Dissolved	µg/L	126/126	2.12	5.39	n/a	40/40	1.92	3.82	n/a
Zinc, Total	µg/L	264/264	2.89	8.34	n/a	138/138	3.29	9.04	n/a
Semivolatiles									
1,2,4-Trichlorobenzene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
1,2-Dichlorobenzene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
1,2-Diphenylhydrazine	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
1,3-Dichlorobenzene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
1,4-Dichlorobenzene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
2,4,5-Trichlorophenol	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
2,4,6-Trichlorophenol	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
2,4-Dichlorophenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
2,4-Dimethylphenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
2,4-Dinitrophenol	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
2,4-Dinitrotoluene	µg/L	0/52	n/a	n/a	0.10	0/42	n/a	n/a	0.11
2,6-Dinitrotoluene	µg/L	0/52	n/a	n/a	0.10	0/42	n/a	n/a	0.11
2-Chloronaphthalene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
2-Chlorophenol	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
2-Methylnaphthalene	µg/L	0/52	n/a	n/a	0.40	0/42	n/a	n/a	0.45
2-Methylphenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
2-Nitroaniline	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
2-Nitrophenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
3,3'-Dichlorobenzidine	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
3-Nitroaniline	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
4,6-Dinitro-O-Cresol	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
4-Bromophenyl Phenyl Ether	µg/L	0/52	n/a	n/a	0.10	0/42	n/a	n/a	0.11
4-Chloro-3-Methylphenol	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56

Chemical	Units	Ambient				Storm			
		Detection Frequency	Avg Detect	Max Detect	Max Detect Limit	Detection Frequency	Avg Detect	Max Detect	Max Detect Limit
4-Chloroaniline	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
4-Chlorophenyl Phenyl Ether	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
4-Methylphenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
4-Nitroaniline	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
4-Nitrophenol	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
Acenaphthene	µg/L	0/52	n/a	n/a	0.10	0/42	n/a	n/a	0.11
Acenaphthylene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Aniline	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
Anthracene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Benzidine	µg/L	0/52	n/a	n/a	6.0	0/42	n/a	n/a	6.7
Benzo(a)anthracene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Benzo(a)pyrene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Benzo(b)fluoranthene	µg/L	0/52	n/a	n/a	0.40	0/42	n/a	n/a	0.45
Benzo(g,h,i)perylene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Benzo(k)fluoranthene	µg/L	0/52	n/a	n/a	0.40	0/42	n/a	n/a	0.45
Benzoic Acid	µg/L	8/52	1.21	1.53	1.0	0/42	n/a	n/a	1.1
Benzyl Alcohol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Butyl Benzyl Phthalate	µg/L	0/52	n/a	n/a	0.15	1/42	0.15	0.15	0.17
Bis(2-Chloroethoxy)Methane	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Bis(2-Chloroethyl)Ether	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Bis(2-Chloroisopropyl)Ether	µg/L	0/52	n/a	n/a	0.50	0/42	n/a	n/a	0.56
Bis(2-Ethylhexyl)Phthalate	µg/L	44/52	0.477	2.49	0.15	42/42	1.10	23.8	n/a
Caffeine	µg/L	0/52	n/a	n/a	0.050	3/39	0.067	0.83	0.56
Carbazole	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Chrysene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Coprostanol	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
Dibenzo(a,h)anthracene	µg/L	0/52	n/a	n/a	0.40	0/42	n/a	n/a	0.45
Dibenzofuran	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Diethyl Phthalate	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Dimethyl Phthalate	µg/L	0/52	n/a	n/a	0.10	0/42	n/a	n/a	0.11
Di-N-Butyl Phthalate	µg/L	5/52	0.331	0.483	0.25	6/42	0.760	1.2	0.24
Di-N-Octyl Phthalate	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Fluoranthene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Fluorene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Hexachlorobenzene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17

CHEMICAL	UNITS	AMBIENT				STORM			
		DETECTION FREQUENCY	AVG DETECT	MAX DETECT	MAX DETECT LIMIT	DETECTION FREQUENCY	AVG DETECT	MAX DETECT	MAX DETECT LIMIT
Hexachlorobutadiene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Hexachlorocyclopentadiene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Hexachloroethane	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Indeno(1,2,3-Cd)Pyrene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Isophorone	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Naphthalene	µg/L	0/52	n/a	n/a	0.40	0/42	n/a	n/a	0.45
Nitrobenzene	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
N-Nitrosodimethylamine	µg/L	0/52	n/a	n/a	1.0	0/42	n/a	n/a	1.1
N-Nitrosodi-N-propylamine	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
N-Nitrosodiphenylamine	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Pentachlorophenol	µg/L	0/52	n/a	n/a	0.25	0/42	n/a	n/a	0.28
Phenanthrene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17
Phenol	µg/L	0/52	n/a	n/a	1.0	1/42	2.01	2.01	1.1
Pyrene	µg/L	0/52	n/a	n/a	0.15	0/42	n/a	n/a	0.17

Because many organic compounds are not typically detected in ambient grab samples, particularly in the dissolved or bioavailable phase, semipermeable membrane devices (SPMDs) were also deployed to collect data for PCBs,[47] chlorinated pesticides, and PAHs at 1 and 3 meters below the water surface at the Duwamish/Diagonal (RM 0.5) and Brandon (RM 1.1) CSOs. PAHs were also measured in the grab samples, but none were ever detected (Table 4-7). The SPMD sampler consists of layflat, polyethylene tubing, a high molecular-weight neutral lipid. SPMDs mimic the transport across biological membranes and are able to provide time-averaged chemical concentrations in water that may include episodic contamination events. Given an adequate deployment time, the concentrations of lipophilic compounds in the SPMD should come close to equilibrium with the concentrations in the water that passes through it. Ambient water concentrations were predicted using the weight of chemical detected in each SPMD and the chemical-specific partition coefficients between the polyethylene and water, which were derived from laboratory experiments conducted at Battelle's Marine Science Laboratory. Chemical concentrations in the SPMD were corrected for both matrix and trip blank contributions. The predicted water concentrations are shown in Table 4-8.

Predicted water concentrations of all chemicals, with the exception of PCB congeners 8, 66, and 77, and 4,4'-DDT, were greater than zero. Concentrations of a single chemical were much less variable between sites compared to the variability between chemicals, which ranged over several orders of magnitude (Table 4-8). Average predicted concentrations of PAHs were up to 21 ng/L. None of the predicted water concentrations for PAHs were higher than the detection limits achieved during analysis of the grab water samples (100 ng/L).

Table 4-8. Predicted water concentrations (ng/L) at Duwamish/Diagonal and Brandon CSO sites from semipermeable membrane device deployment during King County Water Quality Assessment

ANALYTE	DUWAMISH/DIAGONAL		BRANDON		AVERAGE [a]
	1 m	3 m	1 m	3 m	
PAHs					
Acenaphthene	30	16	19	18	21
Acenaphthylene	1.6	0.91	0.80	0.71	1.0
Anthracene	2.3	1.6	1.6	1.4	1.7
Benzo(a)anthracene	0.36	0.21	0.22	0.17	0.24
Benzo(a)pyrene	0.033	0.030	0.024	0.020	0.027
Benzo(b)fluoranthene	0.15	0.11	0.095	0.081	0.11
Benzo(g,h,i)perylene	0.048	0.061	0.030	0.027	0.042
Benzo(k)fluoranthene	0.12	0.027	0.078	0.066	0.073

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[47] SPMDs were analyzed for Aroclors and selected PCB congeners. Not all PCB congeners were analyzed because of the lack of congener-specific partitioning coefficients needed for estimating PCB congener concentrations in water.

Analyte	Duwamish/Diagonal		Brandon		Average [a]
	1 m	3 m	1 m	3 m	
Chrysene	0.40	0.24	0.21	0.17	0.26
Dibenzo(a,h)anthracene	0.0044	0.0052	0.0034	0.0027	0.0039
Fluoranthene	20	7.0	7.5	6.3	10
Fluorene	20	11	11	9.9	13
Indeno(1,2,3-c,d)pyrene	0.022	0.019	0.015	0.0093	0.016
Naphthalene	16	nd	6.6	nd	5.7
Phenanthrene	25	13	13	11	16
Pyrene	7.0	3.8	3.8	3.1	4.4
Pesticides					
Aldrin	0.0059	0.0040	0.0037	0.0030	0.0042
g-Chlordane	0.0013	0.000077	0.00011	nd	0.00037
a-Chlordane	0.0026	0.0017	0.0015	0.0013	0.0018
Dieldrin	0.033	0.023	nd	0.020	0.019
Endrin	0.014	0.0089	0.0064	nd	0.0073
2,4' DDD	0.013	0.0067	0.0079	0.0063	0.0085
4,4' DDD	0.015	0.0091	0.010	0.0085	0.011
4,4' DDE	0.0065	0.0019	0.00093	0.000034	0.0023
4,4' DDT	nd	nd	nd	nd	nd
PCBs					
PCB 8	nd	nd	nd	nd	nd
PCB 18	0.041	0.019	0.022	0.015	0.024
PCB 28	0.021	0.015	0.011	0.0082	0.014
PCB 44	0.016	0.0091	0.010	0.0086	0.011
PCB 49	0.049	0.038	0.032	0.027	0.037
PCB 52	0.031	0.017	0.020	0.017	0.021
PCB 66	nd	nd	nd	nd	nd
PCB 77	nd	nd	nd	nd	nd
PCB 87	0.0034	0.0021	0.0022	0.0025	0.0026
PCB 101	0.013	0.0072	0.0079	0.0065	0.0087
PCB 105	0.0028	0.0019	0.0022	0.0012	0.0020
PCB 118	0.0042	0.0024	0.0028	0.0022	0.0029
PCB 128	0.00047	0.00063	0.00047	nd	0.00039
PCB 138	0.0028	0.0015	0.0017	0.0013	0.0018
PCB 153	0.0043	0.0022	0.0024	0.0018	0.0027
PCB 170	0.0021	nd	nd	nd	0.00053
PCB 180	0.0015	0.00019	0.00085	0.00066	0.00080
PCB 187	0.00075	0.00038	0.00041	0.00020	0.00044
PCB 195	nd	0.000014	nd	nd	0.0000035
Aroclor 1242 (max) [b,e]	1.2	0.68	0.89	0.68	0.86
Aroclor 1242 (min) [c,e]	0.037	0.020	0.026	0.020	0.026

ANALYTE	DUWAMISH/DIAGONAL		BRANDON		AVERAGE [a]
	1 m	3 m	1 m	3 m	
Aroclor 1242 (avg) [d,e]	0.15	0.082	0.11	0.081	0.11
Aroclor 1254 (max) [b,e]	1.4	0.81	0.82	0.67	0.93
Aroclor 1254 (min) [c,e]	0.041	0.024	0.024	0.020	0.027
Aroclor 1254 (avg) [d,e]	0.17	0.098	0.098	0.080	0.11

[a] Predicted concentrations shown as nd (non-detect) were assumed to be zero for purposes of the calculation of arithmetic averages because sample-specific detection limits were not calculated.

[b] The maximum Aroclor concentration was estimated based on minimum partitioning coefficient developed by Lefkovitz and Crecelius (1995) for the congeners listed in the table.

[c] The minimum Aroclor concentration was estimated based on maximum partitioning coefficient developed by Lefkovitz and Crecelius (1995) for the congeners listed in the table.

[d] Average Aroclor concentration was estimated based on average of partitioning coefficients developed by Lefkovitz and Crecelius (1995) for the congeners listed in the table.

[e] Aroclor concentrations were estimated because a partitioning coefficient could not be developed for either Aroclor mixture. Only detected Aroclor mixtures are shown.

Average concentrations of pesticides and PCB congeners were less than 0.050 ng/L, but Aroclor concentrations were several times higher (Table 4-8). In general, concentrations were higher for all chemicals in the 1-m samples than in the 3-m samples. Estimated water concentrations of pesticides and PCBs were at least an order of magnitude lower than applicable state water quality criteria. There are no such criteria for PAHs.

4.2.6 Groundwater

Site-specific groundwater chemistry and flow data are described in detail in Appendix G. Groundwater data were reviewed for 12 sites that have been identified on a preliminary basis as sites of interest to EPA and Ecology for evaluation in this Phase 1 RI. These sites and COCs at each site are listed in Table 4-9. Groundwater data for the most recent monitoring events from wells closest to the LDW at each site are presented in Appendix G. In general, the chemicals most frequently identified as COCs were chlorinated solvents and metals.

Table 4-9. Chemicals of concern in groundwater

SITE	CHEMICALS OF CONCERN IN GROUNDWATER
Advance Electroplating	trichloroethene, tetrachloroethene, cadmium, chromium, and nickel
Boeing Developmental Center	tetrachloroethene, benzene, gasoline-range TPH, arsenic, copper, lead, nickel
Boeing Isaacson	arsenic
Boeing Plant 2	cis-1,2-dichloroethene, 1,1-dichloroethene, vinyl chloride, arsenic, cadmium, copper, lead, nickel, zinc, selenium, silver, thallium
Great Western International	chlorinated solvents
Long Painting	metals and chlorinated solvents
Malarkey Asphalt	PCBs
PACCAR	arsenic, chlorinated solvents
Philip Services Corporation	trichloroethene, tetrachloroethene, TPH, vinyl chloride
Rhône-Poulenc	toluene, metals
South Park Landfill	vinyl chloride
T108/Chiyoda	PAHs and metals

4.2.7 Fish and shellfish tissue

Site-specific fish and shellfish chemistry data have been collected for several different species and sample types, as described in Section 2.3.5. Most data are from analyses of composite samples, but samples consisting of individual fish, primarily salmon, were also analyzed (Table 2-5). Almost all the samples were collected in the northern reach of the LDW (RM 0 to 1.4) (Map 2-9). These data are discussed in this section by species and sample type. Summary statistics for each group are presented in Tables D-6a-j in Appendix D.

4.2.7.1 Adult chinook salmon fillet samples

Eighty-three samples of adult chinook salmon fillets have been collected and analyzed from the LDW since 1992 as part of the Puget Sound Ambient Monitoring Program (West et al. 2001). All samples were collected in the vicinity of Kellogg Island (RM 1.0). These data were not used in the Phase 1 risk assessments because the chemical concentrations in these fish are largely unrelated to sediment contamination in the LDW (O’Neill et al. 1998). All of these samples were analyzed for organochlorine pesticides and PCBs (Table D-6a). Nineteen samples were analyzed for semivolatile organic compounds, arsenic, mercury, lead, and copper.

The semivolatiles were rarely detected; only BEHP was detected in 4 of 19 samples at a maximum concentration of 5,350 µg/kg ww. Lead was never detected, but the other three trace elements were detected in every sample. Maximum concentrations of mercury, arsenic, and copper were 0.15, 1.4, and 1.09 mg/kg ww, respectively. Total DDTs were detected in all samples with a maximum of 58.4 µg/kg ww and total PCBs were detected in 72 of 83 samples with a maximum of 160 µg/kg ww.

Alpha-chlordane was the only other compound detected in more than half the samples.

4.2.7.2 Juvenile chinook salmon whole-body samples

Fourteen whole-body juvenile chinook salmon samples (all composite samples) were collected near Kellogg Island (RM 1.0) and analyzed for PCBs and organochlorine pesticides by Varanasi et al. (1993). Twenty-nine additional whole-body juvenile chinook salmon samples (9 composite and 20 individual samples) from Kellogg Island and Slip 4 (RM 2.8) were reported in NMFS (2002). These data were used in the Phase 1 ERA. Aldrin, heptachlor, gamma-BHC, 2,4'-DDD, 2,4'-DDT, PCB 126, PCB 169, PCB 189, and several chlorinated butadiene compounds were undetected in all samples (Table D-6b). PCBs were detected in every sample. The maximum detected total PCB concentration was 750 µg/kg ww for an individual fish collected in Slip 4 (NMFS 2002). Most of the PCB congeners detected had 4-7 chlorine atoms (tetrachlorobiphenyls to heptachlorobiphenyls).

4.2.7.3 Adult coho salmon fillet samples

Fifty-five adult coho salmon fillet samples have been collected and analyzed from the LDW since 1992 as part of the Puget Sound Ambient Monitoring Program (West et al. 2001). All samples were collected in the vicinity of Kellogg Island (RM 1.0). These data were not used in the risk assessments because the chemical concentrations in these fish are largely unrelated to sediment contamination in the LDW. All these samples were analyzed for organochlorine pesticides and PCBs (Table D-6c). Sixteen samples were analyzed for semivolatile organic compounds, arsenic, mercury, lead, and copper.

Semivolatile compounds were rarely detected. Benzoic acid was detected in one sample and BEHP was detected in 4 of 16 samples at a maximum concentration of 4,750 µg/kg ww. Lead was detected in only one sample, but the other three trace elements were detected in every sample. Maximum concentrations of mercury, arsenic, and copper were 0.053, 1.6, and 0.924 mg/kg ww, respectively. Total DDTs were detected in all samples with a maximum of 19.8 µg/kg ww and total PCBs were detected in 45 of 55 samples with a maximum of 97.4 µg/kg ww. Alpha-chlordane was detected in almost half the samples (24 of 55), but the other pesticides were detected much less frequently.

4.2.7.4 English sole whole-body samples

Three composite samples of whole-body English sole were collected near Kellogg Island (RM 1.0) and analyzed for trace elements, TBT, and PCBs as part of King County's Water Quality Assessment (Table D-6d). These data were used in the Phase 1 ERA. Antimony, cadmium, and silver were never detected; all other chemicals were detected in every sample. The maximum total PCB concentration was 2,306 µg/kg ww, which was higher than the total PCB concentration in any other tissue sample collected from the LDW.

4.2.7.5 English sole fillet samples

English sole fillet samples were analyzed during four sampling events, as described in Table 2-5. These data were used in the Phase 1 ERA and HHRA. Most fish were captured in the vicinity of Kellogg Island, but 15 fish captured in the upper reach (> RM 2.0) of the LDW were divided into 3 composite samples. Samples were analyzed for semivolatile organics (6 samples), pesticides, PCBs, arsenic, copper, and TBT (9 samples), and mercury and PCBs (15 samples) (Table D-6e). Semivolatile organic compounds were all undetected, except for BEHP and di-n-butyl phthalate, which were each detected in one sample at concentrations close to the detection limit. Arsenic and mercury were detected in every sample. The maximum concentrations of 15.1 and 0.083 mg/kg ww, for arsenic and mercury, respectively, were both found in fish collected near Kellogg Island. The maximum arsenic concentration in English sole fillet samples was the highest for any species from the LDW. The maximum total DDT and total PCB concentrations were 10.9, found near Kellogg Island, and 526 µg/kg ww (found near RM 4.0), respectively.

4.2.7.6 Dungeness and red rock crab samples

Six composite samples of Dungeness or red rock crab edible meat and one composite sample of hepatopancreas were analyzed during two different sampling events, as described in Table 2-5. All samples were collected between RM 0 and 1.0. These data were used in the Phase 1 ERA and HHRA. All six edible meat samples were analyzed for PCBs, mercury, and TBT; only two edible meat samples and the hepatopancreas sample were also analyzed for semivolatile organics and other trace elements (Table D-6f). The hepatopancreas data are not included in Table D-6f, but are included in the data CD attached to the RI report. The maximum copper concentration (15.8 mg/kg ww) was higher than copper maxima for fish species. This may reflect, in part, the fact that the blood of crabs contains hemocyanin, an organocopper compound, for oxygen transport, instead of hemoglobin, as in vertebrates. All semivolatile organic compounds were undetected in both samples. Maximum concentrations of PCBs, mercury, and TBT were 177 µg/kg ww, 0.111 mg/kg ww, and 81.9 µg/kg ww, respectively.

4.2.7.7 Striped perch fillet samples

Three composite samples of striped perch fillets were collected near the southern end of Harbor Island (RM 0 to 0.2) and analyzed as part of the West Waterway HHRA (ESG 1999). These data were used in the Phase 1 HHRA. Two fillets from each fish, one with skin and the other without skin, were distributed into separate composite samples (a total of 3). The data reported in Table D-6g are from the samples with skin. Each sample was analyzed for PCBs, mercury, and TBT, which were detected in all samples. Maximum concentrations of PCBs, mercury, and TBT were 228 µg/kg, 0.070 mg/kg, and 16 µg/kg, respectively.

4.2.7.8 Shiner surfperch whole-body samples

Three composite samples of whole-body shiner surfperch were collected near Kellogg Island and analyzed as part of the King County Water Quality Assessment. These data were used in the Phase 1 ERA. Samples were analyzed for semivolatile organic compounds, trace elements, PCBs, and TBT (Table D-6h). Semivolatiles were largely undetected, although acenaphthene was detected in one sample, and benzoic acid and benzyl alcohol were detected in all three samples. Maximum detected concentrations of arsenic and mercury were 1.39 and 0.088 mg/kg ww, respectively, which were similar to maximum concentrations in most other species. Maximum detected concentrations of PCBs and TBT were 616 and 179 µg/kg ww, respectively. The maximum TBT concentration in shiner surfperch was higher than the maxima for all other species and sample types.

4.2.7.9 Amphipod samples

Four composite samples of amphipods were analyzed as part of the King County Water Quality Assessment. These data were used in the Phase 1 ERA. These samples were collected in the vicinity of Kellogg Island. Samples were analyzed for semivolatile organic compounds, trace elements, PCBs, and TBT (Table D-6i). Semivolatiles were largely undetected, although BEHP, fluoranthene, phenol, and pyrene were detected in one or more samples. Maximum concentrations of mercury (0.017 mg/kg ww), PCBs (408 µg/kg ww), and TBT (36 µg/kg ww) in amphipods were similar to or lower than maxima for other species and sample types.

4.2.7.10 Mussel samples

Twenty-two composite samples of resident mussels were analyzed as part of the King County Water Quality Assessment. These data were used in the Phase 1 HHRA. Samples were collected in the vicinity of two CSOs (Brandon St. and Duwamish/Diagonal) and at three other locations (Terminal 107, Slip 4, and Kellogg Island). All samples were analyzed for semivolatile organic compounds, PCBs, trace elements, and TBT; 11 samples were also analyzed for chlorinated pesticides (Table D-6j). Most semivolatile organic compounds were undetected, but nine compounds were detected in one or more samples. Two PAHs, fluoranthene and pyrene, were detected in more than half the samples.

Maximum concentrations for PCBs (60 µg/kg ww), mercury (0.0228 mg/kg ww), arsenic (1.07 mg/kg ww), and TBT (36.7 µg/kg ww) in mussels were either similar to or lower than maxima for other species and sample types. Maximum concentrations for the 25 detected chemicals were most frequently located at one of the two CSO sampling locations (7 at Brandon St. and 12 at the Duwamish/Diagonal CSO). Three other maxima were found at Slip 4, two at Kellogg Island, and one at Terminal 107.

4.2.7.11 Rockfish

One composite fillet sample of quillback rockfish was collected near Kellogg Island and analyzed in 1996 as part of the Puget Sound Ambient Monitoring Program (West et al. 2001) for chlorinated pesticides and PCBs (Table D-6k). These data were not used in the Phase 1 risk assessments because the relative abundance of rockfish in the LDW is not known.[48] Alpha- and gamma-chlordane and total DDTs were detected; all other chlorinated pesticides were undetected. The total PCB concentration was 43.1 µg/kg ww, which is lower than most other species and sample types.

4.3 SOURCES, PATHWAYS, AND SOURCE CONTROL

This section describes potential ongoing sources of contamination to the LDW and pathways through which chemicals could migrate to the LDW. Some historic sources that are no longer present, but may be acting as continuing secondary sources of contamination, are also characterized using readily available data. A comprehensive review of all historic sources was beyond the scope of the Phase 1 RI. Many historic sources were not characterized because data were not readily available. Additional characterization of both current and historical sources may be conducted during the Phase 2 RI.

This section also discusses general approaches being taken to control ongoing sources of contamination. A conceptual model of chemical sources and pathways to the LDW is shown in Figure 4-1, as an overview for this section. Information presented in this section will be used in the remedial process to assist in determining whether certain activities or sites are potentially current sources of chemicals that pose an unacceptable risk, and to determine whether additional source control actions are necessary to prevent recontamination of areas that are remediated. In addition, this information is used to develop a conceptual site model of chemical sources, fate, and transport to assist in decision-making for remedial actions.

The information presented in this section is compiled from existing sources of data; no additional data collection activities were conducted during Phase 1. Source characterization data gaps may be filled during the Phase 2 RI and early remedial actions to aid in making remedial decisions.

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[48] No definitive surveys have been conducted targeting this species and creel surveys conducted in the LDW by King County for the Water Quality Assessment did not record any caught by recreational or subsistence fishers.

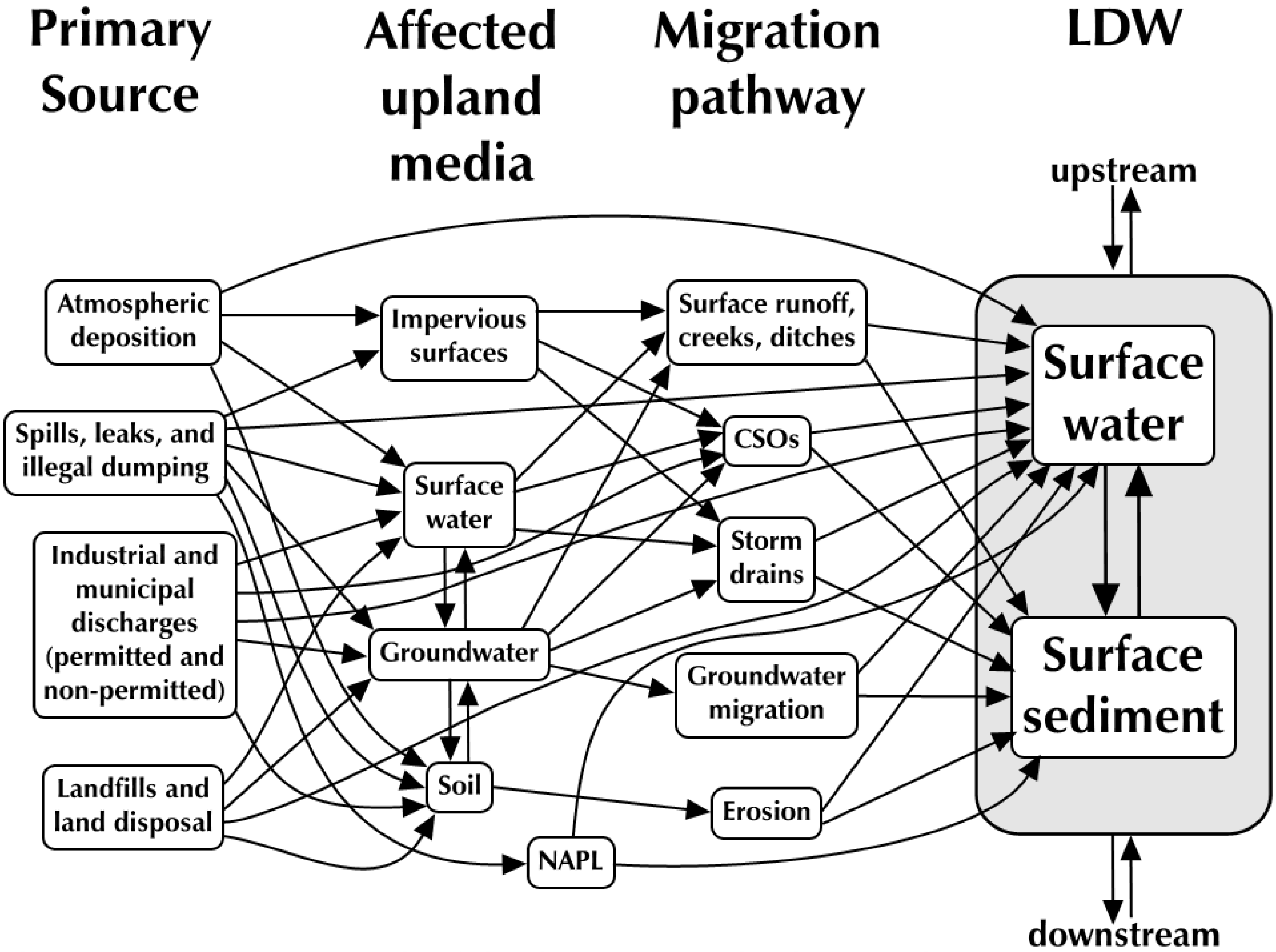

Figure 4-1. **Conceptual model of chemical sources and pathways to the LDW**

A considerable number of regional and site-specific source investigations and associated control actions have been performed in the LDW study area under a wide range of RCRA, CWA, and MTCA actions, along with other independent control efforts. Chemical loading, sources, pathways, and control efforts within the LDW were initially compiled and reviewed by Metro in 1983 (Harper-Owes 1983), based on a synthesis of numerous investigations conducted from 1960 to 1982. A more recent data compilation was prepared by King County as part of the 1999 Water Quality Assessment for the Duwamish River and Elliott Bay (King County 1999a). Building on these and other studies, Ecology is currently developing an overall source control strategy for the LDW. Ongoing source investigation and control efforts are briefly outlined in the sections below.

4.3.1 Potential sources

Primary potential sources of chemicals to the LDW are industrial or municipal discharges; spills, leaks, or illegal dumping; atmospheric deposition, and waste disposal on land or in landfills. As shown in Figure 4-1, chemicals from these sources may contribute to elevated chemical concentrations in various upland environmental media, including soils, groundwater, surface water, and impervious surfaces that can then act as secondary sources to the LDW. Primary sources may also discharge directly to the LDW. Table 4-10 lists databases used in this section to summarize information on potential, but unconfirmed, chemical sources to the LDW.

This section also discusses specific sites of interest in the LDW as identified by Ecology and EPA for this Phase 1 RI. This preliminary list of sites includes some of the potential sources to the LDW that are undergoing investigation or cleanup under Ecology's or EPA's lead. The identification of these sites is an ongoing process. In addition to the databases listed in Table 4-10, business inspection programs conducted by King County and Seattle Public Utilities may provide information about potential sources; these programs are described in Section 4.3.3.

Table 4-10. Databases used to summarize information on potential sources to the LDW

TYPE OF INFORMATION	DESCRIPTION	SOURCE OF DATA
National Pollutant Discharge Elimination System (NPDES) permits	Permits are issued for industrial, municipal, and large construction area discharges to surface water bodies by Ecology under the NPDES program	Ecology database[a] (Thomas 2002)
Toxics Release Inventory (TRI) program reports	TRI reports are filed with Ecology and EPA annually by certain types of facilities. These reports estimate the amount of toxic chemicals released into the air, land, and water.	Ecology (2001)
Confirmed and Suspected Contaminated (CSC) sites list	This list is derived from a database used by Ecology's Toxic Cleanup Program to track progress on all confirmed and suspected contaminated sites in Washington State.	Ecology website[a] (Ecology 2002a)
Underground Storage Tanks (USTs) and Leaking Underground Storage Tanks (USTs) list	Ecology maintains a list of regulated USTs that are operational or have been closed, and LUSTs that have been cleaned up or are currently undergoing cleanup.	Ecology website (Ecology 2002d)
King County Industrial Waste Permits	King County issues permits or discharge authorizations for industries discharging into their wastewater treatment system.	King County (Hulsizer 2002)
Environmental Report Tracking System (ERTS)	Ecology maintains a database containing oil spills and hazardous material releases to water bodies.	Ecology database (Williams 2002)
Seattle Public Utilities (SPU)	SPU maintains a record of hazardous material spills involving the SPU infrastructure through its spills coordinator program.	Schmoyer (2002a)

[a] Sites potentially affecting the LDW were sorted from the database using zip codes 98106 and 98108.

The following four sections describe each of the four categories of primary sources of chemicals to the LDW.

4.3.1.1 *Industrial and municipal discharges and contaminated sites*

Chemicals may originate from specific industrial, municipal, commercial, and residential sites before discharging to the LDW. There are a number of pathways for these chemicals originating in upland areas adjacent to the LDW. These pathways include direct discharge to the LDW via natural onsite drainage pathways, privately-owned wastewater systems, spills/leaks from boats or activities immediately adjacent to the LDW, and storm drains. Indirect discharge to the LDW may occur via groundwater or a combined or sanitary sewer system during overflow events or emergency overflows (e.g., pump system failure or sanitary sewer blockage). This section discusses sites with permitted discharges to the LDW, and sites that have been identified by EPA or Ecology as potential sources of chemicals to the LDW. There were no sites in the LDW area reporting Toxics Release Inventory (TRI) releases to water.

Permitted Discharges

As the delegated authority under the federal NPDES program, Ecology regulates the following discharges to the LDW[49]: 1) industrial and municipal stormwater, 2) discharges from construction sites larger than 5 ac, and 3) CSOs. Ecology currently permits and regulates shipyard, boatyard, and sand and gravel facilities near the LDW, and industrial, construction, and municipal stormwater discharges to the LDW. Both general and individual permits are issued. General stormwater permits are issued within categories of dischargers, such as industry, boatyards, or sand and gravel operations. Individual permits are issued to a subset of industries that have unique processes and environmental concerns so that requirements for treatment, monitoring, or reporting of discharges may be tailored to the individual facility. Names of industries with NPDES permits are listed in Appendix E and their locations are shown on Map 4-35.

Combined sewer overflows occur in the combined sewer system during rainfall events when the capacity of the system is inadequate to carry both the sanitary wastewater and stormwater flows. When system capacity is exceeded, the excess flow is discharged to the LDW via an overflow structure. This excess flow consists of a combination of untreated sanitary wastewater and stormwater runoff. Both the City of Seattle and King County operate and have permits to discharge combined sewer overflows to the study area under the municipal wastewater NPDES permitting program. Details related to CSO discharges in the LDW, including discharge volumes, locations, and potential chemicals discharged, are discussed in Section 4.3.2, which focuses on chemical migration pathways. CSOs discharging into the LDW may be operated by either the City of Seattle or King County. The City owns and operates the local sanitary sewer collectors and trunk lines, and King County owns and operates the large interceptor lines that transport flow from the local system to the municipal wastewater treatment plant at West Point that serves the LDW area of Seattle. The City of Seattle's CSO system has an individual NPDES permit (listed in Appendix E), and the King County CSOs entering the LDW are covered under the NPDES permit issued for the West Point Treatment Plant. In addition to the permit for CSOs, the City of Seattle has been issued a stormwater permit for municipal storm drains in the city.

Discharges of industrial wastewater to the sanitary sewer system are permitted by King County under their Industrial Pretreatment Program. A list of industries with pretreatment permits and discharge authorizations authorized under this program is provided in Appendix E and their locations are shown on Map 4-35.

Contaminated sites

Ecology's Toxic Cleanup Program maintains a list of current confirmed and suspected contaminated (CSC) sites within the state. The CSC list contains information about

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[49] There are currently no NPDES-permitted industrial process water discharges to the LDW. Process water from industrial facilities located in upland areas adjacent to the LDW currently discharges to the sanitary sewer, under the King County industrial pretreatment program (see Section 4.3.3.3).

sites in Washington state that are undergoing cleanup and sites that are awaiting further investigation and/or cleanup. Sites are added to the CSC site list for various reasons, including type of industry, spills, leaking underground storage tanks (LUSTs), and complaints. The Seattle King County Public Health Department, under an Ecology grant, conducts site hazard assessments and either recommends no further action or ranks sites using the Washington State Ranking Method Model (WARM). Sites with high ranking get priority for Ecology to initiate action. Some of the CSC sites in the vicinity of the LDW are shown on Map 4-35 and listed in Appendix E, along with site status, WARM ranking, affected media type, and types of contamination. This list was obtained from Ecology's website (Ecology 2002a) and was last updated in November 2002. Once a site is added to the list, information is not updated if new data become available. For this reason, the table is not a reliable indicator of the type of contaminant at a particular site. Site-specific reports should be reviewed for correct, updated information on each site.

Ecology has generated a preliminary subset of CSC sites of interest near the LDW; at most of these sites, data are available or are currently being collected, and in some cases active cleanup either has already occurred or is being conducted, as discussed below (Huey 2002; Thomas 2002). These sites include South Park Landfill, Boeing Developmental Center, Boeing Isaacson, Great Western International, Philip Services Corporation (Burlington Environmental, Inc.), Malarkey Asphalt, Long Painting, PACCAR (Kenworth Truck Company), Puget Park, and the Tacoma Smelter Plume.

In addition to Ecology's list, EPA provided a preliminary list of several current RCRA sites that are considered potential sources to the LDW (Sanga 2002), including Advance Electroplating, Rhône-Poulenc, Boeing Plant 2, and Malarkey Asphalt.[50] The following sections provide general information about the sites under investigation as identified by Ecology and EPA. Locations are shown on Map 4-34. Additional information on the nature and extent of groundwater contamination for some of these sites is presented in Section 4.2.6 and Appendix G. The potential for migration of chemicals from these sites to LDW sediment is discussed in Section 4.3.2.4. The ASARCO Tacoma Smelter Plume is discussed in the section on atmospheric deposition (Section 4.3.1.2) and South Park Landfill is discussed in the section on landfills (Section 4.3.1.4).

Advance Electroplating

Advance Electroplating is located approximately 100 m (330 ft) from North Fork Hamm Creek and approximately 1 km (0.6 mi) west of the LDW near RM 4 (Map 4-34). The site was used from approximately 1964 to 1992 as an electroplating facility, and more recently as a chrome buffing facility. Known areas of soil contamination on the site appear to have resulted from waste disposal, spillage, and leaking pipes and containers. Primary chemicals detected in groundwater include trichloroethene,

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[50] Malarkey was initiated under RCRA, but was cleaned up under CERCLA in 1999.

tetrachloroethene, cadmium, chromium, nickel, and TPH (Ecology and Environment 1997)).

EPA initiated a time-critical removal action in 1995 and 1996, which involved the removal of over 500 drums containing liquid and solid hazardous waste. Approximately 1,500 tons of soil with chemicals exceeding site-specific removal action levels of 100 mg/kg for trichloroethene and 300 mg/kg for chromium were excavated and treated and/or disposed of off-site.

Boeing Developmental Center

The Boeing Developmental Center is located adjacent to Slip 6 and on the east side of the LDW from RM 4.2 to 4.4 (Map 4-34). Activities at this RCRA corrective action site are being conducted under Ecology's Voluntary Cleanup Program. The groundwater contains low concentrations of tetrachloroethene, BTEX, and TPH, and is currently monitored at several different areas. In the Building 9-101 area, contaminated groundwater was addressed with pump and treat technology. The treated groundwater was discharged to the LDW, and the effluent quality met NPDES permit standards. Because of declining VOC concentrations, Ecology agreed to allow the treatment to be terminated in December 2001. Groundwater monitoring is being conducted to determine whether the treatment system can remain off. The Building 9-60/61 area groundwater is under remediation by an enhanced bioremediation technology.

Boeing Isaacson

The Boeing Isaacson Facility is located on the east side of the LDW between RM 3.7 and 3.8 (Map 4-34). Environmental investigations and remedial actions were completed at the site from 1983 through 1992 to address elevated concentrations of arsenic detected in soil and groundwater. Several phases of arsenic-contaminated soil removal and on-site encapsulation were completed during this period. Groundwater monitoring since 1991 indicates that dissolved arsenic is present in site groundwater at concentrations greater than area background. Reports documenting the investigation and remediation of arsenic in the soil and groundwater at the site have been submitted to Ecology.

Boeing Plant 2

Boeing's Plant 2 is located on the east side of the LDW between RM 2.8 and 3.6 (Map 4-34). Most of this 43-hectare (107-acre) site is covered with buildings and pavement. Chemicals have migrated to soil and groundwater beneath the facility and to sediment along the plant's shoreline of the LDW.

In 1994, EPA and Boeing signed an AOC, which required Boeing to investigate and perform corrective action at Plant 2 under RCRA. Under the 1994 order, approximately 2,100 soil samples from more than 400 locations were collected and analyzed. In addition, groundwater samples were collected from monitoring wells at over 350 locations, and sediment samples were collected from over 100 stations in the

LDW. Chemicals detected in soil and groundwater were VOCs, SVOCs, PCBs, TPH, and metals. Chemicals detected in sediment were PCBs, PAHs, and metals. The results of the investigation are summarized in the 1998 RCRA facility investigation report (Weston 1998). EPA did not identify any imminent danger to human health or the environment as a result of this contamination.

Several interim corrective measures have been completed by Boeing, including the installation of sheet pile containment structures in three areas to confine VOCs. Soil and sediment were excavated at several locations to remove contamination. In addition, a network of shoreline wells was installed to monitor groundwater closest to the LDW. Boeing recently completed four quarterly sampling events of these wells. Chemicals found in these monitoring wells include VOCs and metals. An evaluation of concentrations of chemicals in groundwater from these wells concluded that the area where future sediment remediation is proposed by Boeing at Plant 2 would not be recontaminated from groundwater at the facility (Weston Solutions 2003). EPA is currently reviewing these conclusions regarding potential recontamination. In addition, Boeing recently completed a groundwater sampling program to evaluate the effectiveness of the sheet pile containment cells. This evaluation confirmed that VOCs are not migrating from the containment cells.

Additional sediment investigations in the LDW have been conducted by Boeing to aid in designing the most effective remedy to manage risk posed by chemicals in the sediment.

Boeing has begun a corrective measures study to evaluate and select the final cleanup action for the facility. The study defines cleanup goals, develops site-specific cleanup levels for soil and groundwater, and evaluates potential cleanup technologies.

Great Western International

Great Western International is located on the east side of the LDW approximately 120 m (400 ft) from the LDW between RM 2.3 and 2.4 (Map 4-34). Soil and groundwater are contaminated with solvents and tetrachloroethene as a result of past spills and a leaking underground storage tank left on the site (Huey 2002). In 1996, source control was attempted using a soil vapor and groundwater extraction system, but this system failed to perform as expected. Great Western International conducted an additional pilot study and investigation, and subsequently submitted an RI/FS report. Ecology accepted the source control cleanup alternative of a dual vacuum system with thermal destruction treatment on site, and recommended enhanced natural attenuation for the groundwater plume between the site and the LDW, but cleanup has not yet been implemented (Huey 2002).

Long Painting

The Long Painting property is located approximately 100 m (328 ft) southwest of the LDW between RM 2.9 and 3.1 (Map 4-34). In addition to the property shown on Map 4-34, Long Painting has a support yard that has been used for truck repair, refueling, solvent stilling, and hazardous waste storage, that extends along South Elmgrove St. from 10th Avenue South to the LDW (Huey 2002). The site has been used as a commercial and industrial painting facility since the 1960s. Long Painting has been in operation on the site since 1973, although the company recently moved their main office, support facility, and trucking operations to Kent. A diesel spill that occurred several years ago was cleaned up and some underground storage tanks were removed. A site assessment found low concentrations of tetrachloroethene and trichloroethene in soils and groundwater. Data are currently being reviewed by Ecology to determine if further action is needed at the site (Cargill 2002).

Malarkey Asphalt

The Malarkey Asphalt site is a former asphalt plant located approximately 18 m (60 ft) from the LDW at RM 3.6 on the west side of the LDW (Map 4-34). The property is currently owned by the Port of Seattle. Soils at the site were contaminated with PCBs, which probably originated from waste oil stored and used at the site (Onsite 2000). Surface runoff from the site generally flows into the LDW. The primary area of concern was a former ponding area and an adjacent ditch. In 1999, cleanup activities were conducted at the site as a CERCLA Emergency Removal Action under an AOC between the Port of Seattle and EPA. This Removal Action included removal of PCB-contaminated soils and implementation of site stabilization measures. The cleanup included the removal and treatment of impounded stormwater, excavation and disposal of over 2,000 tons of contaminated soil, backfilling, installation of storm drain improvements, and site paving (Onsite 2000).

PACCAR (Kenworth Truck Co.)

PACCAR is a former truck manufacturing facility located adjacent to the east bank of the LDW between RM 3.9 and 4.0 (Map 4-34). Data collected to date indicate that groundwater beneath the site contains arsenic, chlorinated solvents, and free phase petroleum product, although a complete screening of chemicals has not yet been completed (Madakor 2002). Active source control will be needed to remove the free phase petroleum product in groundwater. Ecology is awaiting completion of a data gaps report before proceeding with further actions on this site (Madakor 2002).

Philip Services (Burlington Environmental)

The Philip Services Corporation site is a permitted hazardous waste storage facility located about 1.3 km (0.8 mi) east of the LDW (Map 4-34). The primary chemicals in groundwater are benzene, trichloroethene, and breakdown products of trichloroethene. Evidence of a dense nonaqueous phase liquid (DNAPL) containing chlorinated solvents has been found in groundwater beneath the site (a discussion of DNAPL is presented in Section 4.3.2.4). The revised RI for this site will be completed in October 2003. The facility is planning to close by the end of 2003. Plans for a barrier wall around the extent of DNAPL are currently being prepared and the 30% design report is expected to be completed in January 2003.

Puget Park/McFarland Property

The Puget Park property, including the former McFarland property, is located north of Puget Creek at approximately RM 0.7 on the west side of the LDW (Map 4-34). At this site, a portion of a ravine was filled with 39,000 m^3 (51,000 yd^3) of cement kiln dust in the early 1970s. When saturated, the cement kiln dust produces leachate with a high pH, which enters Puget Creek during some storm events. The cement kiln dust also contains elevated concentrations of lead and arsenic. Puget Creek flows into the storm drain system, which discharges through an outfall near Terminal 105. After preliminary investigation, remedial measures (installation of gravel precipitate chambers) were implemented, and two years of monitoring and analysis have been completed. Further studies to be conducted in early 2003 will determine what, if any, additional remediation measures need to be undertaken at the site to prevent stormwater and/or groundwater from passing through the cement kiln dust into the creek (Hart Crowser 1999).

Rhône-Poulenc

The Rhône-Poulenc facility is situated adjacent to Slip 6 and east of the LDW between RM 4.0 and 4.2 (Map 4-34). Soil and groundwater data show elevated concentrations of toluene and metals (EPA 2000). Several rounds of groundwater monitoring data were collected between January 2000 and April 2002. An engineering plan has been proposed to provide an interim measure for hydraulic control of groundwater migration to the LDW. This plan proposes pumping and treating of groundwater and installation of a barrier wall (Brown 2002). A final remedy for cleanup has not yet been determined.

4.3.1.2 Atmospheric deposition

Chemicals released to the air may be deposited directly onto the waterway surface, or may be deposited on land before potential transport to the LDW via surface runoff. Atmospheric chemical loading data were not available, although direct loading on the water surface of Elliott Bay and the LDW was estimated by Tetra Tech (1988) using total suspended particulate matter (TSPM) emissions and assuming the composition of TSPM was similar to street dust. Results showed that direct loadings of metals and PAHs from the atmosphere were negligible compared to inputs from storm drains and CSOs. Inputs from storm drains include chemicals that were deposited on land surfaces and flushed during precipitation events. The proportion of chemicals in LDW surface runoff derived from atmospheric sources versus other urban sources is not known.

There were 23 sites within the LDW area reporting TRI air emissions to Ecology and EPA in 1999 (Ecology 2001). These sites are listed in Appendix E, along with the types and quantities of chemicals released from these industries.

Smokestack emissions from the now-closed Asarco copper smelter located northwest of Tacoma are a potential historical source of contamination to the LDW (Huey 2002).

A study conducted from 1999 to 2001 sampled soil at 75 locations over a 520 km^2 (200-mi^2) area in King County. Washington's MTCA soil cleanup levels were exceeded at 62 locations for arsenic (cleanup level of 20 mg/kg) and 13 locations for lead (cleanup level of 250 mg/kg). The highest arsenic and lead concentrations in King County were 260 and 790 mg/kg, respectively, found in samples collected about 8 to 16 km (5.0 to 10 mi) south of the LDW. The historical plume of contamination leads from the Asarco site to the northeast, towards the LDW, as shown in Figure 4-2 (located in Oversize Maps and Tables). Arsenic and lead from this plume may have been deposited directly onto the LDW, and also onto land surfaces throughout the watershed. This potential watershed deposition could contribute to increased loading of these chemicals into the LDW.

4.3.1.3 Spill and leaks

Spills and leaks may enter the LDW via: 1) direct discharge to the LDW, 2) releases to soil or groundwater, which may enter the LDW through groundwater migration or soil erosion, or 3) releases to storm drains, sanitary sewers, or surface runoff pathways that discharge to the LDW.

Ecology receives spill reports, which are tracked through the Environmental Report Tracking System (ERTS). In addition to responding to spills, Ecology regularly refers reports of spills in the LDW area to Seattle Public Utilities (SPU) or the US Coast Guard for response.[51] Records of spills to the LDW from 1995 to present from the ERTS database are included in Appendix E. SPU has a spill coordinator (SSC) program that responds to spills of hazardous materials involving the SPU infrastructure. Spills are typically reported to the SSC by city crews or departments, or by other local agencies. Records of spills responded to by the SSC in the LDW area are listed in Appendix E. In addition the city has a water quality complaint response program, with a hotline number for calls from the general public or local agencies, which generally handles smaller problems or complaints than the SSC program. Records of water quality complaints in the LDW are available from SPU.

In 1974, PCBs were spilled in Slip 1. This spill occurred at the US General Services Administration dock when a transformer was dropped and cracked while being loaded onto a barge in Slip 1, resulting in the release of approximately 980 liters (260 gal) of near-pure PCB (Aroclor 1242) into the river (EPA 1975). Two separate dredging operations were conducted after the spill. An initial cleanup by EPA in 1974 using hand dredges recovered approximately 300 liters (80 gal) of PCBs. A second dredging attempt by EPA and the ACOE in 1976 was required to recover PCBs that had spread throughout Slip 1 and into the river channel, in part due to a 20-year flood that occurred in the winter of 1975/76. The second cleanup involved low-entrained-water (Pneuma pump) hydraulic dredging of PCBs in the northwest corner of Slip 1. About

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[51] The US Coast Guard also maintains a database on oil and chemical spills into water bodies. However, since any spills reported to the Coast Guard are subsequently reported to Ecology, the ERTS report should include all spills in the Coast Guard database.

38 million liters (10 million gal) of PCB-contaminated slurry was piped to settling lagoons on the Chiyoda Corporation property (formerly the Diagonal Avenue Sewage Treatment Plant property and currently the location of the Port of Seattle's Terminal 108; Map 4-34), located about 150 m (492 ft) south of the Diagonal / Duwamish CSO / SD. Most of the slurry was deposited in one of the lagoons located closest to the river, while the second lagoon received overflow water from the first lagoon. Water pumped from the lagoons was filtered through a sand and charcoal filter to remove suspended particles and PCBs before discharging to the LDW. It was estimated that the second dredging removed another 640-980 liters (170 gal) of the 980-liter (260-gal) spill (EPA 1975; King County 2002).

Leaking underground storage tanks (LUSTs) are a potential source of chemicals to soil and groundwater. Ecology currently regulates active storage tanks owned by entities such as gas stations, industries, commercial properties, and governmental agencies. Ecology maintains lists of inactive and active underground storage tanks (USTs) and LUSTS. There are currently approximately 1,500 USTs and 300 LUSTs on Ecology's lists in the vicinity of the lower Duwamish River (Ecology 2002d), including sites on Harbor Island and north of the LDW site boundary. The UST list contains sites that are operational as well as those that have been closed. The LUST list contains sites that have been cleaned up or are currently being cleaned up. The LUST sites are shown on Map 4-35 and are listed in Appendix E.

4.3.1.4 Landfills/land disposal

The historic South Park Landfill is located at 8200 Second Avenue South (Map 4-34). This site was a casual dumping area from the early 1900s to the 1940s. In the 1940s, the landfill was expanded and developed by the local health department. In the late 1940s, the City of Seattle took over operation of the site under permission of the property owners. In the mid-1950s, King County acquired the property as a result of tax liens. The City formally leased the property from the County in 1958. The landfill was operated as a burning dump until the late 1950s. Filling of the site with refuse continued until the closure of the landfill in 1978. It was reported that the landfill received mixed waste including industrial refuse (Sweet Edwards 1985). In 1965, the City purchased the northeast portion of the site and developed the South Transfer Station. The northwest portion of the landfill was developed by private entities into an industrial park and also was the location of an auto wrecking yard. Various portions of the site were periodically used as auto wrecking yards. King County owns 7.9 ha (20 ac) of the site. From 1993 until 1997, portions of the King County property were leased to trailer storage tenants by King County. Currently, King County is conducting an independent remedial investigation of the site and on-going monitoring (see Appendix G; King County Solid Waste 2000). The remaining portions of the landfill area have been developed for industrial uses in addition to the Seattle Recycling and Transfer Station.

A former landfill located at 6th Avenue South was identified as a potential source of chemicals to the Diagonal CSO (King County 2000a). This landfill operated for 30 years prior to about 1955 and received dredged sediments from the LDW. Other areas where waste has been stored or disposed on the soil surface in the LDW area were identified by Sweet Edwards (1985), but a more recent comprehensive list of potential source areas has not been compiled. A summary of the waste sites identified in 1985 and their locations is presented in Appendix D.

4.3.2 Pathways to LDW

Chemicals released to upland environmental media such as soil, groundwater, surface water, or impervious surfaces may migrate to the LDW through various pathways. As shown in Figure 4-1, these pathways include CSOs, storm drains, surface runoff, groundwater migration, erosion, and direct discharge. For example, an industrial release to groundwater could migrate via several pathways, such as groundwater flow directly to the LDW or seepage into a storm drain or creek. In addition, an industrial release could be discharged directly to the LDW. This section describes the primary pathways to the LDW for which information is available—CSOs, storm drains, and groundwater migration. The extent of erosion or surface runoff discharging directly into the LDW has not been evaluated because of limited available information. Also, very little information was available on Puget Creek and Hamm Creek, the two creeks in the area that enter the LDW. These creeks are shown on Map 4-34. Puget Creek enters the storm drain system at West Marginal Way and flows into the LDW near Terminal 105.

4.3.2.1 Combined sewer overflows (CSOs) and emergency overflows (EOFs)

A CSO is an overflow from the combined sewer system that occurs during storm events when system capacity is exceeded. CSOs are permitted by Ecology. An emergency overflow (EOF) is a discharge that can occur from either the combined or sanitary system that is not related to storm conditions and system capacity limitations. EOFs are typically caused by pump station failures or line blockages and are not covered under the City or County CSO wastewater permits. Relief points are provided in the collection system to discharge flow to the LDW under emergency conditions to prevent sewer backups. There are CSOs and pump stations operated by both the City of Seattle and King County. The City of Seattle owns and operates the local sanitary sewer collectors and trunk lines and King County operates the large interceptor lines that pick up flow from the local system and transport it to the West Point sewage treatment plant.

There are 13 CSO/EOF discharge points in the LDW study area. The City of Seattle owns and operates 2 CSOs (S. Brighton and Diagonal), and 2 EOFs (Slip 4 and Isaacson) and King County operates 9 CSO/EOFs. One outfall (Diagonal) carries overflows from both County and City CSOs and receives combined sewer overflows from 7 separate overflow points in the collection system, one of which is operated by the County (Hanford #1) and six of which are operated by the City. Locations of

CSO / EOF outfalls are shown on Map 4-34. Map 4-35 shows the basin boundaries for the area served by sanitary and combined sewer that could discharge to the LDW via a CSO.

Table 4-11 presents modeled current annual overflow volumes for King County CSOs. The model uses 48 years of Seattle rainfall records to develop a long-term average of the number of CSO events and their annual volume. Michigan, Hanford #1, and Brandon are the county CSOs with the highest overflow volumes. The East Marginal outfall is a pump station EOF, so discharge at this station would only occur under an emergency condition such as a power failure. King County has no record of an overflow at this location. The Duwamish CSO is an emergency bypass for a pump station and also serves as the Duwamish siphon overflow. This CSO has not overflowed since 1989 (King County 2000a).

Table 4-11. Current modeled King County CSO volumes

CSO and Discharge Serial Number	Average Annual Volume (MGY)	Average Annual Frequency
8th Ave/W. Marginal Way (040)	8	6
Brandon (041)	49	28
Duwamish (034)[a]	1	1
Hanford #1 (031)[b]	65	11
E. Marginal (043) [c]	<1	<1
Michigan (039)	150	28
W. Michigan (042)	2	5
Norfolk (044)	1	1
Terminal 115 (038)	2	3

Source: Huber (2002)

MGY – Millions of gallons per year

[a] No outflows at this CSO since 1989 (King County 2000a)

[b] Hanford #1 CSO discharges enter the LDW through the Diagonal outfall.

[c] An emergency overflow CSO

The City of Seattle’s Diagonal CSO is the only city CSO with significant discharges (Table 4-12). The overflow data presented in Table 4-12 do not include discharges from the county’s Hanford #1 CSO; those discharges are presented in Table 4-11. The Isaacson CSO is an emergency overflow for a pump station. SPU has no record of an overflow at this location. The South Brighton CSO only discharges during extreme events, generally once in five years or more (Tetra Tech 1988). SPU records show that the South Brighton CSO has not overflowed since monitoring began in March 2000.

Table 4-12. Contribution of discharge to the Diagonal outfall by the City of Seattle’s Diagonal CSO (not including Hanford #1 discharges)[a]

Year	Volume (MGY)
1998	1.61

1999	5.21
2000	0.58
2001	2.74

Source: Schmoyer (2002b)

MGY – millions of gallons per year

[a] Diagonal is the only city CSO with relatively large discharges; these volumes do not include Hanford #1, which are presented in Table 4-11.

Surface water chemistry data have been collected from the LDW to determine effects from King County CSOs on water quality. Water samples were collected at five locations in the vicinity of CSOs in the LDW and the Seattle waterfront over a 9-month period in 1996-1997 (King County 1999a). Samples were collected before, during, and after discharges. Organic compounds were rarely detected (see Table 4-7 for detection frequency). Metals were detected at elevated concentrations following discharge events, but none of the metal concentrations exceeded applicable ambient water quality criteria (see Section 4.2.5).

Whole effluent samples were collected in 1996 and 1997 from six CSOs along the LDW, including two CSOs (Norfolk and Brandon) that discharge to the LDW and four CSOs (Hanford, Chelan, Connecticut, and King) that discharge just north of the LDW but drain similar land use areas. Table 4-13 presents a summary of effluent data for Norfolk and Brandon, as well as combined data for the six CSOs. The latter data are presented to provide a more robust estimate of CSO effluent chemistry based on the larger sample size (where n=>100). Only three metals (copper, chromium, and zinc), caffeine, and coprostanol have been detected in 100% of the samples collected in 1996 and 1997. Other metals, phthalates, several PAHs, 1,4-dichlorobenzene, 4-methylphenol, benzyl alcohol, and benzoic acid have been regularly detected. Several organic compounds, including PCBs and DDTs, have not been detected[52] in these CSO whole effluent samples.

Water chemistry data have not been collected from city CSO outfalls, but estimates have been made based on other CSO data. The City of Seattle conducted a study in 2000 to predict the chemical quality of Seattle's CSO discharges based on data from CSOs in other municipalities in the Northwest, and to determine whether there is any evidence that chemicals in sediment adjacent to outfalls can be attributed to CSOs (EVS 2000). Of the five chemicals of concern for which discharge was estimated (copper, zinc, fluoranthene, phenanthrene, and BEHP), only copper and possibly zinc were predicted to have a reasonable potential to exceed ambient water quality criteria at the end of the pipe. The EVS (2000) study reported exceedances of CSL in the sediment offshore of the Diagonal (111) outfall for BEHP, mercury, benzoic acid, butyl benzyl phthalate, silver, and 1,2-dichlorobenzene (based on 13 samples located within 76 m [250 ft] of the outfall). However, based on a spatial trend analysis conducted in the GIS, only BEHP contamination appeared to be related to the outfall. At the South

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[52] Detection limits for organic compounds have ranged from 0.005 to 1.0 µg/L.

Brighton CSO (116), PCB concentrations exceeded the CSL in one of five sediment samples collected within 76 m (250 ft) of the outfall. However, PCB concentrations were below the CSL at the four stations located closest to the outfall.

Table 4-13. Chemical concentrations in King County CSO effluents

CHEMICAL	NORFOLK CSO			BRANDON CSO			COMBINED CSOs[a]		
	DETECT. FREQ. (%)	MEDIAN (µg/L)[b]	SD (µg/L)	DETECT. FREQ. (%)	MEDIAN (µg/L)[c]	SD (µg/L)	DETECT. FREQ. (%)	MEDIAN (µg/L)[d]	SD (µg/L)
TOC	100	13,900	3,240	100	12,100	14,500	100	18,600	20,400
TSS	100	167,000	48,300	100	74,800	155,500	100	97,600	89,600
Arsenic, total	100	4.43	0.49	100	2.81	1.82	37	17.8	17.3
Cadmium, total	100	0.30	0.021	100	8.35	9.72	38	1.53	1.79
Chromium, total	100	11.0	0.49	100	10.2	24.3	nd	nd	nd
Copper, total	100	25.5	7.0	100	37.4	59.2	100	45.0	41.4
Lead, total	100	25.8	4.53	100	39.1	52.8	58	40.4	66.0
Mercury, total	50	0.23	0.028	24	0.20	0.32	18	0.17	0.33
Nickel, total	100	10.9	0.92	100	12.6	173.3	nd	nd	nd
Silver, total	50	0.88	na	65	0.92	0.59	nd	nd	nd
Zinc, total	100	87.0	11.0	100	173	135	100	206	330
1,4-Dichlorobenzene	100	0.44	0.21	97	0.45	0.48	87	0.32	0.35
2-Methylnaphthalene	0	na	na	19	0.64	0.49	29	0.71	2.12
2-Methylphenol	0	na	na	35	0.38	6.44	33	0.45	3.52
4-chloro-3-methylphenol	0	na	na	19	0.64	0.22	9	0.66	0.66
4-Methylphenol	50	0.60	0.49	55	0.98	6.02	69	0.25	0.25
4-Nitrophenol	0	na	na	61	0.96	0.74	24	0.89	0.67
Acenaphthene	0	na	na	6	0.16	0.05	20	0.18	0.12
Benzo(a)anthracene	0	na	na	13	0.17	0.05	19	0.17	0.19
Benzoic acid	50	1.85	0.91	90	2.5	6.1	86	9.44	60.4
Benzyl alcohol	50	0.36	0.035	52	0.52	0.82	71	1.18	5.68
Benzyl butyl phthalate	100	0.30	0.48	81	0.65	4.63	82	0.55	2.51
BEHP	100	1.55	1.61	100	5.0	1.38	98	4.93	3.28
Caffeine	nd	nd	nd	100	3.74	6.30	100	7.77	19.5
Chrysene	25	0.20	na	77	0.23	0.08	40	0.21	0.20
Coprostanol	100	22.8	24.55	100	22.7	22.7	100	32.5	28.7
Diethyl phthalate	100	1.03	0.50	87	0.51	0.39	96	0.15	0.14
Dimethyl phthalate	0	na	na	77	0.13	0.07	67	1.18	0.98
Di-N-butyl phthalate	0	na	na	77	0.57	3.6	71	0.60	2.05
Di-N-octyl phthalate	0	na	na	100	1.21	0.63	74	0.50	0.68
Fluoranthene	75	0.21	0.038	97	0.31	0.13	76	0.29	0.31
Fluorene	0	na	na	13	0.19	0.12	26	0.18	0.20
Naphthalene	0	na	na	3	0.45	na	23	0.56	1.07

CHEMICAL	NORFOLK CSO			BRANDON CSO			COMBINED CSOs [a]		
	DETECT. FREQ. (%)	MEDIAN (µg/L) [b]	SD (µg/L)	DETECT. FREQ. (%)	MEDIAN (µg/L) [c]	SD (µg/L)	DETECT. FREQ. (%)	MEDIAN (µg/L) [d]	SD (µg/L)
Pentachlorophenol	0	na	na	81	0.35	0.10	37	0.33	0.10
Phenanthrene	75	0.18	0.090	81	0.26	0.15	84	0.28	0.36
Phenol	0	na	na	26	2.28	5.03	47	2.80	3.30
Pyrene	75	0.23	0.044	97	0.32	0.13	71	0.29	0.25

[a] Samples collected at Norfolk, Brandon, Hanford, Chelan, Connecticut, and King CSOs

[b] n= <5 except for TSS (n=2 for metals, n=4 for organic compounds)

[c] n= >30 (n=40 for metals, n=31 for organic compounds)

[d] n= >100 (n=32 for phthalates)

[e] Median values reflect all samples taken, regardless of type of grab sample.

na- not applicable

nd- no data available

Reported metals concentrations are total metals; all other metals were also detected.

Detection frequency was less than **5%** for 2,4-dimethylphenol, anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, carbazole, dibenzofuran, lindane, indeno(1,2,3-c,d)pyrene, isophorone, N-nitrosodimethylamine, N-nitrosodiphenylamine; all other organic compounds (including PCBs, DDTs, and other pesticides) were not detected in these CSO samples

Detection limits ranged from ~0.005-1.0 µg/L for organic compounds and ~0. 001-1.0 µg/L metals.

Modeling of sediment deposition off Duwamish / Diagonal CSOs in 1999 showed that BEHP, lead, and chrysene may accumulate in sediments at concentrations above state standards. Samples collected in the vicinity of various CSOs have shown BEHP concentrations consistently above state standards, but lead and chrysene concentrations were not above state standards. Additional modeling conducted on sediment deposition off CSOs (Appendices H and I; King County 2001b) predicted BEHP and butyl benzyl phthalate may continue to accumulate at concentrations above state standards; sediment sampling tends to confirm these results. However, these models also predicted that other metals may exceed state standards, although these predictions were not confirmed in actual sediment samples. The models do not appear to be refined enough at this time to accurately predict sediment chemical concentrations.

Sediments associated with two CSO outfalls in the LDW have been characterized as part of the requirements of a 1991 Consent Decree defining the terms of a settlement for natural resource damages with the city and county. These two CSOs are the Norfolk CSO and the Duwamish / Diagonal CSO / SD. At the Norfolk CSO, the primary sediment-associated chemicals were mercury, 1,4-dichlorobenzene, BEHP, and PCBs. In addition, there is a private storm drain that discharges just downstream from the Norfolk outfall. The Duwamish CSO and the Diagonal CSO / SD discharge into the LDW within about 30 m (100 ft) of each other. Also included in this general area is the Diagonal Avenue South SD, located about 300 m (1,000 ft) south of the Duwamish / Diagonal CSO outfalls. Primary chemicals of concern at the

Duwamish / Diagonal CSO outfalls were PCBs, mercury, BEHP, and butyl benzyl phthalate. Remediation efforts at these two areas are described in Section 4.3.3.

4.3.2.2 Historic sewer discharges

Prior to the creation of the Metro in 1958, the City of Seattle had several independent sewer systems that discharged raw sewage into the LDW at several locations, and the Diagonal Avenue sewage treatment plant (STP) that discharged primary-treated effluent near RM 0.6 (Figure 4-3, located in Oversize Maps and Tables) (Brown and Caldwell 1958). The independent systems serviced relatively small areas that discharged to the LDW. The sewerage system that flowed to the Diagonal Avenue STP (built in 1940) intercepted flows from the Rainier Beach area of Lake Washington and the East Marginal Way area of the Lower Duwamish from the STP down to Turning Basin 3. In 1962, Metro took over operation of the Diagonal Avenue STP until its closure in 1969, when the Elliott Bay Interceptor was brought on-line and diverted most flows to the West Point STP. Prior to 1958, there were also a number of individual industrial properties along the LDW with direct sewer discharges to the LDW (Brown and Caldwell 1958).

The total sewered area in 1958 was 2,400 ha (5,350 ac) to the east of the LDW and 790 ha (1,950 ac) to the west although some of that western portion discharged to the West Waterway north of the LDW site boundary, as shown in Figure 4-3 (Brown and Caldwell 1958). Little is known about the volumes of these raw sewage discharges, although these likely increased as the area developed. The Diagonal Avenue STP had a plant capacity of 7–8 million gal per day, and would run at capacity during almost any wet weather event. Flow to the plant was limited by upstream regulators that provided bypass directly to the LDW at what is now the S. Brighton CSO discharge point between Slips 2 and 3. Because sections of the intercepting sewer line leading to the STP had only about 10% of the capacity of the tributary lines, up to 90% of the wet weather flows discharged into the LDW at several locations in addition to the South Brighton outfall (Brown and Caldwell 1958).

Starting in 1969, most of the city and private sewer lines were connected into the Elliott Bay Interceptor and any subsequent system overflows occurred at the current CSO locations discussed in Section 4.3.2.1. In some cases, connections could not be made until complex connecting structures and pumps were built, so raw sewage discharges continued for several more years. For example, the raw sewage outfall into Slip 4 continued until 1976 (City of Seattle 1992).

4.3.2.3 Storm Drains

The LDW area is served by a combination of public or municipal and private storm drain systems. Most private storm drain systems discharge to a local municipality-owned system before discharging to the LDW. In some cases, primarily for waterfront properties, the private storm drains discharge directly to the LDW. For the purpose of this document, private storm drain refers to any entity's own drainage pipes other than the local municipality's system, whether that entity is a public or private organization.

Storm drains entering the LDW carry primarily urban runoff generated during or shortly after precipitation events. A wide range of chemicals may become dissolved or suspended in runoff as water contacts and flows over the land surface. Impervious surfaces may accumulate particulate material, dust, oil, asphalt, rust, rubber, metals, pesticides, detergents, or other material as a result of urban activities, which are flushed into storm drains during wet weather. Storm drain discharge volumes are generally substantially higher than CSO discharge volumes. Modeled estimates for the Diagonal/Duwamish CSO/SD show that approximately 1,100 million gallons per year (MGY) flows from the storm drain, compared to 65 MGY from the county CSOs and less than 10 MGY from the city CSOs (Tables 4-11 and 4-12) (Huber 2002; Schmoyer 2002b).

Private storm drains generally serve relatively small drainage basins (less than 2 ha) immediately adjacent to the LDW and are located primarily in their respective industrial areas. However, there are private storm drains that serve areas that are not immediately adjacent to the LDW. For example, large portions of I-5 drain directly to the LDW through dedicated drain lines. Alternately, the City of Seattle and City of Tukwila drains serve the larger metropolitan area and may receive runoff from drainage basins containing up to 570 ha (1400 ac) (Tetra Tech 1988). There are numerous municipal storm drains entering the LDW, as shown on Map 4-35, although the locations of the outfalls have not yet been field-verified. There is currently no comprehensive compilation of information on private storm drains discharging to the LDW. The City of Seattle is currently developing an updated map of outfalls to the LDW. As an interim measure for depicting outfalls, points were placed at locations where sewer or storm drain lines end at the LDW shoreline, using SPU GIS drainage and sewerage system maps. Surface drainage basins for the municipal storm drains discharging to the LDW are shown on Map 4-35.

The Diagonal storm drain is the city's largest stormwater outfall, carrying runoff from approximately 1,070 ha (2,640 ac) of residential, commercial, and industrial properties and approximately 11 km (6.8 mi) of I-5 in both the Diagonal and Hanford drainage basins (Schmoyer 2002c; King County 2002). These basins include areas of I-5, the Central District, the Rainier Valley, the Duwamish industrial area, and residential Beacon Hill. The Diagonal drainage basin is located on the east side of the LDW and the Hanford drainage basin is located in the Rainier Valley, with stormwater flows transported to the Diagonal outfall via the Hanford tunnel. These two basins contain numerous manufacturing and industrial businesses (King County 2000a).

Based on basin size, land use, and number of businesses with a high potential to pollute stormwater, the City of Seattle identified six priority stormwater drainage basins where stormwater would be discharged to Elliott Bay or the LDW (City of Seattle 1998). Stormwater from three of the six basins identified would discharge into the LDW. These basins are Diagonal Ave South, South Norfolk St, and Southwest Riverside St.[53] As discussed previously, the Diagonal basin is the largest by area, draining 1,070 ha. The South Norfolk basin was identified as draining 334 ha (825 ac) along the I-5 corridor from South Myrtle St to about RM 5.3.[54] The Southwest Riverside St basin was identified as draining 89 ha (220 ac) from the South Park area on the west side of the LDW from approximately RM 2 to RM 3.

A study was also conducted in the 1980s by Tetra Tech (Tetra Tech 1988) to evaluate potential sources of chemicals to Elliott Bay and the LDW. This study identified and ranked CSOs and storm drains, primarily based on sediment data collected from within the drains. The results are not discussed here because the study is dated and has some inconsistencies with current knowledge.

Storm water chemistry data are available for some King County and private storm drains, and although no data have been collected at the City of Seattle storm drains, data collected by King County may adequately characterize the stormwater quality in a City-owned storm drain. Available King County data are from 1997 for four drains associated with the Norfolk outfall and five Boeing storm drains (KCDNR 1998), and from 1995 for the Duwamish/Diagonal storm drain (Stern 2002). For private storm drains, NPDES monitoring data are available from Ecology for three sites with individual permits: Boeing Developmental Center, Lafarge, and Duwamish Shipyard. At these sites, storm water has been monitored for at least five years on a quarterly or monthly basis for site-specific lists of analytes. Available NPDES monitoring data will be discussed in the Phase 2 RI. Additional storm water samples have been collected by private entities at their outfalls, but a database containing data from all sites is not available from Ecology, and thus a comprehensive analysis of storm drain monitoring data was not possible in Phase 1.

One of the goals of the LDW Source Control Work Group is to compile source data and identify chemicals of concern (see Section 4.3.3.1); these results will include any available stormwater data and will be presented in documents produced by the LDW Source Control Work Group, and incorporated into the Phase 2 RI. In addition, the new Washington State General NPDES permit regulations will require monitoring of all permitted industrial storm water discharges for a limited number of parameters beginning in the second quarter of 2003 (see Section 4.3.3.6). Current phase I municipal stormwater permit requirements do not require monitoring of storm drain outfalls.

4.3.2.4 Groundwater transport

Groundwater chemistry data are available for 12 of the sites identified by Ecology and EPA for the Phase 1 RI.[55] These data are discussed in detail in Appendix G with

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[53] The basins used in the 1998 City of Seattle report are not exactly the same as those shown in Map 4-35.

[54] Measured from the southern tip of Harbor Island.

[55] These sites represent the limited information available at the time this document was written. Additional information on groundwater chemistry may be collected and/or analyzed by EPA and Ecology during the period Phase 2 of the RI is being completed.

respect to the potential for groundwater-associated chemicals to reach the LDW. Other primary sources, such as spills, leaks, and injection wells[56] could also contaminate groundwater. This section provides a general discussion of chemical behavior and transformations and physical processes that could affect chemical fate and transport within groundwater in the vicinity of the LDW.

Groundwater flow in the Duwamish basin is towards the LDW, although the direction may vary locally depending upon the nature of subsurface material, local precipitation recharge patterns, and proximity to the LDW (see Section 2.2.2, Map 2-1). The groundwater pathway from a specific area near the LDW can be identified based on a study of the hydrogeologic units and groundwater elevation data (see Appendix G). Determining whether a chemical identified in groundwater will reach sediment and surface water in the LDW is more complex, and is discussed in general in this section.

Redox[57] and Tidally Influenced Conditions

In general, the shallowest water-bearing zones are likely to receive oxygenated water through precipitation infiltration,[58] and thus would be expected to foster aerobic conditions. However, much of the valley plain adjacent to the LDW is paved, limiting the amount of infiltration. In most areas, the shallow aquifer contains abundant natural organic material within silty layers that are interbedded within the sandy aquifer. These materials, native from the former tideflat condition, would be expected to deplete oxygen through natural biological oxygen demand. Thus, where sand layers are shallow and vertically continuous, more oxygenated waters are expected, whereas, in alluvial sequences[59] interbedded with organic-rich silts and clays, the oxygen demand could create a reducing groundwater environment. Areas contaminated by chemicals that are readily biodegraded, such as petroleum hydrocarbons, can also create localized zones of reducing conditions.

Near the LDW, tidal action can alter groundwater flow direction, rates, and water quality. Typically, the groundwater hydraulic gradient is toward the LDW as upland recharge and regional groundwater inflow provide a higher elevation potential within the groundwater system. At low tide, the hydraulic potential between the groundwater system and the LDW is typically at its highest for inducing groundwater flow to the LDW. At high tide, the hydraulic gradient often reverses with the higher water level providing a hydraulic potential for LDW water to flow inland into the groundwater system. The amount of LDW water intrusion into the aquifer depends on the tidal stage and site-specific aquifer conditions, such as permeability, and the current precipitation recharge conditions within the groundwater system.

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[56] An additional potential historical source of groundwater contamination is the possible former use of underground injection wells to dispose of waste fluids. There are no known active wells in the LDW, although their presence has not been ruled out, and the existence of closed wells with contamination is still a possibility (Sanga 2002).

[57] The transformation of a substance by losing (oxidation) or gaining (reduction) electrons

[58] Rainwater that penetrates below the ground surface

[59] The layering pattern of different types of sedimentary material under the ground surface

This tidal action causes a constant oscillation of groundwater particles within the zone of tidal influence. Site-specific studies (see Appendix G, Booth and Herman 1998) have shown that this zone of oscillation typically ranges from 91 to 180 m (300 to 600 ft) inland of the LDW. The periodic reversal in flow direction caused by tidal action has the effect of enhancing the retardation of migrating constituents dissolved in the groundwater. These processes include increased sorption to soil particles (discussed below) and the slowed migration due to a more circuitous travel path, thus providing a greater residence time within the nearshore aquifer and greater opportunity for chemical transformation and decay. Figure 4-4 provides a conceptual depiction of the tidal influence on a water particle within the Duwamish valley alluvial aquifer system.

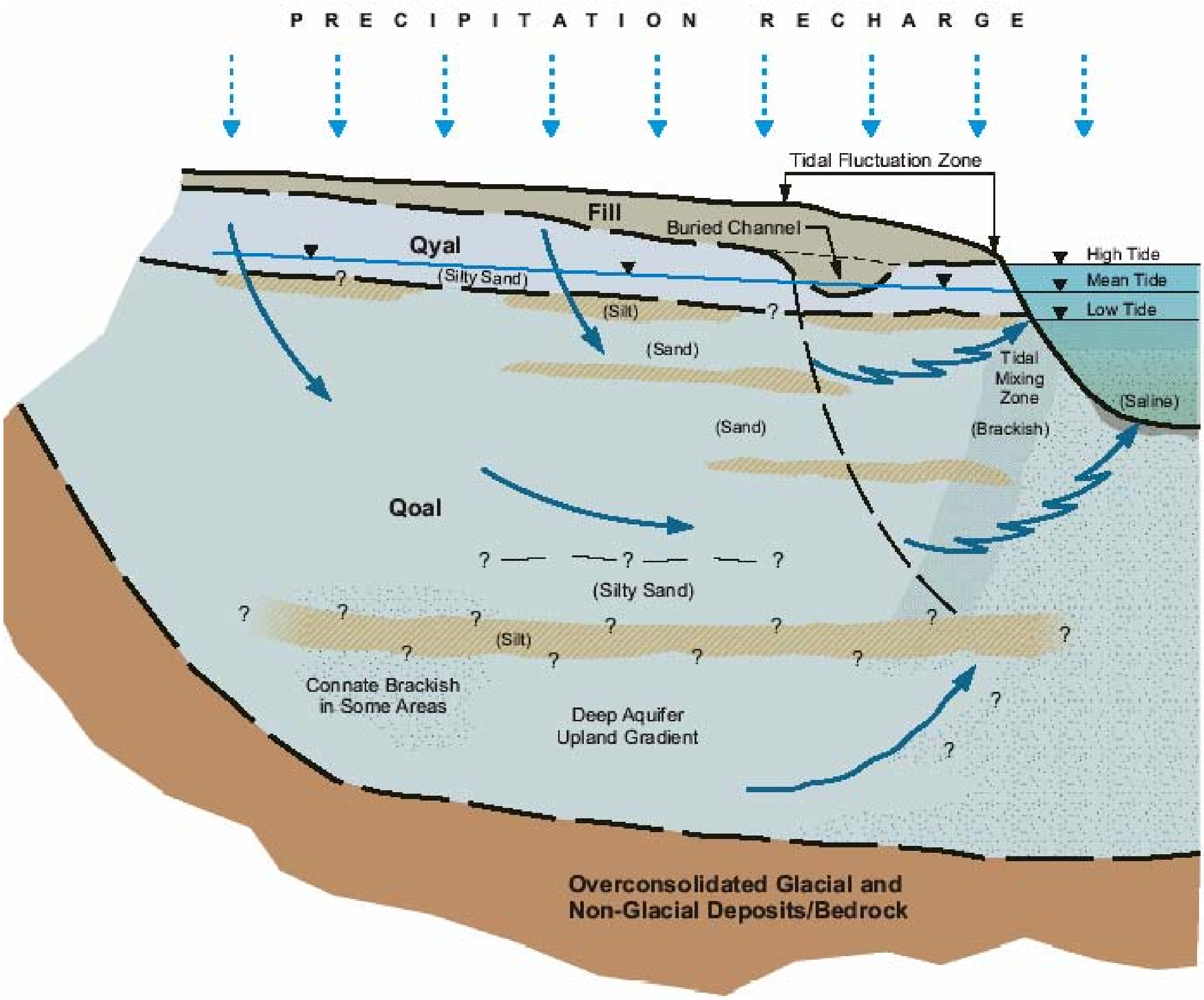

Figure 4-4. **Conceptual in-aquifer tidal mixing (Aspect 2003)**

LDW water intrusion into adjacent shallow water-bearing zones during high tides can influence nearshore groundwater chemistry. Because the LDW is an estuary with a variable mixture of fresh and marine water, LDW water is relatively saline containing high concentrations of chloride, sulfate, and carbonate in its downstream sections;

thus groundwater may be expected to contain higher concentrations of these constituents near the LDW in these areas. In addition, the infusion of oxygen from LDW water containing up to 10 mg/L dissolved oxygen to groundwater generally containing less than 2 mg/L of oxygen provides a catalyst to biochemical reactions and the potential formation of biofilms[60]. Oxygen is a strong oxidant and many organic chemicals (e.g., TPH/BTEX and vinyl chloride) are readily biodegraded under aerobic conditions. The potential for increased oxygen concentrations in nearshore groundwater can also provide conditions for sorption and coprecipitation of dissolved metals and iron and manganese (hydr)oxides and clay minerals. The net effect of the tidal-groundwater exchange is that many chemicals may exhibit enhanced natural attenuation in these tidally fluctuating groundwater zones as a result of active biogeochemical processes taking place there (Boatman and Hotchkiss 1997).

Advective Flow and Constituent Partitioning

Dissolved chemicals migrate in the direction of groundwater flow in a process called advection. Advection is the movement of groundwater through soil pores and is primarily dependent on the characteristics (e.g., hydraulic conductivity) of the aquifer through which it moves, and the hydraulic gradient driving the groundwater flow. The observed concentration of chemicals in groundwater is influenced by their aqueous solubility, presence of cofactors such as organic solvents, salinity, specific ions and chelating agents for metals, pH, oxidation-reduction (redox) potential, and to some extent, the degree and duration of contact between moving groundwater and contaminated soil. Because of partitioning to aquifer solids, the migration of organic chemicals and metals is retarded with respect to the prevailing groundwater velocity. The degree to which chemicals travel more slowly than groundwater—the retardation factor[61]—depends on the dry bulk density and porosity of the aquifer and the soil-water partitioning coefficient of the chemical (Fetter 1993). The presence of an oxic zone in groundwater prior to discharge, which can occur in tidally fluctuating zones (Boatman and Hotchkiss 1997), can increase site-specific retardation significantly as a result of the presence of iron and manganese (hydr)oxides with high sorptive capacity for metals and organic carbon.

For organic chemicals, a general soil-water partitioning coefficient can be estimated as the product of the organic carbon content of the aquifer and a chemical-specific water-organic carbon partitioning coefficient. For ionizable substances such as benzoic acid and pentachlorophenol, the organic carbon-water partitioning coefficient is dependent on groundwater pH, decreasing with increasing pH. Table 4-14 lists values of the water-organic carbon partitioning coefficient from MTCA (WAC 173-340, Table 747-1) and Montgomery (1996), as well as calculated potential retardation factors. The retardation factors indicate the relative mobility of organic chemicals relative to

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[60] A biofilm is a community of micro-organisms attached to a solid surface.

[61] A chemical with a retardation factor of 100, for example, will travel 100 times more slowly than a conservative tracer in groundwater.

groundwater transport. Low molecular weight organic compounds such as vinyl chloride and methylene chloride and ionizable organics such as benzoic acid are the most mobile compounds, with retardation factors close to 1. That is, compounds with low soil-water partitioning coefficients migrate at close to the rate of groundwater flow. Higher molecular weight compounds such as fluorene (60 times slower than groundwater) and mixtures of high molecular weight compounds, such as PCBs (approximately 6,000 times slower), are the least mobile. Relative to the chlorinated and non-chlorinated solvents and other VOCs, the metals (i.e., cadmium, chromium, copper, silver, and arsenic) are less mobile with retardation factors of 55 to 233 (Table 4-15). Nickel and lead are even less mobile, with potential retardation factors relative to groundwater of 521 and 80,000, respectively (Table 4-15).

Table 4-14. Organic compound partitioning coefficients and potential retardation factors

CONSTITUENT	ORGANIC CARBON-WATER PARTITIONING COEFFICIENT [a] (L/kg)	RETARDATION FACTOR [b]
Non-ionizable organics		
Tetrachloroethene	265	3.12
Trichloroethene	94	1.75
cis-1,2-Dichloroethene	**1.0**	1.01
trans-1,2-Dichloroethene	38	1.30
1,1-Dichloroethene	65	1.52
Vinyl chloride	**2.5**	1.02
1,1,1-Trichloroethane	135	2.08
1,1-Dichloroethane	53	1.42
1,2-Dichlorobenzene	379	4.03
Methylene chloride	10	1.08
PCBs (Aroclor 1016)	107,285	859
PCBs (Aroclor 1260)	822,422	6,580
Non-chlorinated hydrocarbons		
Benzene	62	1.50
Toluene	140	2.12
Ethylbenzene	204	2.63
o-Xylene	241	2.93
m-Xylene	196	2.57
p-Xylene	311	3.49
1,2,4-Trimethylbenzene	1.0	1.01
Fluorene	7,707	62.7
Ionizable organic compounds [c]		
Benzoic acid	0.50	1.00
Pentachlorophenol	410	4.28

[a] Bolded values from Montgomery (1996); all other values from WAC 173-340, Table 747-1.

[b] Calculated assuming soil organic carbon content of 1000 mg/kg, soil bulk density of 2 gm/cm^3 and porosity of 25%.

[c] Value at pH 8.0 from WAC 173-340, Table 747-2.

Table 4-15. Metals partitioning coefficients in groundwater and potential retardation factors

METALS	SOIL-WATER PARTITIONING COEFFICIENT [a] (L/kg)	RETARDATION FACTOR [b]
Arsenic	29	233
Cadmium	6.7	54.6
Chromium	19	153
Copper	22	177
Lead	10,000	80,000
Nickel	65	521

[a] Source: WAC 173-340, Table 747-3

[b] Calculated assuming soil bulk density of 2 gm/cm^3 and porosity of 25%.

The mobility of metals is generally influenced by their solubility under prevailing pH, salinity, redox potential, cation exchange capacity, organic carbon content, and degree of interaction with iron oxides, hydroxides, and sulfide minerals present in the aquifer solids. For some metals, reducing environments such as occur in many areas within the LDW valley, produce the more soluble and mobile valence state of the metals such as iron, manganese, and arsenic (USGS 1999). However, the solubility of these metals will be limited by precipitation with common groundwater anions such as sulfate, chloride, carbonate, or hydroxides, whose availability is influenced by the same processes. Low pH can bring metals into solution, but the low pH condition generally does not persist in the subsurface environment. In reducing environments, chromium is reduced to the less soluble (and less toxic) trivalent chromium (Robertson 1975).

Other Physical Processes

In addition to advection, several physical processes may influence chemical concentrations downgradient of an area with elevated groundwater chemical concentrations, and ultimately the concentrations in groundwater discharging to the LDW. These include:

- volatilization—the process whereby low molecular weight compounds migrate from groundwater into the vapor phase in unsaturated soil above the water table
- diffusion—the movement of molecules along chemical concentration gradients; generally more significant at low groundwater velocities; for example, through silt and clay layers

- dispersion—the small scale mixing process that results from the varying paths individual chemical molecules follow while traveling through porous media. A substantial amount of dispersion can occur in fine silty sand sediment from the constant oscillation of the tidal flux.
- dilution—a process that occurs along the groundwater flow path from an area with elevated groundwater chemical concentrations to the LDW as a result of precipitation recharge. Dilution also occurs at the point of discharge to a tidally influenced water body as a result of fluid exchange between the LDW and the aquifer. Many tidal monitoring studies indicate intrusion of water from a surface water body into the adjacent aquifer during high tides and discharge of a groundwater-surface water mixture at low tides. This in-aquifer mixing reduces the concentrations of dissolved chemicals discharging to the surface water body (Yim and Mohsen 1992).

An additional process that may affect groundwater chemistry is the potential presence of a DNAPL. A DNAPL is a separate-phase liquid that is denser than water (e.g. certain chlorinated solvents). After release at the soil surface, free-phase DNAPL moves downward under the force of gravity or laterally along the surface of sloping fine-grained stratigraphic units. Some of this DNAPL becomes trapped in pores and fractures, resulting in residual saturation. This residual material may persist for many years in the subsurface and slowly release chemicals to the groundwater through dissolution. Major factors controlling DNAPL migration in the subsurface include: 1) volume released, 2) area of infiltration at the entry point to the subsurface, 3) duration of release, 4) properties of the DNAPL, such as density, viscosity, and interfacial tension, 5), properties of the soil/aquifer media, such as pore size and permeability, 6) general stratigraphy, such as the location and topography of low-permeability units, and 7) micro-stratigraphic features, such as root holes or small fractures (EPA 1992b).

Biological Degradation Processes

Biotic and abiotic transformation processes can also exert significant influence over the fate of organic chemicals. Non-chlorinated hydrocarbons such as total petroleum hydrocarbons (TPH), low molecular weight PAHs, benzene, toluene, ethylbenzene, and xylenes (BTEX), and trimethylbenzene are readily degraded under aerobic conditions (Wiedemeir et al. 1994) wherein oxygen serves as the electron acceptor for microbial respiration. Hydrocarbon compounds can also be degraded by sulfate- and nitrate-reducing bacteria although more slowly than by aerobic processes (Wiedemeir et al. 1994).

The rate of microbial degradation of chlorinated hydrocarbons depends on the redox environment and oxidation state of the compound. The more oxidized compounds, tetrachloroethene, trichloroethene, and 1,1,1-trichloroethane are more readily degraded under reducing conditions, where they can serve as electron acceptors for microbial respiration of natural or anthropogenic organic carbon. The more reduced compounds, cis- and trans-1,2-dichloroethene, 1,1-dichloroethene, 1,1-dichloroethane, and vinyl chloride are more readily degraded under aerobic conditions, where they serve as electron donors for microbial respiration (Vogel and McCarty 1987). The compound 1,1,1-trichloroethane is also abiotically transformed by a dehydrohalogenation process to 1,1-dichloroethene (Cooper 1987). The presence of the less-oxidized halogens vinyl chloride, cis-1,2-dichloroethene, and 1,1-dichloroethane in groundwater is likely the result of in situ biodegradation of the more oxidized parent compounds (tetrachloroethene, trichloroethene, and 1,1,1-trichloroethane) that have been used extensively in industrial processes.

To be degraded, organic compounds generally must come into contact with the cell membranes of microorganisms. Consequently, degradation rates are generally higher for more soluble compounds. For example, benzene is more rapidly degraded than the less soluble xylenes, and both are more rapidly degraded than fluorene (Mackay et al. 1992).

Although microorganisms do not degrade metals in the environment, they can play an important role in altering their mobility by influencing the redox potential and to a lesser extent, pH, of the groundwater system. In marine sediments, microbial oxidation of natural and anthropogenic carbon consumes available oxygen, sulfate, and carbon dioxide within a short distance below the sediment-water interface, creating strong reducing conditions (Moore et al. 1988). Reducing conditions can mobilize iron, manganese, arsenic, and other metals naturally present in or sorbed to sediment particles, although if sufficient sulfide is present, the precipitation of sulfides can be effective in decreasing mobility in metals. In oxic conditions, the mobility of these metals is generally decreased through sorption to or coprecipitation with iron and manganese (hydr)oxides. The combination of these processes creates a metals sequestering area in the transition zone between the deeper anoxic layers and the oxic sediment surface layers.

Implications for LDW Sediment and Surface Water Quality

Organic compounds that are the most mobile in groundwater will have the lowest affinity for sorption to sediments in the LDW and will generally be more biodegradable. Consequently, compounds that are relatively mobile in groundwater such as tetrachloroethene, 1,1,1-trichloroethane, and BTEX, are generally not likely to result in sediment contamination because of their lower affinity for sediment solids and their biodegradation potential. These compounds may, however, present risks via aqueous exposure to benthic organisms if released in sufficient quantity, because they are not affected by normal sediment remediation, such as dredging and capping. Thus these issues are typically addressed through source control activities. However, all of these compounds have relatively high volatility and photolytic degradation potential. Therefore, their residence time in surface water is typically less than a few days (Mackay et al. 1992).

In contrast, fluorene and PCBs have substantially higher affinity for sediment solids and thus may pose some potential for sediment contamination if present in groundwater in sufficient quantity. However, given the higher affinity of fluorene and PCBs for aquifer solids, the flux of these compounds in groundwater is likely to be very low unless the contaminated groundwater is located immediately adjacent to the LDW or mobility enhancement mechanisms such as preferential flow paths or co-solvents are present. Aroclor 1260 has a retardation factor of 6,580 (Table 4-14), and thus would migrate through groundwater 6,580 times slower than a conservative tracer. Thus, for a site with a groundwater velocity of 30.5 m/yr (100 ft/yr), for example, Aroclor 1260 would migrate at 0.006 m/yr (0.02 ft/yr). Therefore, source control actions, such as contaminated soil removal, would be the most effective control in reducing the potential for PCB migration to the LDW.

Non-chlorinated hydrocarbon compounds (e.g., benzene) will tend to be used as electron donors for microbial respiration and consequently will likely be strongly attenuated during migration toward the LDW, unless the source is close to the river or the flux of these compounds exceeds the available electron acceptor supply.

If reducing conditions are observed along the flow path to the LDW, groundwater conditions may favor reductive dechlorination. This process will tend to attenuate migration of the more oxidized chlorinated hydrocarbons (e.g., tetrachloroethene). On the other hand, this process may increase downgradient concentrations of the less oxidized daughter products, notably vinyl chloride and cis-1,2-dichloroethene.

The fate and transport potential of metals identified in groundwater is influenced by their interactions with complexing agents and their varied response to groundwater redox potential. Generally, metals dissolved in groundwater are expected to stay in solution unless the redox potential or concentrations of complexing agents change along the flow path towards the LDW. Because of tidally mediated intrusion of oxygenated river water into the shallow aquifer near the LDW, higher concentrations of chloride, sulfate, and carbonate are expected in groundwater near the LDW. Reactions with these anions would, for example, be expected to lower the mobility of some metals, such as silver, lead, and barium. In addition, oxic conditions possibly in the tidally fluctuating zone would result in the formation of iron and manganese (hydr)oxides that are highly effective surfaces for the sorption and co-precipitation of other metals, such as copper and zinc.

The solubility and mobility of natural or anthropogenic arsenic is controlled by adsorption and desorption reactions, and solid-phase precipitation and dissolution reactions (USGS 1999). Both redox conditions and pH can affect the valence state and thus the amount of dissolved arsenic in the hydrogeologic environment. In a reducing environment, such as found within many areas of the Duwamish alluvial aquifer, the more soluble form of arsenic (i.e., arsenite) is favored. Thus, a natural increase in dissolved arsenic might occur where the natural organic chemicals have created a strongly reducing environment. Releases of organic chemicals, such as petroleum hydrocarbons, also cause reducing conditions as natural biodegradation uses the available oxygen, subsequently causing the dissolution of natural arsenic from soil grains. Arsenic is commonly found in groundwater within the Duwamish valley, due primarily to natural and anthropogenic reducing conditions. As dissolved arsenic approaches sufficiently oxidizing conditions, as may be encountered in the tidal mixing zone, arsenic may be oxidized to arsenate, which will tend to sorb onto iron oxide coatings and clay minerals (USGS 1999). If sufficiently oxidizing conditions are encountered prior to groundwater discharge due to increasing oxygen levels in the tidal mixing zone, arsenic will be further attenuated prior to discharge.

4.3.3 Source control efforts

The LDW Superfund Site is being jointly administered by the EPA and Ecology to meet the requirements of both CERCLA and MTCA. Under the Memorandum of Understanding signed by the two agencies, Ecology was designated lead agency for source control activities. A source control plan is being developed to identify and manage sources of sediment contamination to the LDW. Ecology will coordinate all the activities to implement that plan. Discussed below are Ecology's process and several existing programs that are key components to the source control strategy.

4.3.3.1 LDW site source control activities

Ecology is preparing a source control strategy for identifying and managing sources of chemicals to sediments in the LDW, with the goal of developing the strategy into area-specific plans in 2003 (Huey 2003). Components of the draft strategy include linking source control with sediment cleanup; addressing post-cleanup sediment recontamination; developing source control partnerships with public agencies as well as private property owners, businesses, and industry; and primary steps toward source control (Ecology 2002a). In the development of the strategy, Ecology is working with the LDW Source Control Work Group, which includes Ecology, EPA, King County, the City of Seattle, and the Port of Seattle, to obtain input from and coordinate with implementing agencies, affected parties, and other stakeholders.

Ecology has identified four steps for source control efforts to be applied for the LDW:

- identification and mapping of sources of site chemicals of concern (COC)
- management of identified sources
- tracking and reporting of source control activities and implementation schedules
- measurement of source control effectiveness (Ecology 2002a).

Both historic and ongoing sources will be identified in the basin(s) draining to a site. The potential for a particular source to contribute to the contamination at the site will be assessed. Management of contributing sources will include, as appropriate, administrative controls (e.g., notices, orders, decrees, permits); engineering controls for active source reduction or elimination; stormwater management; upland site cleanup; and technical assistance and education. Implementation and compliance schedules will be tracked to ensure that all actions are completed. Monitoring will be required to evaluate effectiveness of source control measures and additional actions will be taken where initial measures prove inadequate.

As candidate sites for early actions are identified and further evaluated for their potential for early remedial action, source control efforts will begin at those sites. The goal at those sites will be to identify and manage source control issues specific to a cleanup project in a timeframe that will reduce the potential for any recontamination of the cleanup site.

In addition to site-specific efforts, there are also programmatic efforts that will be applied to the entire LDW drainage basin. These programmatic efforts include ongoing implementation of regulatory programs that target discharges of chemicals, the storage and disposal of chemicals, and the identification and cleanup of contaminated upland sites. These efforts are described below. Coordination with these programs will be used to focus efforts in the project-specific areas and target specific COCs as needed. For example, drainage basin studies have been conducted on identification and control of phthalate sources in both Diagonal/Duwamish CSO/SD and Norfolk CSO/SD. Also, investigations into releases of materials have been conducted to find the sources of oil and a sticky white material emanating from the Diagonal/Duwamish CSO/SD. Ecology is working with other public agencies that have authority and responsibility for implementing aspects of the strategy and plan in the LDW.

4.3.3.2 Stormwater inspection programs

The City of Seattle conducted a stormwater inspection project in the 1990s to control sources of pollutants entering storm drains that discharge to Elliott Bay and the Duwamish River. As discussed earlier, three priority storm drain areas entering the LDW were identified based on size of basin, land use, and number of businesses with a high potential to pollute (City of Seattle 1998). These basins are Diagonal Ave South, South Norfolk St, and Southwest Riverside St. The study identified about 1,000 priority businesses within these basins that discharge into city-owned storm drains (those businesses discharging stormwater directly into the river were not included). The focus was on outdoor activities to minimize the presence of onsite chemicals that could come in contact with stormwater runoff. The majority of these businesses involved manufacturing, scrap yards, transportation, or automotive repair. Of these businesses, it was determined that more than 700 did not conduct outdoor activities that could potentially harm the environment. Over 260 priority businesses were inspected to discuss pollution prevention methods with owners. Also, information bulletins were mailed to businesses to promote best management practices, including disposal/storage activities and housekeeping practices, and to increase local awareness of the importance of protecting water quality. A number of measurable actions by businesses were noted as a result of the inspections, including movement of barrels indoors, improvement of housekeeping practices, reducing or diverting contaminated water entry away from storm drains, and other similar actions.

SPU has recently implemented a business inspection program as part of the city's stormwater pollution prevention program. The goals of the inspection program are to reduce the amount of pollutants discharged to city-owned storm drains by improving the pollution prevention practices at local businesses and to improve compliance with the source control requirements of the Seattle stormwater, grading, and drainage control code (SMC 22.800). In 2001, a total of 200 businesses were inspected in the western portion of the Diagonal Avenue South drainage basin (109 drive-by inspections and 91 on-site inspections) and 68 businesses were inspected in the Norfolk drainage basin (24 drive-by inspections and 44 on-site inspections). Inspection reports are maintained by SPU and a database is currently being developed to track the progress of the inspection program.

A total of 149 of the businesses inspected were not in compliance with city stormwater source control requirements. Most of the problems were related to inadequate maintenance of onsite storm drainage systems (33%) and inadequate spill response programs (47%). SPU inspectors worked with the business owners to improve their stormwater pollution prevention practices. As of March 2002, over 91% of the businesses inspected are now in compliance with city stormwater requirements.

The city inspection program will continue conducting source control activities in the Diagonal drainage basin to support the early action cleanup proposed for the Duwamish / Diagonal CSO / SD consistent with the LDW source control strategy. Chemical source inspections will be expanded to cover the eastern portion of the drainage basin that was not covered in 2001. In addition, focused inspections will be conducted at select businesses in the basin to determine whether these facilities are sources of chemicals found in the sediment offshore of the Diagonal outfall. Once other early actions are identified, resources will be directed to basins contributing to those sites.

Another City of Seattle program that reduces chemical inputs from stormwater is the program to clean street catch basins on a regular basis. Street dirt contains a lot of chemicals and a large percentage of the chemicals are attached to the dirt particles. Catch basins are designed to keep the street dirt from traveling into the storm drain pipe where the dirt will either accumulate and plug the pipe or be washed out to the receiving water. The main objective of the catch basin maintenance is to trap the street dirt before it enters the storm drain or sewer pipe. The catch basins tributary to the LDW will be cleaned regularly with an emphasis on areas tributary to cleanup sites, reducing the input of contaminated street dirt in stormwater discharges.

The City of Tukwila has jurisdiction over a portion of the drainage in the southeast part of the drainage area. King County also has jurisdiction over a very small strip of land adjacent to the LDW in the southwest. These jurisdictions will be brought in as appropriate to conduct any necessary stormwater source control activities consistent with the source control strategy. Each entity has existing stormwater site inspection and maintenance programs.

The Port also has a documented compliance inspection program that centers around storm water and the approximately 30 tenants that can potentially adversely affect storm water discharges. These tenants include the container docks, shippers, fishing vessels, barge loading, and marinas. The Port uses these inspection opportunities to observe not only their activities that can affect storm water discharges and to assure their usage of appropriate best management practices, but also any hazardous/dangerous waste generating activities, usage and storage of hazardous materials, and any other environmental concerns including air quality, noise and impacts on neighbors and surrounding communities.

As part of their lease, the Port requires tenants to apply for and obtain their own permits for storm water, air discharges, King County industrial sewer discharges and any SPCC, SWPPP, Health and Safety plans as appropriate. The Port reviews all the permits and plans for adequacy and implementation, protection of the Port liabilities and environmental/public health protection. The Port also strives to maintain a close communication link with the federal, state and local agencies to assure that any concerns or actions are addressed.

4.3.3.3 Industrial waste inspection programs

King County implements an industrial pretreatment program that started in 1969 and became an EPA delegated program consistent with the requirements of the Clean Water Act in 1981. The Industrial Waste (IW) program requires non-domestic users of the metropolitan sewer system to meet certain standards and limits before discharging wastewater into the sewer system. Requirements may include pretreatment before discharge and/or best management practices. King County enforces both federal categorical standards and local limits, whichever are more stringent. King County local limits were established to protect sewerage facilities and treatment processes, public health and safety, and the receiving waters and to enable King County to comply with its NPDES permits. Regulated materials include heavy metals; flammable materials; sulfides; cyanide; pH; fats, oils, and grease; and organic compounds. Since it began in 1969, the program has caused a significant decline of undesirable chemicals in wastewater received by King County treatment plants, and thus also in the CSO discharges.

The IW program issues wastewater discharge permits and discharge authorizations to companies that have industrial processes with the potential to adversely affect King County treatment facilities. Permits are more comprehensive than discharge authorizations and almost always require self-monitoring of the company’s discharge. In addition to self-monitoring, King County staff inspect facilities with discharge permits at least once per year and sample all permitted companies at least twice per year. Permits are issued to “Significant Industrial Users”, federal categorical companies, and those discharging 94,600 liters (25,000 gallons) per day or more. Facilities below the threshold that require permits can be issued discharge authorizations in the minor category (fewer requirements and no self-monitoring) or the major category (requires a limited amount of self-monitoring). King County inspects companies with discharge authorizations at least once every five years but does not regularly sample them, relying instead on self-monitoring at these companies. At the end of 1999, King County had 145 Significant Industrial Users and 279 discharge authorizations.

In 2001, the IW program completed 210 inspections of Significant Industrial Users and 77 inspections of facilities with discharge authorizations. Staff collected 2,628 compliance samples, primarily from Significant Industrial Users. In addition, companies reported that they had undertaken self-monitoring by performing 23,185 analyses of samples. When violations were identified, the IW program conducted follow-up inspections and sampling to verify that conditions causing the violations were corrected and eliminated. None of the violations identified by King County or by self-monitoring caused exceedance of permit limits at King County treatment facilities (King County 2002).

In addition to monitoring discharges by businesses with discharge permits and authorizations, the IW program monitors chemical concentrations at other locations throughout the wastewater collection system. Samples of wastewater influent are collected daily at the Renton and West Point wastewater treatment plants. Samples of wastewater are collected two weeks each year at several pump stations, siphons, interceptors, and key manholes (central points through which all wastewater from each sector of land flows). Each sampling station is monitored continuously for one week during the wet-weather season (November through April) and for one week during the dry-weather season (May through October). Heavy metal and other chemical concentrations are measured and analyzed. The ongoing data collection allows staff to determine the range of chemical concentrations over time. When heavy metals or other chemicals are detected at unusually high concentrations, King County often can determine the approximate direction from which a chemical is coming, track the discharge to its source, and take corrective action.

All of these actions significantly lower the concentrations of chemicals in sewage, and thus in any CSO discharges. The ongoing tracking program will continue to identify violations or new sources or dumping. The IW program will provide support to source control investigations in the LDW, starting first in the Diagonal CSO/SD drainage basin. One full-time staff member from IW is allocated to work primarily in the Diagonal CSO/SD drainage basin in 2003 and move on to additional early action sites when identified.

In addition, the Port of Seattle has a multi-phased tenant compliance program that includes an environmental review of all new and renewed tenant leases, a walk-through of all new tenants upon occupancy and exit, and depending on their activity, periodic inspections (weekly, monthly or annual). Most Port tenants do not have industrial activities that require a formal intensive checklist and report type of environmental audit by the Port. The Port has a cooperative, interactive voluntary compliance program with tenants that is successful, largely due to the attention paid to tenants from beginning to end including responsiveness and the technical assistance provided by Port staff.

4.3.3.4 Hazardous waste inspection programs

The Regional Hazardous Waste Management Program complements King County's IW Program by educating local residents and small businesses on ways to reduce hazardous waste and prevent water pollution. The program is a cooperative effort among King County Department of Natural Resources and Parks (Solid Waste and Water and Land Resources Divisions), Public Health-Seattle and King County, City of Seattle Public Utilities, and 38 cities in King County and Snohomish County. This program implements the Local Hazardous Waste Management Plan adopted in 1990 by King County and all the local cities.

The regional Hazardous Waste Management program targets industry groups and geographic areas to provide technical assistance. The program staff make site visits to small businesses throughout King County and all of its incorporated cities and observe operating practices. When problem materials, such as lead, mercury, and solvent-based paints, are being disposed of in the sanitary sewer, program staff counsel the company on correct practices. When necessary, staff can refer the matter to the IW program for regulatory action. In 2000, more than 3,000 businesses were inspected. Follow-up inspections indicate that 75 to 80% of businesses make at least one positive change in hazardous waste management or environmental practices as a result of the initial visit, and some businesses make numerous changes (Galvin 2001). The LDW area has been included in the general coverage of the program, in addition to targeted efforts for all auto body and repair shops, machine shops, photo labs, and dry cleaners in the basin.

In addition to site visits, the program provides vouchers to qualified businesses to help defray the cost of hazardous waste management and equipment upgrading. Program staff conduct household hazardous waste education through a telephone hotline, publications, and public outreach. Also, program staff respond to complaints about pollution incidents related to hazardous materials. The program also provides fixed facilities and mobile services for household hazardous waste collection and disposal.

The Regional Hazardous Waste program will conduct follow-up activities in the Diagonal drainage basin to support the early action cleanup proposed for the Duwamish / Diagonal CSO / SD consistent with the LDW source control strategy. Past business inspections in the Diagonal CSO / SD drainage basin will be identified and compared with current business lists. This information will be used to identify the need for new site visits and to coordinate with the inspection data from both the stormwater and IW inspection programs. In 2003, efforts will be made to focus revisits and to visit new businesses within the Diagonal CSO / SD drainage basin and move on to additional early action sites when identified.

4.3.3.5 Site investigation and cleanups

Ecology maintains a CSC site list, as described in Section 4.3.1.1. Both Ecology and EPA have programs to investigate and cleanup contaminated sites (MTCA and RCRA, respectively).

Consistent with the process developed under the source control strategy, Ecology will coordinate the identification and initiation of site investigations at upland sites deemed to have a significant potential source to targeted remediation sites. The goal will be to control sources in a timely manner to avoid recontamination of remediated sediment sites in the LDW. Ecology will determine the most appropriate regulatory vehicle to use at a site and initiate negotiations with the appropriate parties. Sites that could contribute chemicals of specific concern to early action areas will be prioritized. Sites identified as an ongoing source of a chemical of specific concern to an identified LDW remedial action site will have cleanups initiated under the appropriate program.

4.3.3.6 Industrial and municipal NPDES programs

The NPDES program, as described in Section 4.3.1.1, is the key program for controlling chemicals discharged to waters of the state. Currently, not all facilities with NPDES permits are required to monitor their discharges. However, beginning in the second quarter of 2003, all industrial facilities with NPDES stormwater permits will be required to conduct quarterly monitoring of authorized discharges to surface water (Ecology 2002c). Storm water must be analyzed for turbidity, pH, total zinc, and oil and grease at all facilities. If the value for total zinc exceeds the benchmark value of 117 µg/L for two consecutive quarters, copper and lead must be analyzed as well. Additional monitoring parameters are required as specified by industrial group (Ecology 2002c).

If necessary, Ecology may use the information gathered during the implementation of the Source Control Plan to modify discharge conditions of those permittees discharging to the LDW. Discharges containing chemicals of specific concern will be evaluated and modified as necessary to ensure that cleanup sites will not be recontaminated. Priority will be on early action sites and will eventually target the final cleanup decision goals. Most of the activities under these permits that reduce chemicals in discharges have been discussed above. Several additional components are presented below.

Industries covered by Ecology's NPDES stormwater permits are required to develop and implement a Storm Water Pollution Prevention Plan (SWPPP). The SWPPP for industrial facilities is a documented plan to identify, prevent, and control the contamination of stormwater discharges. As an initial source control step, Ecology has implemented a detailed review of the adequacy of all SWPPPs in the LDW drainage basin and their stage of implementation. Ecology has reviewed 74 SWPPPs for facilities within the LDW basin (Ecology 2002b). Also, Ecology is working with some of the industries to update their plans to provide acceptable controls and to develop compliance schedules for full implementation.

As part of City and County NPDES permits, Ecology requires “the greatest reasonable reduction of combined sewer overflows at the earliest possible date” (WAC 173-245-010). Ecology also requires CSO plans specifying the means of complying with the regulations. King County and the City of Seattle both have plans for reducing CSO inputs to the LDW. Since about 1983, King County has reduced the annual overflow of combined sewage in all county CSOs by 35%, and is committed to reducing this volume further in the years ahead (Brown and Caldwell 2000). King County has plans for reducing volumes at five CSOs in the LDW in the next 25 years (Michigan, Brandon, 8th Ave S, W Michigan, and Terminal 115). The reduction plans include conveyance expansion or increased storage capacity (Brown and Caldwell 2000). In the City of Seattle’s CSO Reduction Plan, the Diagonal CSO was identified as one of the six priority outfall areas in the city for reducing CSO volumes (City of Seattle 2002b); no other CSOs in the LDW were identified as priority areas. The city is currently identifying specific strategies, costs, and schedules for controlling overflows in these priority areas.

In addition to the individual CSO control projects undertaken by the County to reduce CSO flow, there was also a large system-wide project implemented to reduce CSO overflows at all points in the collection system. This system was originally called the CATAD (Computer Augmented Treatment and Discharge); it uses pipe storage to reduce the volume of CSO flow that is discharged. A control system allows regulator gates to be kept closed a longer time, which stores CSO flow in the pipes until they are filled. This storage delays the time when the CSO starts and ultimately reduces the volume of CSO discharged. This system has been improved with more computer technology, which optimized the storage capacity over the entire system by using rain sensors to predict where in the system the CSO flows are likely to occur.

4.4 FATE AND TRANSPORT OF SEDIMENT AND SEDIMENT-ASSOCIATED CHEMICALS

This section describes processes related to fate and transport of sediment and sediment-associated chemicals in the LDW. Organic compounds, metals and organo-metallic COPCs have been identified in the Phase 1 ERA and HHRA (Appendices A and B). The physical-chemical properties of the COPCs affect their distribution between sediment and water, as well as the length of time that these COPCs remain in the LDW. These chemical properties have a strong influence on the potential for exposure of humans and ecological receptors. In addition, the extent to which chemicals bind to sediment particles, combined with information regarding sediment transport and stability, can be used to assess the potential for existing contaminated sediment to be transported to other locations within the LDW. To assess these issues, this section presents a brief overview of partitioning and fate processes of sediment-associated chemicals[62] in the LDW, followed by a more detailed summary of existing data regarding sediment transport. This section also includes a conceptual

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[62] The fate and transport of chemicals in groundwater is discussed in Section 4.3.2.4

model of sediment transport based on a compilation of information from previous studies and reports.

4.4.1 Chemical partitioning to sediment

No site-specific studies of chemical partitioning to sediment or chemical degradation have been conducted for the LDW. The processes summarized below based on numerous studies reported in the literature are generally applicable to the LDW.

4.4.1.1 Organic compounds

Nonpolar organic compounds (e.g., pesticides, PCBs, PAHs) generally have a strong affinity for sediment particles. This association with sediments has important implications for the mobility and bioavailability of these chemicals. Chemicals that are strongly associated with sediment particles are less mobile and bioavailable than chemicals with high water solubility. However, the decreased mobility of chemicals associated with sediments may result in long-term exposure to human and ecological receptors via sediments. In addition, sediments can function as an ongoing source of chemicals to porewater and to surface water as sediment-bound chemicals partition into water or if sediments are resuspended.

The distribution of nonpolar organic chemicals between sediment and water is described as partitioning. The partition coefficient, K_d, is simply the ratio of the concentration of a chemical in a solid phase to the corresponding aqueous phase concentration. Therefore, chemicals with large partition coefficients are much more strongly associated with solid phases such as sediment relative to their aqueous concentration. The association of nonpolar organic compounds with sediment particles is correlated with the sediment organic carbon content (Chiou et al. 1979). Sediments with high organic carbon contents will tend to have higher chemical concentrations than sediments with lower organic carbon concentrations when they are equilibrated with the same aqueous concentration of a chemical. It is common to see sediment concentrations of these compounds compared on an organic-carbon normalized basis to provide a better indication of their bioavailability.

Volatile organic compounds, which are characterized by high vapor pressures and high aqueous solubilities, can be transported in association with groundwater or via aerial deposition. However, these chemicals have very little tendency to be associated with sediment and will tend to volatilize from water into the atmosphere.

Degradation processes for organic compounds in aqueous systems include photodegradation, hydrolysis, and biodegradation. Some organic compounds (e.g., PCBs, dioxins, certain organochlorine pesticides, and PAH compounds) are relatively harder to degrade than other compounds because of their chemical stability. HPAHs, which have 4 or more aromatic rings, for example, tend to persist in sediments. Half-lives for HPAHs range from months to years. Other semivolatile organic compounds, such as phenol and some LPAHs, are less persistent. Half lives for biodegradation of phenol range from less than one day in fresh water to 9 days in estuarine water (ATSDR 1998). For BEHP in water, half-life degradation times have been reported to range from 5 days to 1 month under oxic conditions and from 42 to 389 days under anoxic conditions (Environment Canada 1994). LPAHs such as phenanthrene and anthracene are subject to photodegradation in the water column (Nagata and Kondo 1972).

Biodegradation by bacteria and fungi may be a significant transformation process for PCBs, although the rate is slow (Alder et al. 1993). Half-lives of different PCB congeners in sediment have been estimated to range from 3 to 38 years. Degradation rates are dependent upon characteristics of the aquatic system, concentrations of nutrients, presence of particulate matter, temperature, oxygen concentration, redox potential, microbial populations, and the concentration of the chemical (Sinkkonen and Paasivirta 2000). DDT and its metabolites are also persistent; field and laboratory studies have demonstrated very little breakdown of DDT in estuarine sediments over the course of 46 days (EXTOXNET 1996).

4.4.1.2 Metals and organo-metallic compounds

In general, the fate and transport of metal and organo-metallic compounds is quite different than that described above for nonpolar organic compounds. The fate and transport of metals is primarily driven by speciation of the metal, which is a function of a number of variables, including Eh (oxidation and reduction potential), pH, salinity, temperature, and the type and concentration of available organic and inorganic ligands (i.e., chemicals, either in solution or precipitated, capable of bonding with metal ions, such as sulfate, iron oxides, or natural organic matter). Equilibrium constants and kinetics also determine whether a metal will be associated primarily with the particulate or dissolved phase. The dissolved speciation and sorption of metals to solids affect their bioavailability and subsequent toxicity.

Two organo-metallic compounds that have been identified as COPCs for the LDW are mercury and TBT. Mercury can be methylated by sulfate-reducing bacteria in anaerobic sediments, potentially increasing its bioaccumulation potential compared to inorganic mercury. The production of methylmercury is linked to the production and degradation of carbon within a specific area. High rates of carbon production can result in greater areas of anaerobic sediments and higher rates of mercury methylation. TBT is a manufactured additive to antifouling paints that may be released as a result of spills of paints containing TBT as well as the sandblast grit used in the removal of TBT-containing paints from ships. TBT is also a component of slimicides. Organo-metallic compounds have properties associated with both organic and inorganic chemicals, and are more easily bioaccumulated than the corresponding metals. In addition, these compounds can be associated with sediment organic matter as a result of partitioning in organic matter (Meador 1997) or interactions with inorganic functional groups associated with sediment particles (Arnold et al. 1998).

Many metals form insoluble hydroxide precipitates, especially in environments with high pH. As pH decreases, the solubility of these hydroxide precipitates increases.

Metal ions may bond with molecules to form metal-ligand complexes, such as complexation with natural organic compounds like humic and fulvic acids, and thus can be more mobile in environments with high dissolved organic carbon concentrations. Metal ions may also adsorb onto clay and oxide minerals because of negative charges on their surface. Ion exchange may also occur at the particle surface, where metal ions of one element replace those of another element because of different properties of the element or environmental conditions. The oxidation state of the metal ion influences the speciation of the metal. Reduced iron and manganese species are soluble, whereas oxidized forms of these metals are in the particulate form and tend to also sorb other metals to their surface.

For several divalent metals (i.e., cadmium, copper, lead, nickel, and zinc), a key factor controlling cationic metal activity in sediments appears to be acid-volatile sulfide (AVS) (DiToro et al. 1991, 1992; Carlson et al. 1991; Allen et al. 1993). These metals form relatively insoluble complexes with sulfide, and therefore the presence of sulfide (especially in reducing environments such as subsurface sediments) may serve to bind these metals and make them less bioavailable. Simultaneously extracted metals (SEM) and AVS measurements can be made to assess the potential solubility of these metals.

4.4.2 Sediment transport

Sediment transport within the LDW is influenced by many variables, including hydrodynamic forces attributable to the salt wedge, sediment loading from upstream and upland sources, channel morphology, and resuspension processes, such as propeller scour, bioturbation, bed shear stress, and dredging. Sediment transport may be quantified through the use of numerical models, but empirical evidence based on detailed bathymetric comparisons is also useful for identifying areas subject to net erosion or deposition between survey dates. This section summarizes the results of previous sediment transport investigations within the LDW, and discusses the degree to which the key variables identified above may influence sediment transport within the LDW. No fate and transport modeling was conducted during the Phase 1 RI. The need for such modeling during the Phase 2 RI will be determined during the development of the Phase 2 RI work plan.

4.4.2.1 Previous investigations

Numerous studies of sediment deposition and transport within the LDW have been performed over the past several decades. The type of sediment transport information obtained from these studies is summarized in Table 4-16.

The remainder of this section summarizes sediment transport conditions in the LDW based on a review of the studies listed above, and additional analysis of sediment resuspension potential, bioturbation, sediment loading, current velocity profiles, and bathymetry data performed for the Phase 1 RI.

Table 4-16. Sediment transport studies within the LDW

AUTHOR AND DATE	PORTION OF LDW	TYPE OF SEDIMENT TRANSPORT INFORMATION
Santos and Stoner 1972	Salt wedge extent (approximately RM 4.5)	Suspended sediment load, sediment bedload
Stevens Thompson & Runyan 1972	Navigation channel	Suspended sediment load, sediment bedload, areas of deposition, sediment accumulation rates
Harper-Owes 1981	Entire LDW	Suspended sediment load, relative suspended sediment inputs
Harper-Owes 1983	Entire LDW	Suspended sediment load, relative suspended sediment inputs, sediment accumulation rates
Weston 1993	South of Harbor Island to approximately RM 1.0	Sediment traps and radioisotope dating of sediment cores
McLaren and Ren 1994	Navigation channel bottom	Sediment transport direction, areas of erosion, deposition, or dynamic equilibrium
King County 1999a	Entire LDW	Sediment erosion potential; deposition rates for grid areas within the LDW calculated from sediment mass balance/hydrodynamics
Pentec et al. 2001	RM 2.9 to 3.7 (east bank)	Sediment erosion and recontamination potential
King County 2001b	RM 0.3 to 1.0 (east bank)	Sediment natural recovery, erosion and recontamination potential

4.4.2.2 Sediment input

Harper-Owes (1983) compiled and synthesized the available flow and suspended sediment loading data collected within the LDW over a 20-year period from 1960 to 1980. During this period, the Green River upstream of Tukwila was the predominant source of sediment loading to the estuary, contributing approximately 99% of the total sediment load entering the LDW. The other 1% was contributed from local sources along the LDW such as discharges and runoff. Most of the sediment input to the LDW (as well as output from the system) occurred during peak flow events, as indicated by the observed flow versus suspended solids loading relationship presented in Figure 4-5. Sediment loads measured in the Duwamish River at Renton Junction (RM 12) covary with stream flow; higher flows carry significantly greater amounts of material (Harper-Owes 1983). Approximately 25% of the Green River sediment input at Tukwila occurred as bedload, or coarse sand and gravel particles that roll along the river bottom during high flow events (Santos and Stoner 1972).

Suspended sediment inputs and transport pathways in the LDW have been monitored and evaluated by King County during two investigations (Harper-Owes 1983; King County 1999a). While upstream inputs to the LDW from the Green River dominate sediment inputs to the system, most of this input subsequently deposits within the LDW, particularly in the vicinity of Turning Basin 3 (Harper-Owes 1983). The distribution of that deposition is discussed in Section 4.4.2.3. The finer fractions that remain suspended long enough are transported out of the system in the surface layer. The average total suspended solids (TSS) concentration of surface water discharged from the LDW mouth is relatively low, ranging from 10 to 25 mg/L (average = 18 mg/L).

4.4.2.3 Sediment deposition

As reported by Harper-Owes (1983), the LDW system has been a net sink for sediments (i.e., depositional environment) during the river flow conditions measured (Figure 4-5). On average, the LDW retained approximately 90% of the total incoming sediment load during the 1960 to 1980 period.[63] Sediments deposited within the LDW have either contributed to steady accretion of the bed (see below), or have been removed from the system (disposed off-site) through routine channel maintenance dredging operations.

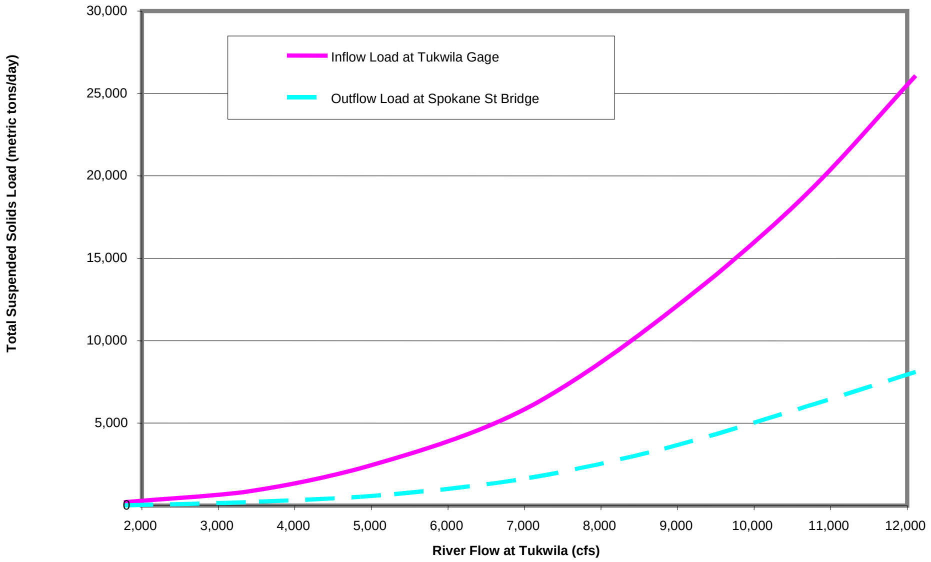

Figure 4-5. Total suspended solids loading as a function of river discharge into the LDW (1960-1980)

Source: Adapted from Harper-Owes (1983). Sediment inputs at Tukwila calculated based on flow-class analyses of detailed monitoring data collected by USGS during 1963 to 1966. Sediment outputs at the Spokane Street bridge based on salt balance analyses and King County (Metro) monitoring data collected over the same general period (1960 to 1970).

One of the most important factors for determining whether a river is more depositional or erosional in nature over a broad scale is channel morphology. Rivers modify their form over time in response to changing flow conditions and sediment delivery. Channel geometry metrics (i.e., channel width, flow depth, cross sectional

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[63] At low flows, the mass balance analysis indicates approximately 95% of the solids are deposited; at peak flows approximately 70% of the solids are deposited. The 90% figure reported by Harper-Owes (1983) is a weighed average calculated using data from Figure 4-4 and the observed flow frequencies.

area, meander patterns) correlate strongly with discharge over a wide range of scale and geographic location (Leopold and Maddock 1953; Leopold et al. 1964). This correlation suggests that for a given set of conditions (e.g. discharge, drainage area, sediment supply, river valley gradient, etc.) a river will assume a “preferred” form. The river may depart from this form in response to disturbance, but over time it will modify itself through sediment transport processes to reassume a condition that matches channel morphology to the constraints and drivers imposed by the drainage basin.

The LDW in its present form is an engineered navigation channel located at the downstream end of a highly modified and engineered drainage basin. The present configuration, past construction, and ongoing maintenance of the LDW constrain the geomorphic processes that shape the river channel. On this man-made template, natural processes physically reconfigure the riverbed through sediment transport and deposition.

The engineered channel is substantially larger than the natural channel one would expect the river to form within this setting. The cross sectional area of the channel increases substantially downstream so that the constructed and maintained channel near the First Avenue South Bridge (RM 2.1) is approximately 100 times larger than the natural river channel at RM 12. Cross sectional areas in the reach from Renton Junction (RM 12) to the East Marginal Way Bridge (RM 5.0) range between 20 and 100 m^2. By comparison, the channel cross section at its widest point near the river mouth is greater than 3,000 m^2 (Stoner 1972).

Rivers of similar scale located in western Washington also provide a useful point of comparison. The US Geological Survey (USGS) maintains long-term stream flow monitoring stations on many rivers in this region and throughout the United States. Local channel cross sections are surveyed regularly as part of the maintenance of these stations. Figure 4-6 superimposes surveyed river cross-sections for the Duwamish/Green River and three other western Washington rivers. Four of the cross-sections shown were selected specifically because they are located within the zone influenced by a large receiving water body. The cross-sections for Green River at Auburn and Duwamish River at Tukwila provide context for the discussion by showing river cross-sections located on the same river system upstream of the LDW. The Puyallup River and Nooksack River both discharge to tidally-influenced water bodies. The Cedar River discharges to a large receiving water body (Lake Washington) that experiences seasonal water elevation variations but is not tidally influenced.

The cross sections shown correspond to the water surface elevation for flow events of approximately 1,200 cfs. The water surface elevation for the Duwamish RM 4.5 cross section corresponds to an extreme low tide to minimize the influence of tides in the cross section comparison. Some local factors that influence the size and shape of the channel cross section cannot be completely controlled or eliminated through careful site selection. Even so, the Duwamish channel cross-section at RM 4.5 is grossly larger than any of the cross sections for any of the other rivers of similar scale.

Given that the LDW channel is artificially enlarged in comparison to the natural channel that would form in this setting, one would expect the channel to progressively grow smaller over time as the river approaches a condition that balances channel form with discharge and sediment delivery. If left alone, this is exactly what would happen. The steady accumulation of sediment within the LDW has required the ACOE to perform regular maintenance dredging to maintain the navigable waterway.

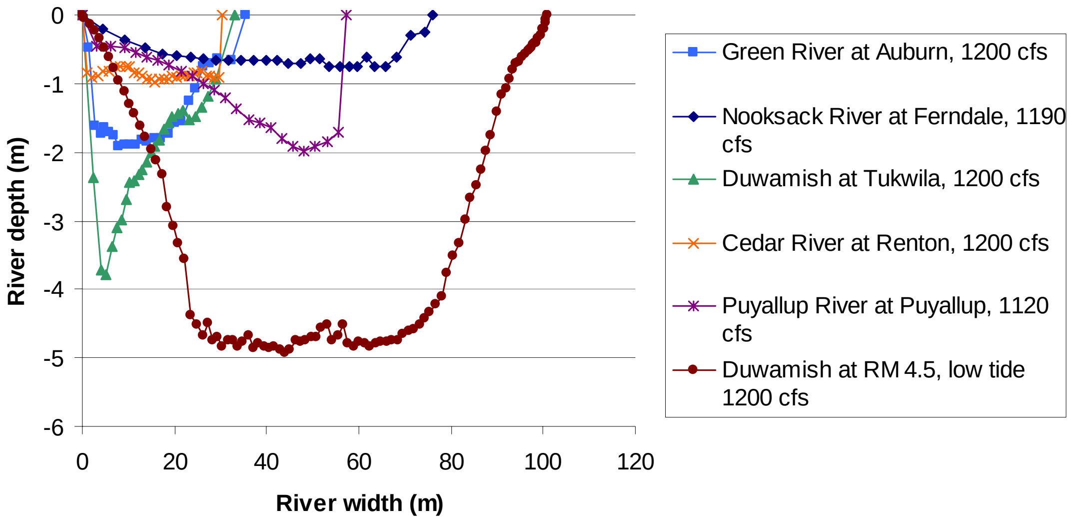

Figure 4-6. **Cross sections for western Washington rivers compared at approximately 1,200 cfs**

Geomorphic conditions within the LDW will continue to be dominated by sediment deposition as long as the channel is maintained to be larger than the channel that would naturally form in this setting.

Hydrodynamics within the LDW, specifically the location of the salt wedge, control the location of bedload deposition and shoaling within the LDW (STR 1972, Harper-Owes 1983). When fresh river water encounters the upstream end of the LDW salt wedge, the fresh water no longer applies a shear stress to the riverbed, but instead applies a stress to the top of the salt wedge. Because the salt wedge normally extends to Turning Basin 3, bedload typically deposits within this area. Salinity also affects settling of cohesive sediment by increasing particle flocculation. Turning Basin 3 is specifically designed and managed to provide a settling basin for the bulk of the bedload sediment coming downstream from the undredged portions of the Duwamish

River. The ACOE focuses its maintenance dredging on Turning Basin 3 and its immediate vicinity to minimize siltation of the navigation channel downstream.

Historical (1960 to 1980) sediment accumulation rates for areas within the LDW have been characterized through: 1) channel condition maps from 1965-1970, and 2) sediment loading mass balance data (STR 1972; Harper-Owes 1983). As discussed by Harper-Owes (1983), both lines of evidence yield similar sediment accumulation estimates for a given location within the navigational channel. Average (1960 to 1980) accumulation rates varied markedly over the LDW, with highest values (to approximately 100 cm/yr [39 in./yr]) reported at the head of navigation, declining to values ranging between 1 and 50 cm/yr (0.4 and 20 in./yr) throughout the rest of the LDW (Figure 4-7, Table 4-17).

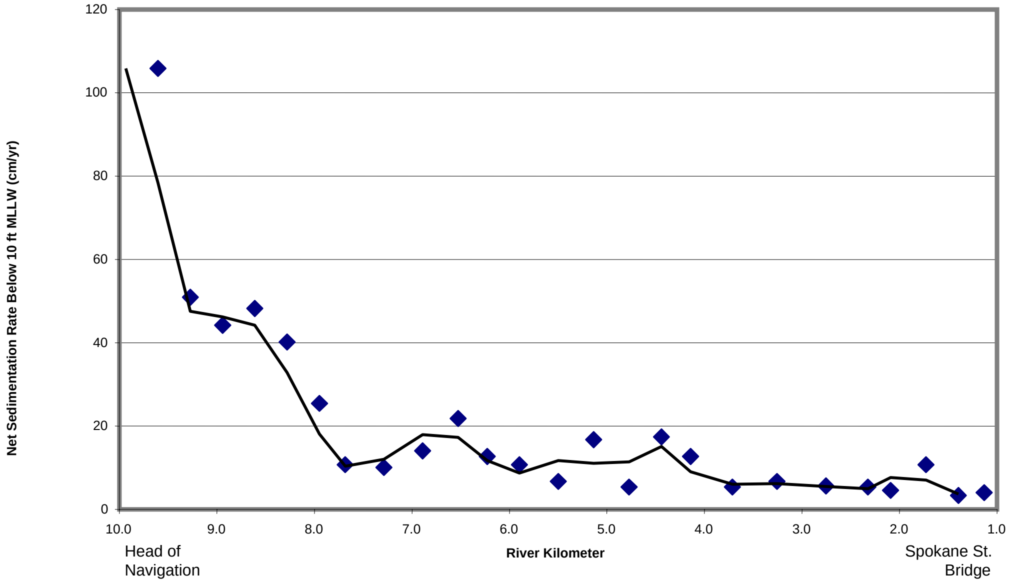

Figure 4-7. **Longitudinal variation in net sedimentation rates within the LDW navigation channel (1960-1980)**

Source: Adapted from Harper-Owes (1983)

Table 4-17. Annual sediment accumulation rates reported for the navigation channel in the LDW study area

REACH	(CM/YEAR)	(DRY KG/YR X 10^6)
16th Ave. Bridge to Turning Basin 3 (RM 3.4 to RM 4.7)	20 – 110	113
Slip 2 to 16th Avenue Bridge (RM 1.7 to RM 3.4)	10 – 25	36
Harbor Island to Slip 2 (RM 0 to RM 1.7)	1 – 15	38
West Waterway	1 – 5	12
East Waterway	1 – 5	13

Source: Harper-Owes (1983)

During the mid to late 1960s, approximately 120,000 cubic yards per year of sediment accumulated and were dredged in the LDW reach between Turning Basin 3 and the 16th Avenue Bridge (RM 4.7 to 3.4; STR 1972). Similar quantities of sediments accumulated and were subsequently dredged from this area during the 1970s and 1980s (Harper-Owes 1981; Harper-Owes 1983). However, during the past 10 years, dredging rates have declined to approximately 50,000 to 60,000 cy/yr; dredging of Turning Basin 3 now commonly occurs every other year (Kendall 2002).

Differential settling rates of incoming material appear to result in marked gradients of particle size within the LDW, particularly near the upper turning basin where relatively coarse bedload is deposited (see Map 2-2). Sand deposits are also present adjacent to CSO and storm drain discharges (Weston 1999). Finer-grained silty sediments are typically located in remnant mudflats, along channel side slopes, and throughout most of the federal navigation channel.

Sediment transport along the bottom of the navigation channel was evaluated by McLaren and Ren (1994) using Sediment Trend Analysis, which uses detailed data on sediment grain size to identify potential areas of erosion, stability, and deposition. The methods employed by McLaren and Ren are based on the theory that changes in sediment grain size can be used to infer the direction of sediment transport as well as the relative importance of accretion and erosion processes. Samples were collected only from the dredged channel, which resides at a lower elevation than benches along either side of the channel. The deeper portion of the channel is likely to be more saline and thus more highly influenced by the tides, whereas the benches are more likely influenced by both tidal and riverine processes.

The authors found that for the most part the navigation channel was either subject to net deposition or in dynamic equilibrium. The authors suggested that within the lower portions of the LDW (from Harbor Island to Slip 2), fine sediment appeared to have a net residual transport downstream, but a pattern of net upstream transport of fine-grained sediment particles may be occurring from Slip 3 to Turning Basin 3. McLaren and Ren (1994)concluded that results from the upstream portion of the LDW should be viewed as preliminary because of limited numbers of samples and difficulties in data interpretation, and that “the transport trends in this region [upstream of Slip 3] should not be considered very reliable.” There are no other empirical data to confirm the conceptual transport model for fine-grained sediment particles postulated by McLaren and Ren (1994).

4.4.2.4 Sediment erosion potential

Sediment erosion potential is determined by channel morphology, current speed, and sediment cohesiveness. In addition, episodic events such as dredging and propeller scour, and ongoing processes such as bioturbation, can also influence sediment erosion. The discussion of channel morphology presented in Section 4.4.2.2 suggests that significant erosional events affecting the entire LDW are unlikely once the river enters the man-made navigation channel at Turning Basin 3.

Sediment resuspension and movement may occur during relatively infrequent high current velocity events, such as during certain ebb and flood tide portions of the tidal cycle, storm surges, dredging, or as a result of propeller scour. Tidal, storm, or propeller scour forcing can potentially increase velocities in both the upper and lower layers. Dredging can mechanically reintroduce sediment into the water column.

Dredging and propeller scour, or other erosive forces, can potentially increase the suspended solids concentration on a local scale. These suspended particles would then settle to the bottom at a distance dictated by their size, ambient currents, and the distance above the bottom they were resuspended. Based on typical current and dispersion characteristics in the vicinity of the Duwamish / Diagonal CSO / SD (RM 0.3 to 1.0), resuspended silt-sized particles could be transported a distance up to approximately 400 m (1,300 ft) from the point of propeller erosion, depending on the height of resuspension above the sediment surface (King County 2001b). Thus, water column TSS concentrations could potentially be increased up to roughly 400 m from the point of propeller scour and dredging, or other erosive force.

The actual transport at a particular location would be the result of the ambient currents in the lower water column, which is dominated by the tidal prism, as discussed in Section 2.2.5. Thus, because the current along the bottom varies in speed and reverses during the tidal cycle, the distance suspended sediment would be transported from any location would likely be much smaller than if flow were unidirectional. The likelihood of exceeding erosional velocities and the relatively low rates of sediment resuspension within the LDW, even on a local scale, are discussed further below.

Sediment erosion is characterized by a critical value, called the critical shear stress for initiation of motion, at which a significant number of particles on the bottom begin to erode under an applied force. Although there are various hypotheses and a number of computational procedures available to estimate such a bottom sediment threshold parameter, empirical approaches using sediment flumes are often used to observe sediment movement, either in the laboratory or in situ. No sediment flume studies have been conducted in the LDW, but a 1985 in situ flume study conducted just west of Duwamish Head outside Elliott Bay (Striplin et al. 1985) provided data that were used by the Puget Sound Dredged Disposal Analysis program (PSDDA 1988a, 1989) to identify dispersive and non-dispersive dredged material disposal sites throughout Puget Sound. For the purposes of the Phase 1 RI, the results of this study will be used to discuss current velocities associated with bed sediment movement. Additional work may be conducted in Phase 2 to provide additional empirical data for the LDW on this topic.

Striplin et al. (1985) deployed an underwater video camera attached to a two-sided flume chamber that was placed on the sediment surface at various locations within the study area. Voltage applied to a shipboard-activated motor drew water from the flume chamber through the cylinder mounted above one end of the flume. The voltage at which any visible movement first occurred and when the sediment bed first moved was recorded and later converted to water velocity (Striplin et al. 1985).

The flocculant material observed to initially move within the flume has been called the bottom nepheloid layer by Puget Sound researchers (e.g., Baker 1984). This nutrient- and particle-rich layer is present throughout the year and is maintained at a given location at all stages of a tidal cycle (Baker 1984). Because this layer is not maintained by resuspension from the sediment bed, it is often characterized in a conceptual model with surface water rather than with sediment.

The results from Striplin et al. (1985) are presented in Table 4-18. Eighteen measurements were made in six different regions varying in depth and grain size characteristics. Velocities at which any movement was first observed ranged from 23 to 50 cm/s; velocities for bed sediment movement ranged from 48 to 80 cm.

Table 4-18. Calculated bottom velocities associated with initial and bed sediment movement in Elliott Bay flume study

STATION GROUP	WATER DEPTH RANGE (M)	SEDIMENT TYPE	VELOCITIES FOR INITIAL MOVEMENT (CM/S)	VELOCITIES FOR BED SEDIMENT MOVEMENT (CM/S)
A	11 – 13	Sand	29 – 35	> 52 – 62
B	37	Silt	40	> 57
C	69 – 80	Fine sand/silt	23 – 28	57 – 78
D	130 – 134	Very soft silt	30 – 50	48 – 80
E	191 – 192	Very fine	41 – 44	61 – 76
F	8 – 14	Sand with diatoms	35 – 45	> 61 – > 73

Source: Striplin et al. (1985)

Although flume studies of this type are site-specific because of the many different variables that influence sediment transport, the data presented by Striplin et al. (1985) suggest a range of 40 to 60 cm/s for initiation of bed sediment movement. The mineralogic characteristics and bulk density of the sediments tested by Striplin et al. (1985) were not reported, so it cannot be determined how they compare to similar characteristics of LDW sediments.

Knowledge of current velocities within the LDW, based on a combination of field and modeling studies, is required to perform an evaluation of sediment erosion potential. Recent field studies conducted within the LDW provide data to characterize net flow velocities and short-term velocity fluctuations within the upper (freshwater) and lower (saltwater) layers in the LDW (King County 1999a). During the King County WQA, current measurements were obtained at 15-minute intervals at stations SBW (RM 1.1) and BOE (RM 3.5) using acoustic Doppler methods during August to November 1996. The maximum flow recorded during this period at the Auburn USGS gage was approximately 140 m^3/s (5,000 cfs).

Figure 4-8 shows vertical profiles of observed and predicted mean (i.e., long-term net) along-channel velocities at station SBW. The predicted velocities are based on output from King County's LDW hydrodynamic model, and agree reasonably well with the measured velocities. The velocity profiles show a net seaward flow (positive values) in the upper layer (i.e., from 0.5 to 1.0 on the y-axis of Figure 4-8, representing the upper half of the water column) and net upstream flow in the lower, saline layer (i.e., from 0 to 0.5 on the y-axis of Figure 4-8, representing the lower half of the water column). The observed mean flows reflect the circulation portrayed schematically in Figure 2-1. Velocity patterns at station BOE (not shown) are similar to those shown in Figure 4-8, but velocities at BOE were 5-10% less than velocities at SBW.

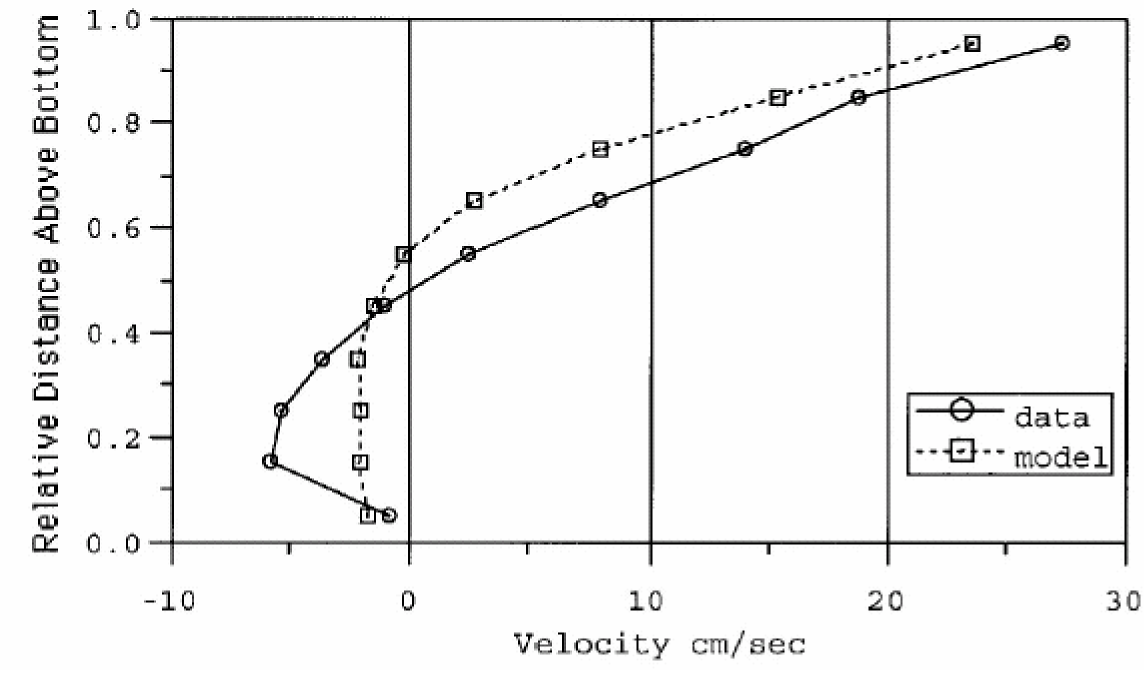

Figure 4-8. **Mean along-channel velocity at Station SBW (King County 1999a)**

The most definitive data available to assess the potential for sediment erosion within the LDW are the acoustic Doppler current meter measurements discussed above (King

County 1999a), but considered individually and not as time-averaged results calculated over one complete tidal cycle. The individual measurements of current velocities provide an instantaneous measurement that integrates the combined effects of tidal forcing, storm surges, and propeller scour. The cumulative frequency distributions of bottom water speeds measured at stations SBW and BOE are summarized in Figure 4-9. The plot is based on approximately 12,000 measurements of instantaneous velocity obtained approximately 1 m (3 ft) above the sediment bed, collected at 15-minute intervals. No bottom water speed greater than 60 cm/s (2.0 ft/s) was observed during the recording interval; the 50th, 90th, and 95th percentile speeds were 17, 33, and 37 cm/s, respectively, for station SBW, and 15, 30, and 34 cm/s, respectively, for station BOE.

Based on the measured velocity distribution, bottom (i.e., 1 m or less above the bottom) currents exceeded 40 cm/s less than 3% of the time at stations SBW and BOE. Based on an integration of the observed velocity distribution (Figure 4-9) with the flume study results presented above, sediment resuspension does not appear to be a process that affects the entire LDW during the measured flow conditions.

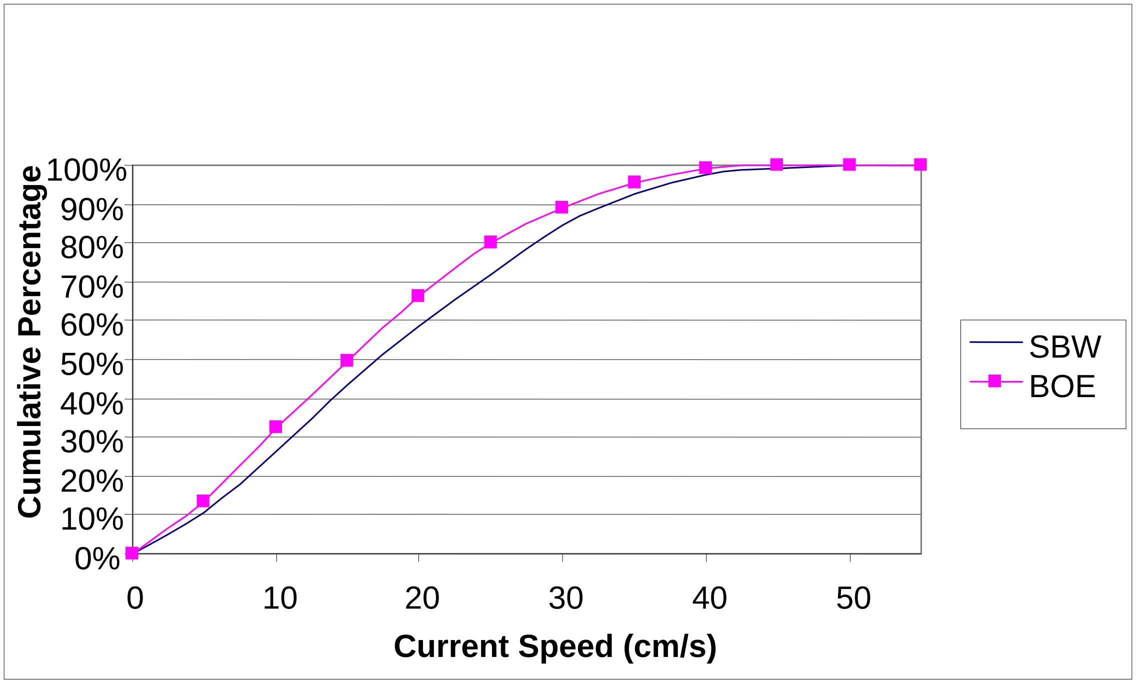

Figure 4-9. **Cumulative frequency distribution of bottom currents at stations SBW and BOE (King County 1999a)**

The analysis of current speeds recorded by the two King County meters (i.e., SBW and BOE), coupled with the assumed threshold current for bed sediment movement (i.e., 40 to 60 cm/s, suggests flow rates less than 140 m^3/s are unlikely to cause system-wide sediment transport. However, river flows commonly exceed 280 m^3/s. One-day average flow exceeded 280 m^3/s ten times between 1960 and 2000. Current measurements associated with these extreme flows have not been recorded, so the probability of sediment movement during these events cannot be estimated empirically.

To provide an approximation of flow velocities and sediment transport during peak flow events, the unsteady flow model HEC-RAS[64] was applied to LDW RM 0 to RM 4 using a flood hydrograph derived from a 336 m^3/s flow event on February 8, 1996 (Cherry 2003) to model the flow velocities from RM 2.8 to RM 4. This flow event represents the largest possible flow under the flow regulation provided by the Howard Hanson Dam. HEC-RAS is a one-dimensional flow model that is not capable of modeling stratified flow, and therefore, does not provide reliable velocity predictions at locations where the salt wedge is present and in general can only provide approximate results when applied to estuarine systems.

For the purposes of the Phase 1 RI, the existing HEC-RAS model was used to provide an approximation of flow velocities under a carefully defined scenario within a limited reach of the LDW. Under this scenario, high flow conditions within the river have been shown to push the salt wedge far enough downstream that stratified flow does not occur within the reach of the river under consideration (i.e., between approximate RM 3 and 4; RK 6.4 in Santos and Stoner 1972).

During peak flow conditions, tidal fluctuations continue to drive water surface elevations within the LDW even though the salt wedge is not present within the river reach under consideration (i.e., between approximate RM 3 and 4). The unsteady boundary conditions for the model were set to represent the rising and falling tide elevations at the downstream boundary of the modeled reach and the rising and falling flood hydrograph at the upstream boundary. This configuration of the boundary conditions resulted in a peak flow within the modeled area larger than 12,000 cfs because the rising and falling downstream water surface elevation added the discharge associated with the tidal prism to the discharge associated with peak river flow. The maximum instantaneous discharge value modeled coincides with the peak flood discharge occurring at the same time as a falling tide.

It is recognized that the salt wedge would drive the unsteady downstream boundary conditions of the model even if the salt wedge were not present within the river reach targeted for analysis. The sensitivity of the model to the presence of a salt wedge was evaluated by configuring the model to represent the salt wedge by blocking a portion of each cross section downstream of RM 2.8 corresponding to the reported location and depth of salt water intrusion during low tides and high rates of flow (RK 6.4 in Santos and Stoner 1972). For high flow conditions, the water surface elevation and

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[64] A HEC-RAS model was previously configured for a limited reach of the Lower Duwamish Waterway for a peak flow scenario as part of the evaluation of cleanup alternatives at Boeing Plant 2. EPA provided several comments on the model, which have not yet been resolved. They will be resolved in the design phase.

velocities upstream of RM 2.8 predicted by the model were not significantly affected by the presence of the salt wedge downstream. At lower flows (closer to average daily conditions), the salt wedge is present throughout the entire modeled reach, and the usefulness of the model results is therefore limited. At lower flows, the presence of the salt wedge influences flow velocities in ways that cannot be represented by a one-dimensional model such as HEC-RAS. At such flows, the flow velocities associated with river flow and tidal velocities have been directly measured by other researchers (King County 1999a; Santos and Stoner 1972). Based on a comparison of published velocity measurements and modeled peak flow velocities, the authors concluded that intermediate flow and low flow conditions would only produce flow velocities smaller than those modeled for the peak flow scenario coinciding with a falling tide (Cherry 2003). The HEC-RAS model predictions discussed here apply only to a very specific scenario designed to represent a flow condition that would produce the highest velocities associated with river flow in a limited reach of the river. This modeling approach does not reliably predict the high flow velocities in other sections of the river, where stratified flow is present further downstream or at lower flow conditions throughout the waterway. Assessment of such conditions will be evaluated in the Phase 2 RI with a multi-dimensional model.

Although HEC-RAS, as a one-dimensional flow model, does not solve the two-dimensional depth-averaged equations of motion, the software package can be configured to provide a first order approximate estimate of cross-channel variations in depth-averaged velocity. The results of the estimation are dictated by variations in flow depth across the channel such that velocity variation will mirror depth variation. Using this component of the software package, HEC-RAS was configured to provide a first order approximate estimate of depth-averaged velocity for 10 equally spaced points across the channel at each cross section. Predictably due to drag, the fastest velocities correspond to the deeper navigation channel at the center of the LDW, and diminished velocities correspond to shallow areas along the perimeter of the LDW.

The highest modeled velocities correspond with peak flow near 336 m^3/s coinciding with a falling tide. For this condition, the largest modeled depth-averaged velocity value of 122 cm/s occurs at the center of the navigation channel in a relatively narrow cross section located at approximate RM 3.7. Between RM 2.9 and RM 3.5, there exists an intertidal bench on each side of the LDW along the margins of the navigation channel. Maximum depth-averaged velocities within cross-sections in this reach peak at approximately 91 cm/s at the center of the navigation channel. Estimated depth-averaged velocity values over the intertidal benches vary from 40 cm/s at the edge of the navigation channel to zero at the edge of water. Estimated maximum depth-averaged velocity is less than 30 cm/s over 90% of the intertidal zone. Although conservative modeling assumptions were employed wherever possible to account for uncertainties, the potential error associated with predicted velocities remains unquantified.

The HEC-RAS model is not designed to calculate vertical velocity profiles, but such profiles were estimated using Equation 2 (Simons and Senturk 1992):

$$u = U + U^* (2.5 + 5.75 \mathrm{LOG}(y/d)) \qquad \textbf{Equation 2}$$

where:

u = point velocity (ft/sec)

U = depth averaged velocity (ft/sec)

U* = shear velocity (ft/sec)

y = elevation above riverbed (ft)

d = total flow depth (ft)

Equation 2 was used to estimate near-bed point velocity (defined as 10% of the flow depth) from modeled depth averaged velocity values from HEC-RAS. For the peak flow scenario, the estimated near-bed point velocity is 64 cm/s (2.1 ft/s) at the center of the navigation channel. Under the same flow scenario on the intertidal channel margins, the estimated near-bed point velocity is 20 cm/s (0.65 ft/s) well below the threshold current velocity for bed sediment movement estimated from the Striplin study above.

These results provide an approximation of peak flow velocities above the range of flow velocities either modeled or measured by the King County WQA. Uncertainty in the modeling results is introduced by several factors not accounted for by the HEC-RAS model. These factors include, for example, the actual influence of the salt wedge, the influence of boundary irregularities, and approximation of certain cross sections with incomplete survey data. Although conservative modeling assumptions were employed wherever possible to address these uncertainties, the potential error associated with model predictions remains unquantified. Because the large uncertainties associated with this first order approximation could result in a wide range of peak flow velocities, it is not possible to establish, at this time, under what flow conditions sediment might be mobilized in the LDW. Additional studies will be proposed in the Phase 2 work plan to determine the probability and magnitude of sediment transport during peak flow events and that future modeling efforts will not be conducted using HEC-RAS, but will involve a multidimensional model which is more suitable for conditions found within the LDW estuary.

Bioturbation by animals living in or on the sediment influences sediment fate and transport. Deposit-feeding invertebrates mix surficial sediments by their feeding strategy, thereby bringing sediments beneath the surface up to the sediment-water interface. On average, the zone within which this mixing occurs is fairly shallow. A world-wide average of approximately 10 cm (3.9 in.), with a standard deviation of 4.5 cm (1.8 in.), has been reported for a wide variety of water depths and sedimentation rates (Boudreau 1998). An identical bioturbation/effective surface mixing depth (10 cm [3.9 in.]) has also been determined throughout Puget Sound using detailed radioisotope analyses (Lavelle et al. 1985; Officer and Lynch 1989). Some infaunal organisms may burrow to depths deeper than 10 cm (3.9 in.). Such organisms are not typically found in great enough concentrations to lower this well-mixed layer in the sediment, but may offer some exchange of sediments at greater depths.

The community structure of animals that may be responsible for bioturbation in the LDW has been documented in several studies, but additional research will be conducted in Phase 2. Dominant benthic species collected from the LDW include polychaete worms, oligochaete worms, bivalves, cumaceans, gammarid amphipods, harpacticoid copepods, and aquatic insects (Table 2-7, Cordell et al. 2001). These benthic organisms are shallow burrowing infauna that generally occupy the top 20 cm (8 in.) of sediment. The deep burrowing species of thalassinid shrimp, commonly referred to as ghost shrimp (*Neotrypaea* spp.), are common inhabitants of Puget Sound. These animals are often singled out as particularly deep bioturbators in Puget Sound. *Neotrypaea* spp. are tube builders that can burrow to depths of 75 cm (30 in.), but this genus has not been observed in the LDW. Although the genus is common in soft sediment habitats in Puget Sound, it is not a common inhabitant in estuaries that experience significant fluctuations in salinities (Simenstad 2000).

Although bioturbation may decrease sediment stability in areas where deposit-feeding invertebrates are abundant, sediment stability may also be increased by biological activity, particularly in sandy environments. Biogenic alteration of the sediment-water interface, including mucus binding, other extracellular products of microorganisms, and flow modification attributable to concentrations of tubes or filaments, may create cohesive sediment that will tend to sequester sediment-bound chemicals (Grant et al. 1982).

It is difficult to generalize about the effects of bioturbation on sediment fate and transport across the entire LDW because many site-specific factors (e.g., sediment and benthic community characteristics, hydrodynamic environment) influence the importance of these processes. Additional analysis of the effects of bioturbation on LDW sediment stability and chemical fate and transport has been conducted as part of the assessment of potential remedial alternatives in two specific areas; additional research may be conducted in the future.

The two sediment cleanup designs currently underway in the LDW (Boeing Plant 2 at RM 2.9 – 3.6 and Duwamish / Diagonal at RM 0.4– 0.6) include sediment caps in conjunction with sediment removal as the selected remedial alternative. A qualitative analysis of bioturbation potential was included in the cap design process for both projects (Pentec et al. 2001; King County 2003). Based on the lack of ghost shrimp and other deep-burrowing animals in the project areas, cap thicknesses of 60 cm (24 in.) at Duwamish / Diagonal (King County 2003) and 120 cm (48 in.) at Boeing Plant 2 (Pentec et al. 2001) were considered sufficient to isolate the capped sediment from the effects of bioturbation. The analyses conducted by Pentec et al. (2001) and King County (2003) are only marginally relevant for characterizing the importance of bioturbation in the rest of the LDW, however, because remedial design objectives do not explicitly quantify bioturbation rates and magnitude. For example, bioturbation from relatively shallow depths (i.e., < 15 cm [6 in.]) can resuspend sediment, but such a phenomenon is unimportant to a design that includes a cap of much greater depth.

4.4.2.5 Empirical evidence of sediment stability

Many previous researchers have presented hypotheses, data, and models to describe LDW sediment transport and stability (Table 4-16). Some of these studies were conducted many years ago and may not reflect more recent conditions. As part of this RI, detailed bathymetric surveys conducted at various LDW locations were evaluated. When these surveys cover the same ground, comparisons between multiple surveys conducted in different years can provide empirical evidence of net sediment deposition or erosion within specific regions of the LDW.

The LDW is not uniform with respect to water depth. The federal navigation channel is periodically dredged so that depths suitable for commercial vessel traffic (4.6 to 9.1 m MLLW; Weston 1999) are maintained. Within the navigation channel, the cross-section is roughly rectangular. Transition zones with steep slopes exist at the edges of the navigation channel. Finally, shallow intertidal benches exist in some areas on either side of slopes extending from the navigation channel. Given the differences in depth and hydrodynamic regime within these three regions (i.e., channel, slope, and bench), different patterns of sediment accumulation and erosion might be expected.

Recent bathymetric data from four surveys of the upper section of the LDW (RM 2.9 to 4.2) were evaluated to identify large-scale trends of deposition or erosion. Three of the surveys were conducted by the ACOE and overlapped in the area from the upper turning basin to just south of the South Park (16th Avenue) Bridge. An additional survey was conducted as part of the investigation of the Boeing Plant 2 site in 2000. The ACOE surveys were completed in 1998, 2000, and 2001. The ACOE bathymetric surveys were conducted along transect lines spaced approximately 200 ft apart and were primarily limited to the navigation channel and the areas immediately adjacent to the navigation channel. The Boeing survey was conducted in the section of the LDW adjacent to Boeing Plant 2 (RM 2.9 to 3.5). The Boeing survey was conducted with closer transect spacing and covered the LDW essentially bank-to-bank. The Boeing 2000 survey was appended to the Corps 2000 survey to provide wider coverage in the area of Boeing Plant 2 and the South Park Bridge. All of the recent bathymetric surveys included in this analysis were conducted using a differential global positioning system with sub-meter accuracy, and a fathometer with vertical resolution finer than 0.1 m (0.3 ft).

The isopachs[65] (see Appendix C for details on isopach development) for 1998 vs. 2000, 2000 vs. 2001, and 1998 vs. 2001, are shown in Figures 4-10, 4-11, and 4-12, respectively (located in the Oversize Maps and Tables volume). These figures indicate that a

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[65] An isopach is a contour that connects points of equal thickness.

majority of the navigation channel is slowly shoaling (accumulating sediments) and that scour (loss of sediments) appears to be limited to the channel edges.

This initial analysis was based on four surveys collected over an approximately 4-year period. The spatial coverage of the surveys outside the main navigation channel was limited and did not extend bank-to-bank. A review of available historic ACOE bathymetry data for selected representative areas of the upper reaches of the LDW was conducted to provide a better understanding of the elevation changes that have occurred in and adjacent to the navigation channel. In addition, by selecting surveys that included more extensive coverage outside the navigation channel, it was possible to provide better information on the changes in elevation that have occurred on representative intertidal and shallow subtidal benches adjacent to the navigation channel.

Four areas were selected for this analysis:

- Downstream of Slip 6 (RM 3.9 to 4.1)
- Boeing Plant 2, upstream of South Park Bridge (RM 3.4 to 3.7)
- Downstream of Slip 4 (RM 2.5 to 2.8)
- Duwamish/Diagonal cleanup study area (RM 0.3 to 0.6)

These areas were selected because they all contain intertidal and shallow subtidal benches adjacent to the navigation channel. The individual surveys selected for the analysis were also chosen because of the availability of the drawings and the data presentation appeared to be compatible between years.

The data analysis for each area is presented in separate sections below. Historical maps used for the analysis downstream of Slip 6, upstream of the South Park bridge, and downstream of Slip 4 are given in Table 4-19. The ACOE stations referred to in Table 4-19 are shown in Figure 4-13 (located in the Oversize Maps and Tables volume). The horizontal and vertical resolution of the surveys listed in Table 4-19 is unknown, but is likely to be lower than that of more recent surveys conducted using modern instruments. Uncertainties associated with historical bathymetry data are discussed in Appendix Section C.2.2.

Table 4-19. ACOE bathymetric surveys used in the analysis of elevation changes in the upper LDW

YEAR	DRAWING NUMBER	DOWNSTREAM OF SLIP 4		UPSTREAM OF SOUTH PARK BRIDGE		DOWNSTREAM OF SLIP 6	
		STN. 168+00 (RM 2.6)	STN. 172+00 (RM 2.7)	STN. 210+00 (RM 3.4)	STN. 216+00 (RM 3.6)	STN. 238+00 (RM 3.9)	STN. 242+00 (RM 4.0)
1963	E-12-2.1-58					X	X
1964	E-12-2.1-60			X	X	X	X
1967	E-12-2.1-63	X	X	X	X	X	X
1970	E-12-2.1-66	X	X	X	X	X	X
1971	E-12-2.1-68	X	X				
1973	E-12-2.1-70			X	X	X	X
1974	E-12-2.1-71	X	X				
1975	E-12-2.1-73	X	X	X	X	X	X
1976	E-12-2.1-75	X	X				
1978	E-12-2.1-79			X	X		
1983	E-12-2.1-90	X	X				

Downstream of Slip 6

Stations 238+00 (RM 3.9) and 242+00 (RM 4.0) are located downstream of Slip 6 (Figure 4-13). Both stations are located along a straight section of the river and both transects are characterized by a wide intertidal bench on the east side of the LDW, with narrower intertidal areas on the west side (left and right sides of Figure 4-14, respectively, looking upstream; located in the Oversize Maps and Tables volume). The change in elevations within the navigation channel between 1963 and 1975 showed substantial accumulation of sediment with frequent periodic maintenance dredging to maintain navigational depths. Maintenance dredging was conducted within the navigation channel along this section of the LDW was dredged in 1964, 1968, and 1971, and some limited dredging was conducted upriver of Station 241+00 prior to the 1975 condition survey.

The average depth of the navigation channel in this reach was approximately -1.5 m (-4.9 ft) MLLW in 1963. During dredging in 1964, the channel was dredged to its authorized -4.6 m (15.1 ft) MLLW depth. Accumulating sediment refilled the main channel to a depth of approximately -1.5 to -1.8 m (-4.9 to -5.9 ft) MLLW by 1967. Dredging in 1968 restored the channel to the authorized navigational depth. By 1970, approximately 0.6 to 0.9 m (2 to 3 ft) of new sediment had accumulated in the channel. An additional round of dredging occurred in 1971 and by 1973 approximately 0.6 to 0.9 m (2-3 ft) of sediment had been redeposited in the navigation channel.

This pattern of sediment accumulation followed by periodic dredging was evident in cross-sections at Station 238+00 and at Station 242+00 through 1970 (Figure 4-14). The 1973 condition survey showed an additional area to the east of the authorized navigation channel near Station 242+00 that appeared to have been dredged. This additional dredged area (with depths approaching -4.6 m (-15.1 ft) MLLW) extended the width of the dredged area an additional 23 m (75 ft) to the east of the navigation channel boundary. The edge of the dredged area parallels the eastern shoreline and extends up to Slip 6. An aerial photograph taken in September 1971 used as a base map for the ACOE 1973 bathymetric survey shows a pier-like structure extending from the shoreline (identified as belonging to Monsanto Chemical) along this section of the LDW. This dredged area was still recognizable in 1975 even though significant shoaling had occurred within the presumed dredge area.

Limited dredging occurred in 1975 in the upper portion of the LDW within the navigation channel and the upper turning basin. This dredging was confined to the centerline of the main navigation channel upriver of Station 241+00 and is apparent in the 1975 cross section at Station 242+00 (Figure 4-14).

Changes in elevation on the channel slopes are limited and appear to be related to the periodic maintenance dredging conducted within the navigation channel and in separate areas adjacent to the channel. The extensive intertidal and shallow subtidal benches adjacent to the channel show little accumulation of sediments on the west or east sides of the channel.

Boeing Plant 2, Upstream of South Park Bridge

Stations 210+00 (RM 3.4) and 216+00 (RM 3.6) are located upstream of the South Park Bridge (Figure 4-13). Station 210+00 is located along a straight section of the river and is characterized by a wide intertidal bench on the left (east) side of the LDW. The right (west) side of the transect is adjacent to a marina. Station 216+00 crosses the LDW 107 m (350 ft) downstream of the bend in the navigation channel. The authorized navigation channel depth upriver of 8th Avenue (ACOE Station 175+00; RM 2.8) to the end of the upper settling basin (Station 275+00; RM 4.7) was approximately -4.6 m (-15.1 ft) MLLW. A series of cross sections of the generated surfaces from the 1964 to 1978 surveys are presented in Figure 4-15 (located in the Oversize Maps and Tables volume). Changes in elevations within the navigation channel between survey years showed substantial accumulation of sediment removed by periodic maintenance dredging to maintain navigational depths.

The survey conducted in 1964 was an after-dredge survey. The channel was dredged in 1964 to -4.6 m (-15.1 ft) MLLW plus an allowed overdredge depth. Sediment accumulation within the authorized channel exceeded 2.4 m (7.9 ft) in places by 1967, especially along the western side of the channel. Maintenance dredging of the main navigation channel was conducted again in 1968. The average channel depth was -5.2 m (-17.1 ft) MLLW in the 1970 condition survey. Approximately 1.5 m (4.9 ft) of sediment had accumulated along the western edge of the navigation channel by 1973, reducing the depth at the edge of the navigation channel to approximately -2.4 m (-7.9 ft) MLLW; by 1975 an additional 0.6 to 0.9 m (2 to 3 ft) of sediment had accumulated along the western side of the navigation channel. Dredging in 1976 restored navigational depths in the channel. The condition survey conducted in 1978 showed depths near the center of the navigation channel were -4.6 m (-5.1 ft) MLLW or greater, but some shoaling had occurred at the channel edges.

Changes in surface elevation on the western channel slope appear related to dredging activity within the navigation channel. Along the east side of the LDW, elevations on the channel slopes appear more stable, with maximum changes in elevation of 0.6 to 0.9 m (2 to 3 ft). The pattern of sediment accumulation on the intertidal and shallow subtidal benches adjacent to the channel shows a slow accumulation of sediments (up to 1.5 m [4.9 ft]) over an 8-yr period on the west side of the channel, but only 0.6 m (2 ft) or less of total change in surface elevations on the eastern side of the channel between 1964 and 1978.

Downstream of Slip 4

Stations 168+00 (RM 2.6) and 172+00 (RM 2.7) are located downstream of Slip 4 (Figure 4-13). The authorized navigation channel depth downriver of 8th Avenue (ACOE Station 175+00; RM 2.8) is -6.1 m (-20 ft) MLLW. Surface elevations from 1967 to 1983 are presented in Figure 4-16 (located in the Oversize Maps and Tables volume). The changing elevations within the navigation channel showed an overall accumulation of sediment from 1967 to 1975. Maintenance dredging occurred in 1977 and 1978 with a proposed project depth of -6.1 m (20 ft) MLLW. A condition survey conducted in 1983 showed elevations in the navigation channel had shoaled slightly from the planned dredge depth of -6.1 m (-20 ft) MLLW.

Within the main navigation channel, there was approximately 0.3 m (1 ft) of sediment accumulation between 1967 and 1970. The elevation of the bottom in the main navigation channel was similar in the 1970 and 1971 surveys; however, by 1974 there was an accumulation of almost 0.6 m (3 ft) of additional sediment within the channel. Surveys conducted in 1975 and 1976 showed little change. Dredging along this section of the LDW occurred in 1977 and 1978. Sediment accumulation over the subsequent 25 years has been sufficiently low that maintenance dredging has not been required along this section.

Changes along the channel slopes of the LDW show average fluctuations in the surface elevations of approximately 0.6 to 0.9 m (2 to 3 ft) over the 16-yr time period. Cross sections at Station 168+00 on Figure 4-16 shows surface elevations on the left side of the channel (looking upstream) noticeably higher (1.5 m [4.9 ft] or more) in 1971 compared to the other years. An aerial photograph (taken in 1966) of this side of the channel showed log-rafting activities on the left (east) side of the channel. Incorrect soundings resulting from sunken log bundles or other anomalies may account for the two data points along this survey transect that are substantially higher than the readings inshore and offshore and upstream and downstream of the suspect area.

The channel slopes and intertidal areas at Station 172+00 show greater variability in surface elevations. The maximum change in elevation along the left side of the LDW at Station 172+00 is approximately 1.2 m (3.9 ft), but the yearly changes do not appear to follow the pattern of gradual accumulation of sediments found in the navigation channel. The elevation data for the right (west) side of the LDW are more limited. Areas of both sediment loss and gain are seen on Figure 4-16; no consistent pattern is seen across the entire cross-section. The surveys conducted in 1967 and 1970 along this transect extend to the west bank of the LDW. Subsequent surveys only extended 18.3 to 21.3 m (60-70 ft) past the edge of the navigation channel boundary. The surveys conducted in 1967 and 1970 show elevations approximately 1.8 m (5.9 ft) lower in 1970 on the channel slope. This change in elevation may reflect dredging activities to improve berth access outside the normal navigation channel. The 1966 aerial photograph does not show any pier structures present in this area; however, a 1972 aerial photograph does show a pier or dock structure in this area. Surveys conducted in 1972 through 1983 did not have soundings recorded from this transect line inshore of the location of the dock structure.

Duwamish/Diagonal

High precision bathymetric surveys (i.e., less than 7.6 m [25 ft] transect spacing using differential GPS) were performed in 1992 and again in 2002 by King County (2002). Bathymetric contours from the two surveys are presented on Figure 4-17 (located in the Oversize Maps and Tables volume). A representative cross-section through the middle of the study area is presented in Figure 4-18 (located in the Oversize Maps and Tables volume). The left side of Figure 4-18 represents the bank and the right side of the figure is toward the navigation channel. The blue trace, representing the more recent bathymetry survey (2002), is at a higher elevation than the orange trace (1992), indicating that net sediment accretion (deposition) has occurred throughout the transect during the last 10 years. The entire Duwamish/Diagonal survey area (Figure 4-17) exhibited either no change or net accretion over the 10-year period.

Conclusions Based on Empirical Evidence

A comparison of a selected set of bathymetric records (between 1963 and 1983) for the upper half of the LDW show that the upper reaches of the LDW are net depositional. The more recent data collected at Duwamish/Diagonal also confirms this observation for this portion of the lower LDW. Deepening of surface elevations within the navigation channel is generally associated with identified periods of maintenance dredging conducted by the ACOE. Changes in surface elevations outside the authorized navigation channel may be attributed to maintenance dredging adjacent to the navigation channel (including the cutting of stable side slopes outside of the channel), other dredging activities conducted to improve ship access to berthing areas or marinas, or other erosive events.

Dredge plans for maintenance dredging conducted by the ACOE along this portion of the LDW specifies a 2h:1v side slope cut outside the authorized navigation channel to provide a stable side slope configuration. A majority of the slopes shown by the cross sections following dredging are more gradual (less steep) than the plan specified 2h:1v; however, it is not apparent from the available survey records if the slopes found are the result of inaccuracies in the bathymetric surveys or construction of the bathymetric surface, or if the slopes reflect some post-dredge stabilization or shoaling associated with the dredge cut.

Deposition or erosion on the broad intertidal and shallow subtidal benches found along sections of the LDW appear to be limited to minor (0.6 m [2 ft] or less) changes in elevation. The benches do not show the steady accretion of river-borne sediment found in the main navigation channel. This finding provides support for the assumption that the benches are dynamically in equilibrium with river sediment processes and that significant erosion or deposition, if it occurs along this portion of the LDW, is localized. Erosional areas (areas of scour, Figures 4-10, 4-11, and 4-12) appear to be associated with limited areas along the upstream channel slopes or with areas where the flow conditions change, such as around bridge structures or channel bends. The major depositional areas include the navigation channel and a significant portion of the channel slope areas.

4.4.2.6 Summary

The data presented in this section suggest that hydrodynamic and sediment characteristics over a broad scale within the LDW are consistent with a net depositional environment. Much of the deposition occurs upstream of RM 4.0, particularly in the vicinity of Turning Basin 3, as indicated by the necessity for frequent dredging in this area (Kendall 2002). Sediment deposition rates downstream of this area are much lower (Harper-Owes 1983).

Sediment erosion and transport on a local and episodic scale can still occur in a net depositional environment via sediment resuspension. Sediment may be resuspended by dredging, propeller scour, or other erosive events. The net residual current direction will influence the net residual sediment transport. However, any net residual sediment transport is likely to be much smaller when compared to the rate of sediment input from sources upstream of the LDW. Additional research on peak flow events (i.e., 280 m^3/s [12,000 cfs]) will need to be conducted in Phase 2 to determine the importance of these events for sediment fate and transport.

As summarized above, there is a considerable body of information available to characterize sediment deposition and transport characteristics within the LDW area. These data have been used in a range of prior water and sediment quality assessments, and have also supported development of sediment remediation plans for potential early action sites in the LDW, including Duwamish/Diagonal (King County 2001b) and Boeing Plant 2 (Pentec et al. 2001). The sediment fate and transport information may also be useful in evaluating potential remedial actions at other LDW locations.

5.0 Summary of the Phase 1 ERA

Appendix A of this RI report is a detailed Phase 1 (scoping-phase) ERA for the LDW. This Phase 1 ERA uses existing site data, and where data are insufficient, conservative assumptions to evaluate the likelihood that adverse biological effects are occurring or may occur as a result of exposure to sediment-associated chemicals in the LDW.

Objectives of the Phase 1 ERA are to provide:

- preliminary risk estimates based on available data for ecological receptors of concern (ROCs) from chemicals of potential concern (COPCs)
- a forum for communication and input from stakeholders regarding key ecological issues and approaches
- a list of uncertainties inherent in the assumptions used for the Phase 1 ERA, characterized by their potential impact on risk conclusions; these uncertainties will form the basis for the identification of data gaps that may need to be filled prior to completion of the Phase 2 ERA
- risk-based analyses to aid in the identification of high-priority sites to be considered for potential early remedial action (Windward 2002)

Subsequent to this Phase 1 RI, a Phase 2 (baseline) ERA will be conducted that incorporates all available data, including additional data from field and analytical investigations performed to fill priority data gaps identified in the Phase 1 ERA. The Phase 2 ERA will be used to aid in management decisions for the site and will be contained in its entirety in the Phase 2 RI.

Much of the information in this RI is used in the ERA process. Information regarding the environmental setting and site usage, presented in Section 2, supports the selection of representative species that may be most exposed and describes the conditions and habitat types through which these species may be exposed. Chemistry data presented in Section 4 provide the information needed to estimate the potential exposure of these species to sediment-associated chemicals. Information on potential sources of the sediment-associated chemicals and fate and transport discussions in Section 4 provide important information for the conceptual site models. These models and the risk estimates provide valuable information for risk managers to recommend appropriate remedies for the LDW.

The Phase 1 ERA in Appendix A has three main components:

- Problem formulation
- Exposure and effects assessments for benthic invertebrates, fish, wildlife, and plants
- Risk characterization and uncertainty assessment

Each of these components is summarized below, and presented in detail in Appendix A.

5.1 OVERVIEW OF PHASE 1 ECOLOGICAL RISK ASSESSMENT

5.1.1 Problem formulation

The problem formulation (Section A.2; section numbers beginning with a letter are found in the Appendix indicated by that letter) establishes the scope of the Phase 1 ERA by conservatively screening existing information regarding the environmental setting; chemical concentrations in sediment, tissue, and water; and ecological resources (i.e., receptors) that use the site. The problem formulation presents the processes for selecting ROCs, COPCs for these ROCs, and assessment endpoints (e.g., growth, survival, and reproduction). It also includes a conceptual site model for the LDW that portrays potential pathways through which ecological species could be exposed to sediment-associated chemicals.

The LDW provides critical habitat for a diverse range of ecological species. Because every species cannot be evaluated in detail, representative species (i.e., ROCs) were selected. Representative species were selected such that if risks are found to be low for these representative species, then risks would be lower (or similar) for the species they represent. ROCs can also be selected if a particular species that uses the site is highly valued by society (such as threatened or endangered species). The ROCs selected in the Phase 1 ERA for the LDW were:

- the benthic community and crab species
- three fish species (juvenile chinook salmon, bull trout,[66] and English sole)
- five avian and mammalian wildlife species (great blue heron, bald eagle, spotted sandpiper, river otter, and harbor seal)
- rooted aquatic plants

A summary of these ROCs and the rationale for the selection of each ROC is presented in Table 5-1.

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[66] It is likely that the piscivorous fish ROC for Phase 2 will change from bull trout to the piscivorous fish selected for collection and analysis in Phase 2.

Table 5-1. ROCs selected for the LDW and a summary of the rationale for selection

RECEPTOR OF CONCERN	EXPOSURE ROUTE	ECOLOGICAL SIGNIFICANCE	SOCIAL SIGNIFICANCE	SITE USE	EXPOSURE DATA AVAILABILITY	SENSITIVITY
Benthic invertebrate community	direct contact, diet, sediment ingestion	food source for other invertebrates, fish, and mammals; nutrient cycling	target community for protection in the development of numerical sediment quality criteria	present year-round; multiple life stages	abundant surface sediment data available	due to the diversity of organisms in this ROC group, the range of sensitivities is represented
Crab	direct contact, diet, sediment ingestion	higher trophic level benthic invertebrate	potential human consumption	primarily used by juveniles and adults	site-specific tissue data available	susceptible to bioaccumulation due to trophic position
Bull trout	diet	top of food chain in LDW; preys on other fish	T&E species; previously important sport fish	present at times of high prey abundance (spring/summer)	no tissue data available; prey tissue data available	susceptible to bioaccumulation due to trophic position
English sole	direct contact, diet, sediment ingestion	important prey items for birds and fish; key benthic predator	some recreational and commercial value	juveniles present year round; adults present except when spawning	site-specific fish and prey tissue data available	NMFS data suggest that they are as sensitive as other flatfish (Myers et al. 1998b)
Juvenile chinook salmon	diet	important prey item for birds/fish; seasonally one of the most abundant in the LDW	T&E species; returning adults important to commercial, sport, & tribal fisheries	generally present April-July; most estuary-dependent juvenile salmonid	site-specific fish and prey tissue data available	believed to be sensitive to a wide range of COPCs
Great blue heron	diet, sediment ingestion	high on food chain; preys on fish	charismatic bird	present year-round; reproduce and feed in LDW	site-specific data available for chemicals in some food resources; egg data available	susceptible to bioaccumulation due to trophic position
Bald eagle	diet, sediment ingestion	top of food chain; preys on fish and other small animals	T&E species (under review for delisting)	present year-round; nests in vicinity	site-specific data available for chemicals in some food resources	susceptible to bioaccumulation due to trophic position
Spotted sandpiper	diet, sediment ingestion	preys on invertebrates; important role as an intermediate predator	protected under migratory bird treaty	present June-September; nests along LDW	site-specific data available for chemicals in some food resources	susceptible to bioaccumulation through consumption of invertebrates
River otter	diet, sediment ingestion	top of food chain; preys on fish and crustaceans	charismatic	present year-round	site-specific data available for chemicals in some food resources	susceptible to bioaccumulation due to trophic position; mustelids shown to be highly sensitive to LDW chemicals, e.g., PCBs
Harbor seal	diet, sediment ingestion	top of food chain; preys on fish	protected under Marine Mammal Act	infrequent	site-specific data available for chemicals in some food resources	pinnipeds suspected to be sensitive to LDW chemicals, e.g., PCBs
Emergent aquatic plants	direct contact	food source for terrestrial and aquatic animals in LDW; provide cover and habitat for a variety of ecological species	important aesthetic concerns; historically important for indigenous cultures' food, basketry, & medicine	present year-round; all life stages present	marsh sediment data available	uncertain; no toxicity data available for estuarine rooted aquatic plants so terrestrial plant toxicity data used

T&E – Species listed as threatened, endangered or sensitive species under the Endangered Species Act.

COPCs were identified for each of the ROCs (see Section A.2.4), as were appropriate assessment endpoints. Fifty-nine COPCs for benthic invertebrates were identified through the comparison of maximum chemical concentrations in surface sediment samples from the LDW with sediment quality standards (SQS) from the Washington State Sediment Management Standards (SMS) and screening levels (SLs) from the Dredged Material Management Program (DMMP).[67] TBT was also identified as a COPC based on an analysis performed by Weston (1999) using the TBT porewater-based SL. COPCs were not screened for crab in the problem formulation; instead all available tissue and effects data were evaluated in the remainder of the ERA.

For fish, COPCs were identified based on either a dietary or critical residue-based approach, depending on the bioaccumulation properties of the chemical. Metals and PAH compounds were evaluated using the dietary approach, in which conservatively estimated concentrations of the chemical in prey were compared to the lowest toxicological data available in the literature. The rest of the chemicals were evaluated based on a critical residue-based approach wherein the highest measured concentration of a chemical measured in fish tissue was compared to the lowest toxicological data available in the literature.

Wildlife COPCs were determined based in part on results of the King County Water Quality Assessment (WQA) wildlife risk assessment (King County 1999a). Also, several additional screens were conducted using conservative assumptions to estimate chemical exposure doses for comparison to the lowest toxicological data available in the literature.

COPCs for plants were identified through a comparison of intertidal and marsh sediment data with soil-based toxicological benchmarks for plants, as well as with Puget Sound background concentrations.

Assessment endpoints considered for these ROCs included effects on survival, growth, and reproduction. Conceptual site models (Figures 5-1, 5-2, and 5-3) were developed to assess the completeness of potential exposure pathways from contaminated sediment to aquatic life and wildlife ROCs[68]. Tables 5-2 and 5-3 present a summary of the ROC/COPC pairs identified for further evaluation in the exposure and effects assessments (Section 5.2) and the risk characterization (Section 5.3), based on the analyses in the problem formulation.

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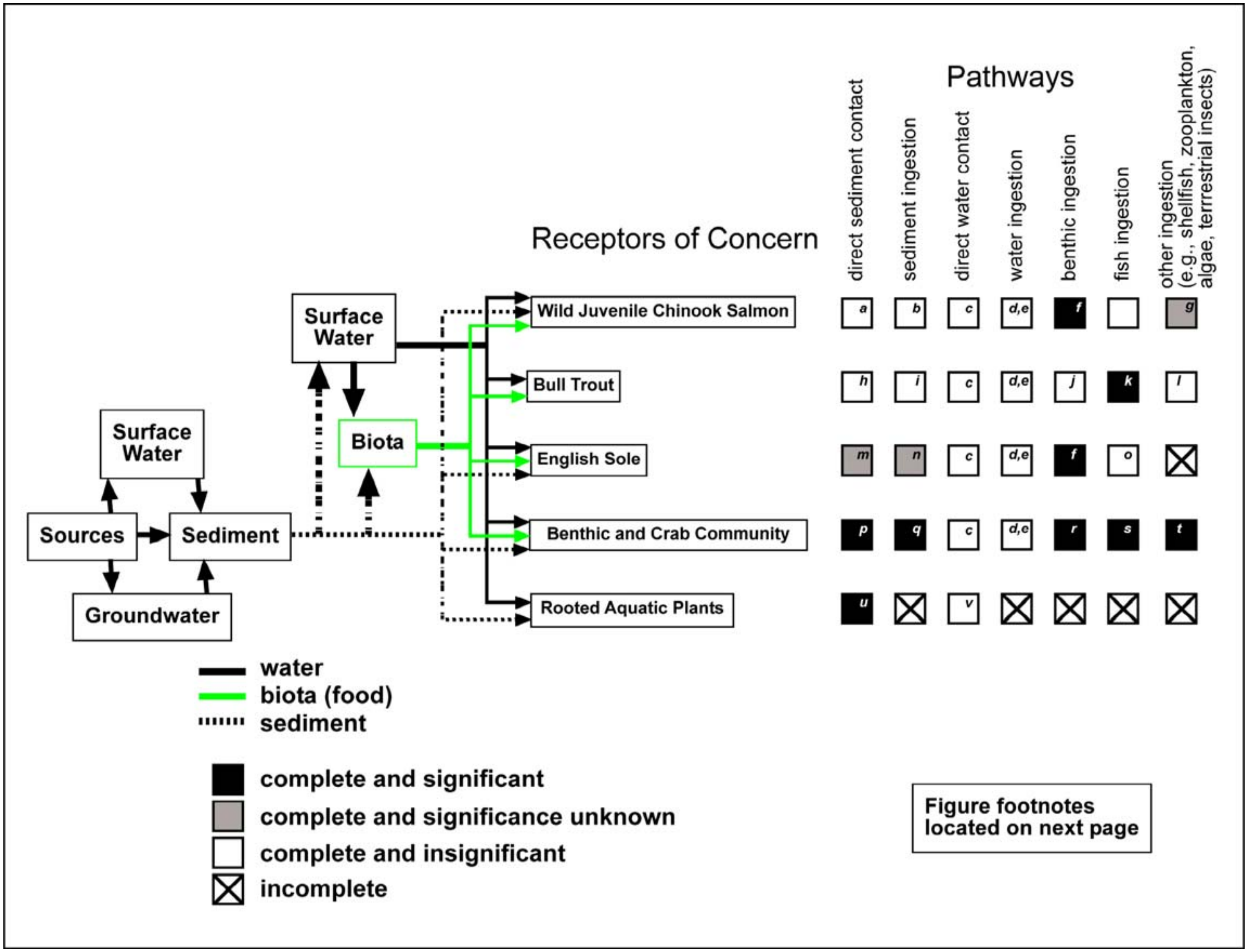
[67] DMMP guidelines were used for chemicals for which SMS standards were not available.

[68] A recent ecological risk assessment (King County 1999a) that included the LDW and Elliott Bay concluded that risks to aquatic life and wildlife from water column exposures were low (see Attachment A.2 in Appendix A). Thus, this assessment focused on risks from sediment-associated chemicals.



Receptors of Concern	direct sediment contact	sediment ingestion	direct water contact	water ingestion	benthic ingestion	fish ingestion	other ingestion (e.g., shellfish, zooplankton, algae, terrrestrial insects)
Wild Juvenile Chinook Salmon	☐ a	☐ b	☐ c	☐ d,e	■ f	☐	▨ g
Bull Trout	☐ h	☐ i	☐ c	☐ d,e	☐ j	■ k	☐ l
English Sole	▨ m	▨ n	☐ c	☐ d,e	■ f	☐ o	☒
Benthic and Crab Community	■ p	■ q	☐ c	☐ d,e	■ r	■ s	■ t
Rooted Aquatic Plants	■ u	☒	☐ v	☒	☒	☒	☒

■ complete and significant
▨ complete and significance unknown
☐ complete and insignificant
☒ incomplete

Figure 5-1. Conceptual site model for fish, benthic invertebrate community, and plants

Notes for Figure 5-1

a Juvenile chinook do not come into direct contact with sediment for a significant period of time; therefore, any exposure via direct sediment contact was considered insignificant in the overall exposure assessment.

b Because juvenile chinook are generally not in direct contact with sediment, this exposure pathway is likely insignificant. Examination of juvenile chinook stomach contents suggests they do not ingest an appreciable amount of sediment (Cordell 2001).

c Aquatic organisms are in direct contact with surface waters; based on a comparison of modeled concentrations of chemicals in water to ambient water quality criteria (King County 1999a), risks to aquatic life through the water pathway appear to be low.

d Based on a comparison of modeled concentrations of chemicals in water to ambient water quality criteria (King County 1999a), risks to aquatic life appear to be low.

e Aquatic organisms may ingest water; however, the significance of this exposure pathway for sediment-associated chemicals is unknown.

f Epibenthic invertebrates were assumed to be a primary component of the diet.

g Juvenile chinook may occasionally consume drift organisms; however, the contribution of this component to the overall diet was unknown.

h In general, bull trout do not come into direct contact with sediment. Therefore, any exposure via direct contact with sediment is considered insignificant in the overall exposure assessment.

i Because bull trout are generally not in direct contact with sediment, this exposure pathway is likely insignificant. Examination of bull trout prey (i.e., juvenile chinook salmon) stomach contents suggests they do not ingest an appreciable amount of sediment (Cordell 2001).

j Ingestion of benthic invertebrates was assumed to be a very small component of the overall bull trout diet. Also, worst-case exposure estimates resulted in low risk (see Section A.7.2.2).

k Fish were considered a primary component of the bull trout diet.

l Bull trout are opportunistic feeders and may occasionally consume other prey items (e.g., water column invertebrates, drift organisms). The overall contribution of this component to the bull trout diet, however, is assumed to be insignificant.

m Sole routinely bury themselves in sediment, and so are in direct contact with sediment and associated porewater. However, no data were available to estimate risk from direct contact.

n Sole reside and forage in the sediments and they are likely to consume some sediment and associated porewater; however, the specific amount consumed is unknown. It was assumed to be 10% in Section A.4.1.2 based on best professional judgment.

o English sole are not known to ingest fish (Hart 1973). Therefore, the significance of this exposure pathway for sediment-associated chemicals was considered insignificant.

p Benthic organisms are generally in direct contact with sediment and associated porewater.

q Some benthic organisms are known to routinely ingest sediment, and therefore, this pathway was considered complete and significant.

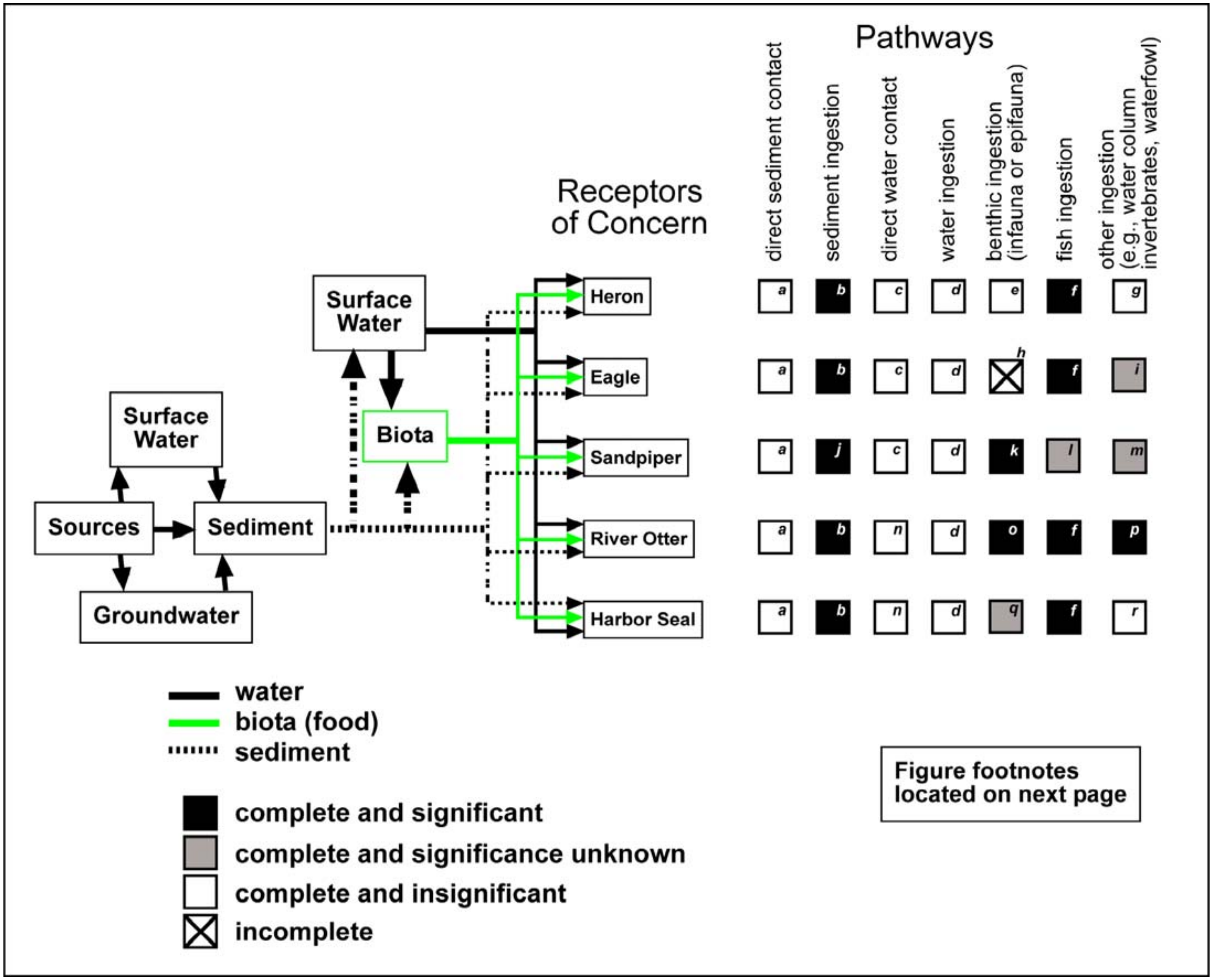
r A significant portion of the diets of some benthic organisms consists of other benthic organisms.

s Although benthic organisms generally do not ingest fish, crabs may ingest dead fish.

t Benthic organisms may ingest algae and detritus.

u Rooted plants are in direct contact with sediment and associated porewater.

v Rooted plants are rarely submerged in the LDW.



	direct sediment contact	sediment ingestion	direct water contact	water ingestion	benthic ingestion (infauna or epifauna)	fish ingestion	other ingestion (e.g., water column invertebrates, waterfowl)
Heron	☐ a	■ b	☐ c	☐ d	☐ e	■ f	☐ g
Eagle	☐ a	■ b	☐ c	☐ d	☒ h	■ f	▨ i
Sandpiper	☐ a	■ j	☐ c	☐ d	■ k	▨ l	▨ m
River Otter	☐ a	■ b	☐ n	☐ d	■ o	■ f	■ p
Harbor Seal	☐ a	■ b	☐ n	☐ d	▨ q	■ f	☐ r

Figure footnotes located on next page

Figure 5-2. **Conceptual site model for wildlife**

Notes for Figure 5-2

a Species may come in contact with sediment when foraging; however, no data were available to assess risks through this pathway. It is generally considered insignificant.

b Species may incidentally ingest a small amount of sediment while foraging.

c Species come in contact with surface water when foraging. Although no data were available to assess risks through this pathway, risks to wildlife through this pathway were assumed to be insignificant.

d Based on King County (1999a), risk from water ingestion accounted for less than 0.5% of the overall risks.

e Great blue heron may occasionally consume benthic organisms, but benthic organisms make up a very small component of their diet (Weston 1993).

f Fish are the primary component of the diet.

g Great blue heron may consume aquatic insects, but insects are not reported to represent a high percentage of their diet (Weston 1993). In addition, herons may also consume amphibians; however, amphibians have not been observed in the LDW, with the exception of a single tadpole.

h Bald eagles generally do not consume benthic invertebrates.

i Bald eagles may consume birds, such as grebes, gulls and waterfowl, and may infrequently consume mussels (EPA 1993). However, no data are available on body burdens in birds or the percent of those body burdens that could be attributable to sediment sources. Eagles may also infrequently feed on marine mammal carcasses, but this pathway is considered insignificant at this site.

j Sandpipers can ingest sediment (assumed to be 18% of diet [Weston 1993]) when foraging or from their food.

k Benthic organisms are a primary component of the sandpiper's diet.

l Spotted sandpipers may occasionally consume small fish, but the percentage of fish in the overall diet and their significance is unknown.

m Spotted sandpipers ingest terrestrial insects (Terres 1987) and may ingest mollusks (e.g., mussels). For terrestrial insects, however, there is no direct connection attributable to sediment sources. The percent mollusk ingestion in the diet and relative importance of sediment-chemicals to mollusk body burdens are unknown, and therefore, the significance of this diet component is unknown.

n Species are in direct contact with surface water when swimming and foraging. Although no data were available to assess risks through this pathway, risks to wildlife through this pathway were assumed to be insignificant.

o River otters may ingest crabs as a significant proportion of their diet (Larsen 1984; Stenson et al. 1984; Weston 1993).

p Mussels may make up a significant portion of the otter's diet.

q Harbor seals may consume crabs as a part of their diet, but the relative percentage is unknown.

r Although squid and octopus can be important prey items, they have not been observed in the LDW and are thus unlikely to make up a significant portion of the seal diet in the LDW.

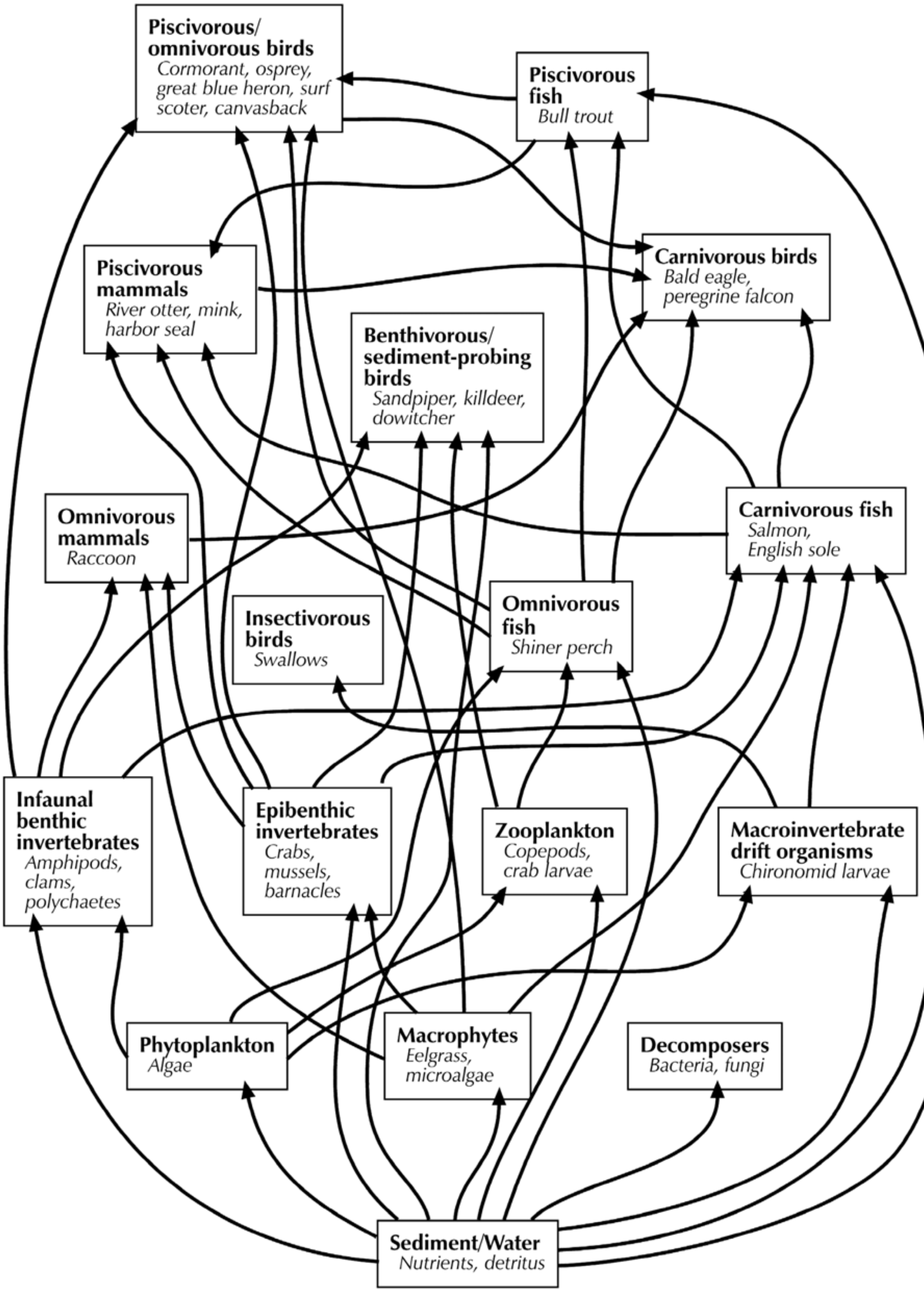


Figure 5-3. **Generalized food-web model for the LDW**

Table 5-2. Phase 1 COPCs retained for benthic invertebrates [a,b,e,f]

Retained due to measured concentration greater than SQS or SL		
1,2,4-Trichlorobenzene	Butyl benzyl phthalate	Naphthalene
1,2-Dichlorobenzene	Cadmium	Nickel[c]
1,3-Dichlorobenzene [c]	Chlordane, alpha[c]	N-Nitrosodiphenylamine[c]
2,4-Dimethylphenol	Chromium	PCBs (total-calculated)
2-Methylnaphthalene	Chrysene	Pentachlorophenol
4-Methylphenol	Copper	Phenanthrene
Acenaphthene	Dibenzo(a,h)anthracene	Phenol
Anthracene	Dibenzofuran	Pyrene
Arsenic	Dieldrin[c]	Silver
Benzo(a)anthracene	Di-n-butyl phthalate	Tributyltin[b]
Benzo(a)pyrene	Fluoranthene	Total DDTs (calculated)[c]
Benzo(g,h,i)perylene	Fluorene	Total HPAH (calculated)
Benzofluoranthene (total)	Hexachlorobenzene	Total LPAH (calculated)
Benzoic acid	Indeno(1,2,3-cd)pyrene	Zinc
Benzyl alcohol	Lead	
Bis(2-ethylhexyl)phthalate	Mercury	
Retained due to detection limit greater than SQS or SL		
1,4-Dichlorobenzene[d]	Dimethyl phthalate[d]	Hexachlorobutadiene [c,d]
2-Methylphenol[d]	Di-n-octyl phthalate[d]	Hexachloroethane [c,d]
Acenaphthylene[d]	Ethylbenzene [c,d]	Tetrachloroethene [c,d]
Aldrin [c,d]	Gamma-BHC [c,d]	Trichloroethene [c,d]
Diethylphthalate[d]	Heptachlor [c,d]	

[a] COPCs retained based on a comparison between maximum sediment concentrations and SMS sediment quality standards (SQS) and DMMP screening levels (SL).

[b] TBT does not have a bulk sediment-based SL or SQS, and was screened in using its porewater SL based on Weston (1999) analysis.

[c] Analyte screened using DMMP SL because no SQS was available.

[d] Analyte had detection limit greater than SQS or SL (when SQS is not available).

[e] Antimony and xylene were screened out, relative to their DMMP guidelines.

[f] No COPCs were screened out for crab in the problem formulation. All available tissue and effects data for crab were evaluated in the exposure and effects assessments as well as in the risk characterization.

Table 5-3. ROC/COPC pairs evaluated in the Phase 1 exposure and effects assessments for fish, wildlife, and plants

	PCBs	PAHs	TBT	BEHP	DDTs	As	Cu	Pb	Zn	Hg
Juvenile chinook salmon	×	×	×	[a]	×	×	×	[a]	[a]	×
English sole	×	×	×	[a]	×	×	×	[a]	[a]	×
Bull trout	×	[d]	×	[a]	×	×	×	[a]	[a]	×
Sandpiper	×	[a]	[a]	×	[b, e]	[a]	×	×	×	[a]
Heron	×	[a]	[a]	[a]	[a]	[a]	[a]	×	[a]	×
Eagle	×	[a]	[a]	[a]	[e]	[a]	[a]	×	[a]	×
Otter	×	[a]	[a]	[a]	[a]	×	[a]	×	[a]	[a]
Seal	×	[e]	[a]	[a]	[a]	[a]	[a]	[a]	[a]	[a]
Emergent aquatic plants	×	[a]	[c]	[a]	[c]	[a]	[a]	×	×	×

BEHP – bis(2-ethylhexyl)phthalate

DDTs – sum of DDT, DDE, and DDD

[a] ROC/COPC pair screened out because maximum potential exposure concentrations were less than NOEC (concentration) or NOAEL (dose) toxicity data.

[b] ROC/COPC pair not screened due to lack of exposure data (pair is discussed in the uncertainty assessment).

[c] ROC/COPC pair not screened due to lack of effects data (pair is discussed in the uncertainty assessment).

[d] ROC/COPC pair not further evaluated due to an incomplete exposure pathway.

[e] ROC/COPC pair not further evaluated in the Phase 1 ERA (HQ<1), but the feasibility and utility of collecting additional exposure data will be discussed during the Phase 2 RI work plan development.

5.1.2 Exposure and effects assessments

For each ROC / COPC pair identified through the screening process in the problem formulation, exposure and effects were further assessed in the Phase 1 ERA. The intent of the exposure assessment was to provide a more realistic picture of potential exposure of ROCs to COPCs, rather than assuming 100% exposure to maximum concentrations in sediment or tissue. In the effects assessment, summaries of available toxicological data were provided in greater detail than in the problem formulation, and appropriate toxicity reference values (TRVs) were selected. The general approaches used to evaluate exposure and effects for benthic invertebrates, fish, wildlife, and plants are described below. Additional details of these assessments are found in Appendix A Sections A.3, A.4, A.5, and A.6.

5.1.3 Risk characterization and uncertainty assessment

The risk characterization synthesizes the exposure and effects assessments for each ROC / COPC pair, and consists of a risk estimation, an uncertainty assessment, and a risk conclusion for each ROC group (i.e., benthic invertebrates, fish, wildlife, and plants). The risk estimation presents the HQs[69] calculated for each ROC / COPC pair. In ERAs, HQs greater than 1 are generally regarded as indicating that there is a potential for adverse effects, particularly if the HQ is based on an effects concentration

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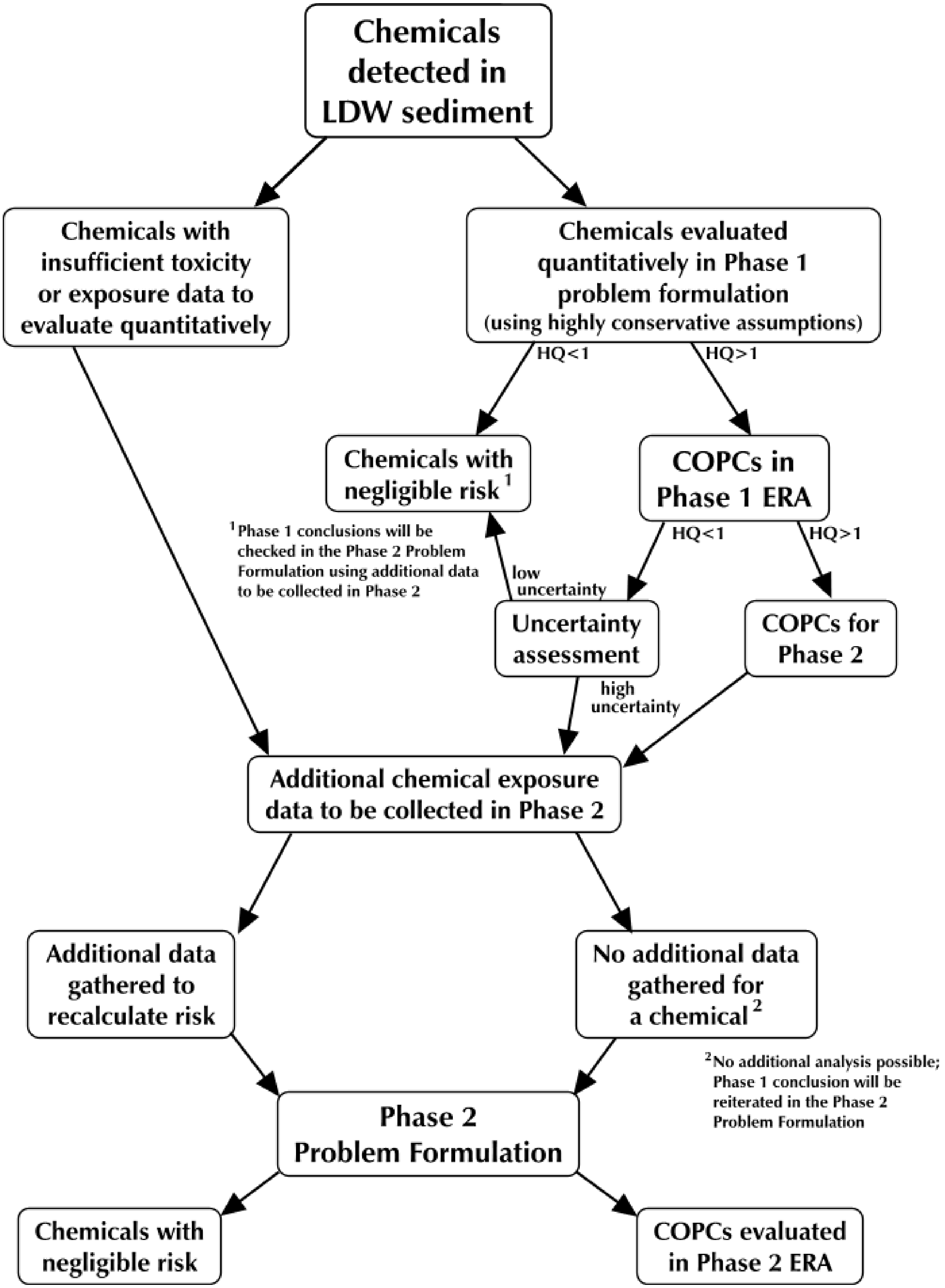
[69] HQ = exposure concentration (or dose) / concentration (or dose) associated with adverse effects

(or dose) at which adverse effects were observed. These HQs are referred to as lowest observed effects concentration (LOEC)- or lowest observed adverse effects levels (LOAEL; for doses)-based HQs. In other words, if the HQ is based on a LOEC or LOAEL and is greater than 1, exposure is believed to be sufficiently high that adverse effects are more likely. HQs are also calculated based on a no observed effects concentration (NOEC) or no observed adverse effects level (NOAEL), for doses. Note that although a NOEC-based HQ may exceed 1, the potential for adverse effects is uncertain because the true threshold for effects occurs at a concentration somewhere between the NOEC and LOEC. Therefore, it is important to calculate both types of HQs to estimate the potential for adverse effects.

Uncertainties inherent in these HQs and in the Phase 1 ERA problem formulation and exposure and effects assessment approach are discussed in the uncertainty assessment. The results of the HQ calculations and the uncertainty assessment are then integrated in the risk conclusions. The magnitude of the preliminary risk estimate and the uncertainty in this estimate will be used during the Phase 2 RI work plan development to propose additional data collection activities.

The Phase 1 ERA identifies sediment-associated COPCs that may be of concern to ecological receptors. However, because this Phase 1 ERA was based on a limited tissue data set and used highly conservative assumptions, not all chemicals identified as chemicals of concern will be risk drivers for the site at the conclusion of Phase 2. On the other hand, chemicals now believed to pose low risk based on the existing data set may be found to pose a higher risk once a more comprehensive dataset has been gathered in Phase 2. Thus, in the problem formulation of the Phase 2 ERA, any additional data gathered to fill data gaps, or identified through other means, will be used in combination with existing data to identify ROC/COPC pairs for Phase 2. This step is necessary because of the limited tissue dataset available in the Phase 1 ERA, and thus the preliminary nature of many of the results. The entire screening process is presented in Figure 5-4 for clarity.



[1] Phase 1 conclusions will be checked in the Phase 2 Problem Formulation using additional data to be collected in Phase 2

[2] No additional analysis possible; Phase 1 conclusion will be reiterated in the Phase 2 Problem Formulation

Figure 5-4. Phased process by which COPCs will be addressed

The risk characterization results and uncertainty discussions for benthic invertebrates, fish, wildlife, and plants are described below. Additional details of these assessments are found in Appendix A Section A.7.

5.2 BENTHIC INVERTEBRATES ASSESSMENT

This section presents an overview of the Phase 1 risk assessment for benthic invertebrates. Additional detail on this assessment can be found in Sections A.3 and A.7.1 in Appendix A.

5.2.1 Exposure and effects assessment

The following three approaches were used for the Phase 1 assessment of benthic invertebrate species:

- Use of sediment chemistry data to estimate exposure and potential effects to epibenthic and infaunal species covered by Washington's SQS and cleanup screening levels (CSLs) and DMMP SLs and maximum levels (MLs) [70]
- For TBT, use of measured and estimated tissue residue data to estimate exposure and effects to benthic invertebrate species
- Use of tissue data to estimate exposure and effects to higher-trophic-level benthic invertebrates, as represented by crab

5.2.1.1 Sediment data and SMS

The exposure assessment for infaunal and epibenthic invertebrates was based primarily on the nature and extent of chemical concentrations in sediment inhabited by these invertebrates relative to the SQS or CSL (or SL or ML guidelines for chemicals without SQS or CSL). Biological endpoints included in the SMS derivation are field measures of benthic infaunal abundance and laboratory toxicity tests with either marine benthic organisms (i.e., amphipods [mortality] and oysters [percent abnormal development of oyster larvae]) or Microtox® (reduced luminescence). Assessment of risks from sediment-associated chemicals to the benthic invertebrate community requires an assessment of both the magnitude and areal coverage of contaminated sediments. SQS or CSL values are based on apparent effects thresholds (AETs). AETs are defined as the highest "no effect" chemical concentration above which a significant adverse biological effect always occurred among the several hundred samples used for its derivation. Generally, the lowest AET for each chemical was identified as the SQS; the second lowest was identified as the CSL. Under the provisions of the SMS, surface sediments with chemical concentrations equal to or less than all the SQS are designated as having no adverse effects on biological resources (WAC 173-204-310(1)(a)).[71] CSLs establish minor adverse effects as a level above which station

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[70] DMMP guidelines were used for chemicals for which SMS standards were unavailable.

[71] Although designated as such under the provisions of the SMS, due to the SQS derivation process, there is some uncertainty in the prediction of effects based solely on comparison with the SQS.

clusters of potential concern are defined[72] (WAC 173-204-520). Because SQS and CSLs can only predict potential toxicity, the SMS regulations allow for a site-specific verification of toxicity using sediment toxicity tests and benthic community characterizations.

Exposure to the 59 chemicals identified in the problem formulation as benthic COPCs was further assessed by grouping the COPCs into categories based primarily on the frequency and magnitude[73] of sediment standard or guideline exceedance. This analysis identified 22 COPCs that warranted a more detailed analysis, although adverse effects from all 59 COPCs could occur. Of those 22 COPCs, total PCBs and bis(2-ethylhexyl)phthalate were the two chemicals with more frequent exceedances of the SQS and CSL than any other chemicals in the sediments.

CSL exceedances of the highest priority COPCs were generally co-located with CSL exceedances of either BEHP or total PCBs (see Map A-7-7 in Appendix A). Using a GIS analysis of multiple chemicals, multiple sediment standard / guideline exceedances[74] were identified at the following areas: south of Harbor Island (RM 0.1[75]), RM 0.3 - 0.6 (east side), Slip 3 and the west side opposite Slip 3 (RM 1.9 - 2.2), most of the east side between Slips 4 and 6, and upstream of Turning Basin 3 (RM 4.8 - 5.5) (see Map A-7-4 in Appendix A).

In the effects assessment, AETs, which form the basis for SMS and DMMP guidelines, were discussed to provide an indication of the types of potential effects covered by the sediment standards and guidelines, and to form the basis for further evaluation of site-specific toxicity data in the risk characterization. In addition, results of several studies of sediment toxicity test and benthic community characteristics conducted within the LDW in the last 10 years were reviewed. These studies focused on small areas; no reconnaissance-level surveys have been conducted for toxicity or community structure. All but two of the sediment toxicity test studies were conducted for dredged material characterization, making them unsuitable for an assessment of surface sediment toxicity.[76] Toxicity was observed in only one sample from the two surface sediment toxicity studies (out of 10 total samples). Although only a few samples have been analyzed for benthic community characteristics, all samples showed some evidence of benthic community alterations relative to reference conditions. The types of benthic community alterations observed, however, are characteristic of areas

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[72] Station clusters are defined to identify potential candidate sites, not for identifying cleanup areas.

[73] The magnitude of the standard or guideline exceedance has no regulatory relevance, and was evaluated to provide relative chemical concentrations.

[74] Multiple CSL exceedances are useful in identifying areas with a higher level of general contamination, but have no regulatory relevance.

[75] As measured from the southern tip of Harbor Island.

[76] The toxicity of subsurface sediments may be very different than the toxicity of surface sediments with similar chemical concentrations due to differences in bioavailability.

affected by organic enrichment, and may not be indicative of chemical contamination (Pearson and Rosenberg 1978).

5.2.1.2 TBT tissue-based assessment

Potential effects of exposure of benthic invertebrates to TBT were evaluated using a tissue residue approach in the Phase 1 ERA. In a tissue residue approach, concentrations of a chemical measured in tissue from field-collected animals, or animals exposed to field-collected materials, are compared to concentrations in tissue associated with adverse effects. In the exposure assessment, the limited available TBT tissue data were summarized (i.e., four composite amphipod tissue samples near Kellogg Island). In addition, a modified[77] biota-sediment accumulation factor (BSAF) was calculated from this limited dataset and used to estimate a range of TBT tissue concentrations in benthic organisms from other areas in the LDW. A threshold screening value for TBT of 3 mg/kg dw, based on EPA (1999b) and Meador (2000), was selected for use in the Phase 1 ERA to provide a preliminary estimate of risk to benthic invertebrates in the LDW.

5.2.1.3 Crab tissue-based assessment

Because of their greater mobility and potential to bioaccumulate COPCs[78] due to their higher trophic position, crab were assessed using a tissue-based approach. In the exposure assessment, available crab tissue data were compiled. These data included relatively few edible meat and hepatopancreas tissue sample data from crabs collected near Kellogg Island. In the effects assessment, tissue concentrations from the scientific literature associated with adverse effects were compiled for crabs or for other decapods[79] when crab data were not available.

5.2.2 Risk characterization and uncertainty assessment for benthic invertebrates

To estimate the potential for adverse effects to benthic invertebrates, sediment chemistry data were compared to SMS SQS and CSL values (or DMMP SL and ML values for chemicals without SMS values.) Approximately 70% of the total LDW area[80] was estimated to have no SQS or SL exceedances for any chemical, based on detected concentrations, and thus risk to benthic invertebrates in these areas is likely to be low based on Phase 1 chemistry data (see Maps A-7-3 and A-7-4 in the ERA map folio). Many sample-specific detection limits for semi-volatile organic compounds also exceeded the SQS/SL. The percentage of the total LDW area without SQS/SL

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[77] The modified BAF was defined as the concentration of TBT in tissue divided by the TOC-normalized concentration in synoptically collected sediment samples.

[78] Impacts resulting from bioaccumulation by higher trophic level benthic invertebrates are not implicitly covered in the SMS.

[79] Decapods are benthic invertebrates with 10 legs such as crab, lobsters, and shrimp.

[80] Percent of area was calculated using Thiessen polygons. Thiessen polygons are a method commonly used in spatial analysis to account for spatial variability in sampling intensity. The Thiessen polygon associates each point in a plane with the closest sampling location for which a measurement is available (Burmaster and Thompson 1997).

exceedances, based on either detected concentrations or one-half detection limits, was estimated at 37%. Risks will be further evaluated through additional data collection, including biological testing, in Phase 2.

The remaining 30% of the area had SMS or DMMP guideline exceedances for at least one chemical, and thus the potential for adverse effects to benthic invertebrates is uncertain in these areas. However, approximately 10% of the area with SMS criteria or DMMP guideline exceedances had concentrations of at least one chemical exceeding its CSL, and thus, potential effects to benthic invertebrates are more likely in these areas. Because the results described above were based solely on chemistry data, potential effects to the benthic community can only be predicted. Effects can be directly measured through the use of sediment toxicity tests and benthic community analyses. However, existing data of these types were very limited for the LDW, and consequently, conclusions regarding measured effects cannot be made except at locations where these data were available.

Based on the few available data, risks to crab from sediment-associated COPCs in the LDW appear to be relatively low (i.e., HQs less than 1), with the possible exception of arsenic (Table 5-4). However, because of the small number of tissue samples available for crab (i.e., two or three composite Dungeness crab samples depending upon the COPC and one hepatopancreas composite sample, all collected near Kellogg Island), the potential to gather additional crab tissue data will be evaluated during development of the Phase 2 RI work plan.

Table 5-4. Crab HQs using hepatopancreas and whole-body exposure and effects data

CHEMICAL	HQ–HEPATOPANCREAS		HQ–WHOLE BODY [c]	
	NOEC	LOEC	NOEC	LOEC
Arsenic	na	na	**10**	na
Cadmium	na	na	0.008[a]	0.0004[a]
Chromium	na	na	0.15	0.05
Copper	na	na	0.59[b]	na
Mercury	0.68	0.67	na	na
Zinc	0.45	0.22	na	na
PCBs	na	na	0.02	na
TBT	na	na	0.65	na

na – not available

NOTE: HQs greater than 1 are noted in **bold type**.

[a] Based on effect concentration in muscle tissue

[b] Based on effect concentration in claw tissue

[c] Whole-body concentrations were estimated by combining hepatopancreas and edible meat concentrations, assuming 85% by mass edible meat and 15% by mass hepatopancreas. All crab tissue data were collected near Kellogg Island.

HQs less than 1 (i.e., 0.06 to 0.30) were calculated for TBT and benthic invertebrates using both measured tissue concentrations and tissue concentrations estimated using the median carbon-normalized TBT concentration in sediment in the LDW (Table 5-5). However, when maximum concentrations of TBT in sediment were used to estimate a tissue concentration for comparison to the threshold screening value, the HQ was 5.3. The highest concentrations of TBT are located in the lower 3 km of the LDW (Figure A-7-8, Attachment A.1, Appendix A). Due to the potentially high HQ (up to 5.3), and the fact that 18 of the 102 stations analyzed for TBT could have an HQ greater than 1 based on tissue concentrations estimated using a modified BSAF, TBT is recommended as a COPC for benthic organisms for further evaluation in the Phase 2 ERA. The utility and feasibility of collecting additional data to support this analysis will be evaluated during development of the Phase 2 RI work plan.

Table 5-5. HQs calculated for TBT using measured and estimated tissue concentrations

BASIS	HQ [a]
Measured maximum tissue concentrations near Kellogg Island	0.06
Tissue predicted using:	
Minimum sediment concentration	0.008
Median	0.30
Maximum sediment concentration	**5.3**

NOTE: HQs greater than 1 are noted in **bold type**.

[a] Based on comparison of the tissue concentration to a threshold (3 mg/kg dw) for effects on survival, growth, and reproduction data for benthic invertebrates (EPA 1999b; Meador 2000)

Uncertainties associated with the benthic invertebrate assessment are summarized in Table 5-6. These uncertainties are categorized as low, medium, or high depending on the level of uncertainty, the potential to impact risk conclusions, and the feasibility of filling the data gap (primarily through field and analytical work). Concentrations of TBT in neo- and mesogastropods are highly uncertain and could have a high impact on the risk conclusion. In the crab assessment, tissue residue data and site usage information for crabs were viewed as having a medium impact on risk conclusions, primarily because the effects data for crab are also uncertain. The uncertainty associated with the use of sediment standards and guidelines to predict risk on a site-specific basis was also categorized as medium, due to the low number of toxicity tests conducted in the LDW. Additional toxicity tests are proposed in Phase 2 to reduce this uncertainty.

Table 5-6. Summary of uncertainties associated with benthic invertebrate risk characterization

Issue	Level of Uncertainty	Effect of Uncertainty on Risk Estimate	Potential Means to Decrease Uncertainty	Potential Impact on Risk Conclusions	Feasibility of Filling Data Gap
Exposure Assessment					
Coverage of sediment data in the LDW for selected COPCs (e.g., DDT and TBT)	medium	unknown[a]	collect additional surface sediment samples	low	high
Use of surface sediment chemistry data to characterize exposure to benthic invertebrates	low	unknown[a]	collect relevant exposure samples	low	high
Use of zero detection limit for risk characterization	medium	possible under-estimation	collect additional sediment with lower DLs	low	medium
TBT tissue concentrations in benthic invertebrates	high	unknown[a]	collect tissue data in areas across a TBT gradient	high	high
Suitable habitat for crabs	medium	possible under-estimation	conduct a site usage survey	medium	high
Use of crabs to represent other ROCs in LDW from an exposure perspective	medium	unknown[a]	collect other organism from similar trophic position[b]	medium	low
Use of limited crab tissue dataset	high	unknown[a], but possibly under-estimated	collect additional crab tissue	medium	high
Effects Assessment					
Use of SMS standards and DMMP guidelines to estimate site-specific effects to benthic invertebrates	low	unknown[a]	conduct additional toxicity tests with LDW sediment	medium	medium
Crab toxicity data	high	unknown[a]	conduct additional toxicity tests with crabs	medium	low
Use of crab as a representative of other upper-trophic-level benthic species	medium	unknown[a]	conduct toxicity test with other species; or conduct literature search or relative sensitivities	low	low; medium

[a] Effect is dependent on whether additional exposure or TRV data would have higher or lower COPC concentrations than existing data.

[b] Relevant toxicological data would need to be available to assess risks.

Level of uncertainty key: **low** = large or relevant dataset
medium = small dataset or limited information
high = very limited data

Potential effect key: **low** = unlikely to result in a change of HQ from less than 1 to greater than 1 (or vice versa)
medium = could result in a change of HQ from less than 1 to greater than 1 if worst-case scenario is used (scenario is viewed as unlikely)
high = HQ could change from less than 1 to greater than 1 (or vice versa) using a scenario that is conservative but more reasonable than the worst-case scenario

Feasibility key: **low** = high budget or difficult research study would be required to address uncertainty
medium = issue could be resolved with a mid-level field sampling event or research study or a detailed assessment of literature
high = issue could be resolved with additional literature search or through limited field sampling

5.3 FISH ASSESSMENT

This section presents an overview of the Phase 1 risk assessment for fish species in the LDW. Additional detail on this assessment can be found in Sections A.4 and A.7.2 in Appendix A.

5.3.1 Exposure and effects assessment

This section provides a summary of the approaches used to evaluate fish ROC/COPC pairs. Exposure of fish to sediment-associated COPCs was assessed using either the critical residue approach or the dietary approach, depending on the potential of the COPC to bioaccumulate (Table 5-7).

Table 5-7. ROC/COPC pairs and approaches evaluated for fish

	PCBS	PAHS	TBT	DDT	AS	CU	HG
Juvenile chinook	CR	D, B	CR	CR	D	D	CR
English sole	CR	D, B	CR	CR	D	D	CR
Bull trout	CR	ne	CR	CR	D	D	CR

ne – Not evaluated

CR – Critical residue approach

D – Dietary approach

B – Biomarker data as a measure of exposure

In the critical residue approach, exposure of fish to PCBs, TBT, DDT, and mercury in the LDW was estimated using the limited tissue data available in field-collected fish. Whole body tissue data were available for English sole, juvenile chinook salmon, and perch. PCBs, TBT, DDT, and mercury were measured in English sole and perch tissue, but only some of these chemicals were measured in juvenile chinook salmon. Further, no tissue data were available for a piscivorous fish, represented by bull trout. Therefore, where necessary, substitution of tissue data from one fish species for another (e.g., adult perch tissue data for juvenile chinook salmon) or predator-prey factors were used.

To estimate exposure to arsenic, copper, and PAHs using the dietary approach, concentrations in prey tissue were estimated using either stomach contents from field-collected fish[81] or concentrations estimated in food. Because limited data were available to estimate tissue concentrations in important prey items in the LDW, relationships between concentrations in sediment and prey items (i.e., bioaccumulation factors) were used. Table A-4-23 in Appendix A provides a summary of exposure concentrations for each ROC/COPC pair.

In the effects assessment, the scientific literature was searched to identify data associated with any fish species relating observed adverse effects on survival, growth, and reproduction with tissue concentrations of PCBs, TBT, DDT, and mercury, or with

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[81] PAHs have been measured in the stomach contents of juvenile chinook salmon.

concentrations of arsenic, copper, or PAHs in food. Summary tables are included in Appendix A, Section A.4.2, which list studies identified and relevant details. A COPC-specific NOEC and LOEC was selected for each ROC and assessment endpoint. The rationale for each selection was also provided. A summary of selected NOECs and LOECs is presented in Tables A-4-24 to A-4-26 in Appendix A.

In addition, relevant field studies conducted in the Puget Sound region involving juvenile chinook salmon and English sole were summarized and assessed (see Section A.4.3 in Appendix A). These studies were addressed separately because they involved exposure to chemical mixtures and subsequent assessment of effect; thus, no chemical-specific NOECs or LOECs could be determined from these studies.

5.3.2 Risk characterization and uncertainty assessment for fish

In the risk characterization section for fish, exposure data and effects TRVs presented in Sections A.4.1 and A.4.2 (Appendix A) were used to calculate HQs for each of the three fish ROCs (Table 5-8).

Three LOEC-based HQs exceeded 1 for fish ROCs and the growth endpoint (i.e., English sole / copper [7.6]; bull trout / PCBs [2.1];[82] English sole / arsenic [1.1]). No other LOEC-based HQs exceeded 1 for any endpoint. Thus, the likelihood for risk is greatest for English sole from copper and arsenic and for bull trout from PCBs. NOEC-based HQs were greater than 1 for 12 ROC / COPC pairs. However, as discussed earlier, due to the uncertainty regarding the concentration associated with effects between the NOEC and LOEC, the interpretation of risk based on NOEC-based HQs is more uncertain. The highest NOEC-based HQs were reported for English sole / copper (15) and bull trout / PCBs (8.2). In addition, NOEC-based HQs were also greater than 1 for at least one fish species for mercury, PAHs, and TBT. Although arsenic HQs were greater than 1, risk may not be elevated relative to background risk in the region. In the Phase 2 ERA, the EPA approach to background evaluations in the CERCLA cleanup program (EPA 2002b) will be followed to address this issue.

In addition to the HQ analysis described above, a few studies were also available in which fish collected from the LDW were evaluated for effects. Based on studies comparing reproductive endpoints in English sole collected from the LDW relative to reference sites, some adverse effects have been observed. These study results are useful by providing another line of evidence through which effects to fish can be considered. However, because English sole are exposed to chemical mixtures in the field over an unknown area, relating these effects to concentrations of specific chemicals is difficult. As discussed below, the area over which English sole may be exposed in the LDW is uncertain; the utility and feasibility of collecting additional field data to reduce this uncertainty will be evaluated during development of the Phase 2 RI work plan.

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[82] Risks to bull trout are based on surrogate species or estimated critical body residues, because tissue concentrations in bull trout were unavailable.

Table 5-8. HQs for fish ROC/COPC pairs

Dietary HQs							
		Arsenic		Copper		PAHs	
		NOEC	LOEC	NOEC	LOEC	NOEC	LOEC
Juvenile chinook	Survival	na	na	0.23	na	0.03	na
	Growth	0.41	0.27	0.24	0.24	**1.7**	0.17
	Reproduction	ne	ne	ne	ne	ne	ne
Bull trout	Survival	na	na	0.01	na	ne	ne
	Growth	0.29	0.19	0.01	0.01	ne	ne
	Reproduction	na	na	na	na	na	na
English sole	Survival	na	na	0.17	na	0.0006	na
	Growth	**1.6**	**1.1**	**15**	**7.6**	0.07	0.03
	Reproduction	na	na	na	na	na	na

Critical Tissue Residue HQs									
		Mercury		TBT		DDTs		PCBs	
		NOEC	LOEC	NOEC	LOEC	NOEC	LOEC	NOEC	LOEC
Juvenile chinook	Survival (composite)	0.003[b]	na[b]	**1.1**	0.11	0.02	0.01	0.001[a]	0.0003
	Survival (individual)	na[b]	na[b]	na	na	0.01	0.006	0.002[a]	0.0004
	Growth (composite)	0.01[b]	0.009[b]	na	na	0.005	na	0.002	0.001
	Growth (individual)	na[b]	na[b]	na	na	0.002	na	0.004	0.002
	Reproduction	ne	ne	ne	ne	ne	ne	ne	ne
Bull trout	Survival	**2.2**	0.94	**1.1**	0.11	0.06	0.04	0.30	0.18
	Growth	0.55	0.34	na	na	0.01	na	**8.2**	**2.1**
	Reproduction	**2.1**	0.21	1.0	0.10	0.37	0.04	**4.2**	0.87
English sole	Survival	0.38	0.16	0.11	0.01	0.01	0.002	0.09	0.05
	Growth	0.10	0.06	na	na	0.0009	na	**2.4**	0.62
	Reproduction	0.36	0.04	0.11	0.01	0.02	0.002	**1.2**	0.25

NOTE: HQs greater than 1 are noted in **bold type**

ne – Not evaluated in the exposure and effects assessment (considered to pose negligible risk based on analyses in the problem formulation)

na – No HQ available because of lack of relevant toxicity tissue data

[a] Value also represents HQ for survival following immunological challenge

[b] No mercury tissue residue data were available for juvenile chinook salmon. Composite HQs are based on mercury tissue residues reported for shiner surfperch.

Effects studies involving juvenile chinook salmon collected from the LDW were also available. While these studies showed increased exposure in the LDW to chemicals such as PCBs, PAHs, and DDT relative to reference sites, potential adverse effects associated with this exposure were inconclusive (see Section A.4.3.1, Appendix A).

Uncertainties associated with the fish assessment are summarized in Table 5-9. The uncertainties with the highest potential to impact risk conclusions are associated with insufficient tissue residue data for whole-body fish and their prey. Collection of additional fish tissue data is considered highly feasible to fill this data gap, and will be evaluated during development of the Phase 2 RI work plan.

An additional uncertainty for piscivorous fish and English sole is limited data regarding site use by these species. The feasibility of conducting site usage studies is relatively low because of the resource-intensive effort that would be required and the difficulty in interpreting such data. The importance of these data is not necessarily to reduce uncertainty in the risk estimates,[83] but rather to provide information to estimate a link between concentrations in fish tissue and concentrations in sediment if needed in the Phase 2 ERA to support management decisions for the site.

There is also uncertainty associated with the risk conclusions for chemicals evaluated using a dietary exposure and effects approach (i.e., arsenic and copper for all three fish ROCs, and PAHs for juvenile chinook salmon and English sole). Limited benthic invertebrate prey tissue data contribute to this uncertainty. This uncertainty could result in either over- or underestimation of risks depending on site use and whether additional data would support the concentrations in existing data. Collection of these tissue data is considered feasible to fill this data gap, although because it may be difficult to collect sufficient tissue for analysis in key areas, the feasibility could be somewhat compromised. Additional uncertainty associated with risk predictions for arsenic, copper, and PAHs for all three ROCs is attributable to the limited LDW dietary composition data for these fish. Risk predictions are based on an assumption[84] that 100% of prey are benthic invertebrates for chinook salmon and English sole, and 100% fish for bull trout.

There is high uncertainty in the available effects data with potentially high impacts on risk conclusions for five of the seven COPCs (see Table A-7-25 in Appendix A). Resolving these uncertainties is considered to have low feasibility because they would generally require additional toxicity testing to verify or supplement toxicological data available in the literature.

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[83] Because whole body data are used in the critical residue approach, as long as the fish primarily uses the LDW as habitat, these data should integrate exposure over preferred habitat.

[84] Alternative dietary scenarios were explored in the uncertainty assessment for fish. Based on this assessment, different dietary assumptions are not likely to affect risk conclusions for these ROC/COPC pairs.

Table 5-9. Summary of key uncertainties in fish risk characterization

Issue	Level of Uncertainty	Effect of Uncertainty on Risk Estimate	Potential Means to Decrease Uncertainty	Potential Impact on Risk Conclusions	Feasibility
Exposure Assessment					
Limited English sole tissue data	medium	unknown[a]	collect whole body English sole	high–PCBs; medium-Hg, TBT, DDT	high
No TBT tissue data for juvenile chinook salmon	medium	low to moderate overestimate of risk to juvenile chinook salmon	collect juvenile chinook TBT tissue data	medium- TBT	high
No tissue data for piscivorous fish	high	unknown[a]	collect piscivorous fish tissue data	high–Hg, TBT, DDTs, PCBs	high
Limited bull trout prey data	medium	unknown[a]	collect prey fish tissue	medium- As; low- Cu	high
Limited benthic invertebrate tissue data	high	unknown[a]	collect benthic invertebrate tissue data or stomach contents	high–English sole As; medium–juvenile chinook salmon As, Cu; low–English sole Cu and PAHs and juvenile chinook salmon PAHs	high
Limited dietary composition data	low	unknown[a]	analyze stomach contents	low - juvenile chinook salmon As, Cu; low - English sole As, Cu, PAH	medium
Limited site use data	medium	unknown, depends if preferential feeding	English sole, piscivorous fish tagging studies	medium–bull trout (piscivores); medium-English sole; low-juvenile chinook salmon	low
Effects assessment					
Application of existing TRVs	see Table A-7-8 in Appendix A	dependent on applicability of study	additional toxicity testing would be required	variable – see Table A-7-8 in Appendix A	low
TRV based on safety factor of 10	medium	potential overestimation of risk	additional toxicity testing would be required	high-bull trout & English sole-TBT high-bull trout-Hg	low

[a] Risk may be higher or lower depending on the concentration of the COPC in the LDW fish population relative to that indicated by the available tissue data.

Level of uncertainty key: **low** = large or relevant dataset
medium = small dataset or limited information
high = very limited data

Potential effect key: **low** = unlikely to result in a change of HQ from less than 1 to greater than 1 (or vice versa)
medium = could result in a change of HQ from less than 1 to greater than 1 if worst-case scenario is used (scenario is viewed as unlikely)
high = HQ could change from less than 1 to greater than 1 (or vice versa) using a scenario that is conservative but more reasonable than the worst-case scenario

Feasibility key: **low** = high budget or difficult research study would be required to address uncertainty
medium = issue could be resolved with a mid-level field sampling event or research study or a detailed assessment of literature
high = issue could be resolved with additional literature search or through limited field sampling

In summary, based on a synthesis of the HQ calculations presented in the risk estimation and the uncertainty assessment for fish, the following recommendations were made, based on available data:

- **Juvenile chinook salmon**. TBT and PAHs are recommended for further evaluation in the Phase 2 ERA. Collection of additional arsenic and copper exposure data is recommended for Phase 2. Mercury, DDT, and PCBs are estimated to pose low risk. However, PCBs are recommended for further evaluation in the Phase 2 ERA due to the ESA status of juvenile chinook salmon.
- **Bull trout.** TBT, mercury and PCBs are recommended for further evaluation in the Phase 2 ERA. Collection of additional arsenic and DDT exposure data is recommended for Phase 2. Copper is estimated to pose low risk, based on available data.
- **English sole.** Arsenic, copper, PCBs, TBT, and PAHs are recommended for further evaluation in the Phase 2 ERA. Collection of additional mercury exposure data is recommended for Phase 2. DDT is estimated to pose low risk, based on available data.

5.4 WILDLIFE ASSESSMENT

This section presents an overview of the Phase 1 risk assessment for wildlife species in the LDW. Additional detail on this assessment can be found in Sections A.5 and A.7.3 in Appendix A.

5.4.1 Exposure and effects assessment

COPCs identified in the problem formulation[85] for the five wildlife ROCs were summarized in Table 5-3. The exposure assessment provided an estimate of each ROC's exposure to COPCs through ingestion of prey and incidental sediment ingestion. Exposure doses were calculated for each ROC/COPC pair, and expressed as mg COPC ingested per kg body weight per day (Equation 1). Estimates of dietary composition and site usage were made using site-specific information, if available, along with species life history information. Exposure dose calculations used spatially weighted average (SWA) sediment concentrations[86] and the lower of either the maximum or 95% UCL mean prey tissue concentrations. A summary of estimated exposure doses for wildlife is presented in Table A-5-20 in Appendix A.

$$\text{Exposure Dose} = \frac{\text{DFC} \times \text{C}_{\text{food}} \times \text{SUF}}{\text{BW}}$$

Equation 1

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[85] The COPC selection process for wildlife was based in part on the King County wildlife risk assessment conducted as part of their Water Quality Assessment (King County 1999a).

[86] Uncertainties in the use of these SWA sediment concentrations were addressed in the uncertainty assessment (Appendix A, Section A.7.3).

where:

Exposure Dose = COPCs ingested per day via food and sediment (mg COPC/kg body weight/day)
DFC = daily food consumption rate (kg food and sediment/day dw)
C_{food} = concentration in prey items plus sediment (mg COPC/kg food and sediment dw)
SUF = site usage factor (unitless)
BW = wildlife species body weight (kg ww)

Concentrations of PCBs in heron eggs were also available from a site near the LDW. These data were also summarized in the exposure assessment because they represent another line of evidence to assess potential risks to herons from PCBs (see Table A-5-20 in Appendix A).

The effects assessment evaluated dietary doses associated with adverse effects on survival, growth, and reproduction for each ROC/COPC pair. Threshold effects concentrations of total PCBs and PCB-TEQs[87] in bird eggs were also compiled. The toxicity literature was searched and relevant data for birds and mammals were compiled and screened against a set of guidelines to select the most appropriate TRVs. TRVs for both no-effects and low-effects data were chosen, as summarized in Tables A-5-21 and A-5-22 in Appendix A.

5.4.2 Risk characterization and uncertainty assessment for wildlife

In the wildlife risk characterization, exposure and effects data presented in Sections A.5.1 and A.5.2, Appendix A, were used to calculate dietary-based HQs for each of the five wildlife ROCs (Table 5-10).

None of the dietary LOAEL-based HQs exceeded 1 for any wildlife ROC. Thus, risks to wildlife appear to be low based on existing dietary data. NOAEL-based HQs were greater than 1 for five ROC/COPC pairs. However, as discussed earlier, due to the uncertainty regarding the concentration associated with effects between the NOAEL and LOAEL, the interpretation of risk based on NOAEL-based HQs is more uncertain. The highest NOAEL-based HQs were reported for river otter/PCBs (8.5), river otter/arsenic (6.1), and sandpiper/lead (4.1). NOEC-based HQs were also just over 1 for mercury and great blue heron and eagle, conservatively assuming a site use factor (SUF) of 1.

However, PCB concentrations measured in heron eggs from the colony in West Seattle indicated a higher potential for risk. The LOEC-based HQ based on this line of evidence was 2.9, while the NOEC-based HQ was 6.6 (Table 5-11). These results are contradictory to the HQs calculated for great blue heron and PCBs using the dietary approach, where LOEC- and NOEC-based HQs were less than 1 (0.12 and 0.27,

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[87] TEQs represent a summation of the TCDD-like equivalents of various PCB congeners multiplied by their corresponding concentrations measured in heron eggs.

respectively). If, however, a TEQ approach was used to assess the PCB risk to great blue heron with the egg data, the NOEC-based HQ would be 3.6, and the LOEC-based HQ 1.8. Considering the uncertainty in these estimates using either approach, differences in risk estimates of this magnitude are not large. It appears that exposure of great blue heron to PCBs in the LDW or surrounding area may be near the level where adverse effects on reproduction could occur, and thus this ROC/COPC pair is recommended for further evaluation in the Phase 2 ERA.

Although arsenic HQs were greater than 1, risk may not be elevated relative to background risk in the region. In the Phase 2 ERA, the EPA (2002b) approach will be followed to address this issue.

Table 5-10. Dietary dose HQs for wildlife ROC/COPC pairs

COPC	EXPOSURE DOSE (mg/kg bw/day)	NOAEL TRV (mg/kg bw/day)	LOAEL TRV (mg/kg bw/day)	NOAEL HQ	LOAEL HQ
Sandpiper					
PCBs	0.363	0.41	0.94	0.88	0.39
Copper	27.5	47	62	0.59	0.44
Lead	8.23	2.0	20	**4.1**	0.41
Zinc	23.9	82	123	0.29	0.19
BEHP	0.419	5.1	350	0.08	0.001
Great Blue Heron					
Lead	0.109	2.0	20	0.04	0.004
Mercury	0.0825	0.0091	0.091	**1.7**	0.17
PCBs	0.0156	0.41	0.94	0.27	0.12
Bald Eagle					
Lead (SUF=0.25)	0.0298	2.0	20	0.005	0.0005
Lead	0.119	2.0	20	0.02	0.002
Mercury (SUF=0.25)	0.0104	0.0091	0.091	0.28	0.03
Mercury	0.0415	0.0091	0.091	**1.1**	0.11
PCBs (SUF=0.25)	0.0026	0.41	0.94	0.07	0.03
PCBs	0.0103	0.41	0.94	0.29	0.13
River Otter					
PCBs	0.128	0.015	0.15	**8.5**	0.85
Arsenic	0.774	0.126	1.26	**6.1**	0.61
Lead	0.0619	0.5	1.5	0.12	0.04
Harbor Seal					
PCBs (SUF=0.25)	0.0103	0.015	0.15	0.69	0.07

NOTE: HQs greater than 1 are noted in **bold type**.

SUF – site use factor. SUFs range from 0 (species does not use the site) to 1 (species uses this site exclusively); all SUFs were assumed to equal 1 unless otherwise indicated.

Table 5-11. Egg HQs for heron

COPC	Egg Concentration (mg/kg ww)	NOEC TRV (mg/kg ww)	LOEC TRV (mg/kg ww)	NOEC HQ	LOEC HQ
PCBs	47	7.1	16	**6.6**	**2.9**
TEQs	1.8×10^{-3}	0.5×10^{-3}	1×10^{-3}	**3.6**	**1.8**

NOTE: HQs greater than 1 are noted in **bold type**.

TEQ – Summation of toxicity equivalence factors (TEF)s multiplied by the corresponding concentration of PCB congeners

Uncertainties associated with the wildlife assessment are summarized in Table 5-12. The uncertainties with the highest potential to impact risk conclusions are associated with sandpiper. For this ROC, uncertainties related to site use and amphipod tissue data could result in an over- or underestimation of ingestion of COPCs, and therefore may affect risk conclusions. Collection of additional amphipod data is considered feasible to fill this data gap, although because it may be difficult to collect sufficient tissue for analysis in key areas, the feasibility could be somewhat compromised. A site use assessment for sandpipers would likely require a higher level of effort.

For eagle, both the potential for ingestion of birds (such as gulls, grebes, and waterfowl) and the fish tissue data are uncertainties that may affect risk conclusions. The potential for bird ingestion to impact the risk conclusion is considered medium for PCBs because an HQ greater than 1 would result only by using the worst-case assumption that the birds consumed by eagles feed entirely on fish resident to the LDW. Feasibility of collecting birds for tissue chemical analysis was given a medium rank because of the level of effort and possible permitting constraints for some species. Fish tissue data collection was considered highly feasible. There is medium uncertainty related to eagle/mercury due to the SUF, because the HQ would equal 1 only if the highly conservative assumption that eagles feed entirely on LDW prey was used.

For heron and otter, the primary uncertainties are related to limited fish tissue data and unknown proportion of fish types in the diet. Using a worst-case scenario of heron ingesting only English sole containing the maximum detected PCB concentration resulted in an HQ of 1, so this uncertainty was ranked as medium. Feasibility of filling the fish tissue data gap was considered high, while determining the proportion of fish in the heron's diet would require a more substantial field effort.

Table 5-12. Summary of primary uncertainty in wildlife risk characterization

ISSUE	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK CONCLUSIONS	FEASIBILITY OF FILLING DATA GAP
Exposure Assessment					
Fish consumption by sandpiper	medium	slight underestimate of risk	observe feeding habits of sandpiper in the LDW	low	low
Bird ingestion by eagle	medium	underestimate of risk assuming birds contain higher COPC concentrations than fish	collect bird data; model tissue concentrations in bird	medium for PCBs, low for mercury and lead	medium
Proportion of fish types in piscivore diets	high	underestimate of risk assuming ROCs consume higher proportions of more contaminated fish	observe feeding habits of heron; analysis of stomach contents, scat samples, or observe feeding habits for seal	medium for heron/PCBs and seal/PCBs, low for others	low
Site usage by eagle	medium	potential underestimate of risk if lower site use factor is used	conduct eagle site use survey	medium for mercury, low for PCBs and lead	low
Amphipod tissue data and site usage for sandpiper	medium	potential underestimate of risk	collect additional amphipod tissue data, conduct sandpiper site use survey	high for PCBs, medium for copper and zinc	high, medium
Fish tissue data	high	unknown[a]	collect additional fish tissue data	medium for PCBs/eagle, PCBs/heron and PCBs/seal, low for otter	high
Daily food consumption rate of otter	medium	unknown; risk could be over- or underestimated	measure daily consumption rates of otter	low	low
Effects Assessment					
Application of available effects data	see Table A-7-39	dependent upon applicability of study	additional toxicity testing would be required	see Table A-7-39	low

[a] Risk may be higher or lower depending on the concentration of the COPC in the LDW fish population relative to that indicated by the available tissue data.

Level of uncertainty key: **low** = large or relevant dataset
medium = small dataset or limited information
high = very limited data

Potential effect key: **low** = unlikely to result in a change of HQ from less than 1 to greater than 1 (or vice versa)
medium = could result in a change of HQ from less than 1 to greater than 1 if worst-case scenario is used (scenario is viewed as unlikely)
high = HQ could change from less than 1 to greater than 1 (or vice versa) using a scenario that is conservative but more reasonable than the worst-case scenario

Feasibility key: **low** = high budget or difficult research study would be required to address uncertainty
medium = issue could be resolved with a mid-level field sampling event or research study or a detailed assessment of literature
high = issue could be resolved with additional literature search or through limited field sampling

For seal, there are uncertainties associated with SUF, diet composition, and fish tissue data. For PCBs, an HQ of 1.5 would be calculated if it were assumed that seals obtain 33% of their food from the LDW[88] and consume only English sole containing the maximum detected PCB concentration (a highly conservative assumption). Therefore, the potential to impact risk conclusions was ranked medium. Feasibility of collecting additional fish data is considered high, but feasibility of gathering information on diet composition is low because of the permitting issues and extended fieldwork that would be necessary.

In summary, based on a synthesis of risk estimation results and the uncertainty assessment for wildlife, the following recommendations were made, based on the available data:

- **Spotted sandpiper.** Lead is recommended for further evaluation in the Phase 2 ERA. The utility and feasibility of gathering additional data for PCBs, copper, and zinc will be evaluated during development of the Phase 2 RI work plan. Based on available data, risk from BEHP appears to be low.
- **Great blue heron.** PCBs and mercury are recommended for further evaluation in the Phase 2 ERA. Based on existing data, risks from lead appear to be low.
- **Bald eagle.** PCBs and mercury are recommended for further evaluation in the Phase 2 ERA. Based on existing data, risks from lead appear to be low.
- **River otter.** PCBs and arsenic are recommended for further evaluation in the Phase 2 ERA. Based on existing data, risks from lead appear to be low.
- **Harbor seal.** The utility and feasibility of gathering additional data for PCBs will be evaluated during development of the Phase 2 RI work plan.

5.5 PLANTS ASSESSMENT

This section presents an overview of the Phase 1 risk assessment for plants. Additional detail on this assessment can be found in Sections A.6 and A.7.4 in Appendix A.

5.5.1 Exposure and effects assessment for plants

Lead, mercury, zinc, and PCBs were identified as COPCs in the problem formulation for rooted aquatic plants. Exposure to plants was assessed through the concentrations of these COPCs in marsh sediment, where plants are most likely to grow based on habitat constraints. These concentrations were also compared to Puget Sound background concentrations to provide perspective. No toxicity data were available for rooted estuarine plants to estimate effects. Thus, available toxicity data for terrestrial rooted plants in soils were used (Efroymson et al. 1997). Large and overlapping ranges of NOECs and LOECs were observed for lead, PCBs, and zinc. A single mercury study was identified, but it was not acceptable due to the presence of co-occurring chemicals.

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[88] A SUF for seal of 0.33 is based on the observation of seals 17 times in the 52 days surveyed in the LDW (WDFW 1999)

NOECs and LOECs selected for the COPCs are presented in Table A-6-4 in Appendix A. Application of this toxicity information is highly uncertain, however, because the relative sensitivity and exposure of the tested species and those present in the LDW marsh areas is unknown.

5.5.2 Risk characterization and uncertainty assessment for plants

Due to the relatively high level of uncertainty in both effects and exposure data available for plants within the LDW, ranges of exposure and effects data were presented and corresponding ranges of HQs were calculated (Table 5-13). HQs were also calculated using the 95% upper confidence limit (UCL) on the mean concentration in marsh sediments (n=7 samples) and the NOEC or LOEC identified in Section A.6.2 (Appendix A) as most suitable.[89]

Scenarios were possible for LOEC-based HQs to be greater than 1 for zinc and lead. HQs calculated for PCBs were less than 1 under all potential scenarios using available data (maximum NOEC-based HQ is 0.94), indicating that risk to rooted aquatic plants from PCBs is likely low. No acceptable plant toxicity thresholds for mercury were identified in the literature, and thus exposure concentrations in LDW marsh areas were compared to the proposed Puget Sound sediment reference area performance standard (PTI 1991) for mercury as an indicator of background concentrations in Puget Sound sediments. Mercury concentrations in marsh sediments of the LDW were found to be similar to this background performance standard (with ratios ranging from 0.6 to 2.5). Because these ratios provide a comparison to background sediment, and not to effects data, the potential for effects is uncertain. The similarity to background concentrations suggests that exposure of plants to mercury in marsh areas is similar to that typically detected in Puget Sound sediments.

Zinc concentrations in marsh sediment were also similar to background concentrations (55-155 mg/kg in marsh sediments vs. 15-133 mg/kg background). Thus, although HQs greater than 1 could be calculated, risk to plants in LDW marsh areas is likely to be similar to regional background levels.

Lead concentrations in marsh sediments were higher than background levels (9.3–330 mg/kg in marsh sediments vs. 0.1–24 mg/kg in background sediments) and HQs ranging from 0.0019 to 37 (NOECs) and 0.0003 to 16 (LOECs) were calculated using the range of available sediment concentrations. Because of the large range and the high uncertainty associated with the effects data, it is highly uncertain if rooted aquatic plants in the LDW are at risk from lead.

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[89] TRV selected based on weight of evidence of data as well as background considerations for Pb and Zn.

Table 5-13. Ranges of HQs for rooted aquatic plant/COPC pairs

COPC	Marsh[a] Sediment Exposure Concentrations (mg/kg dw); range and 95% UCL on the mean[b]	NOECs available, range and selected TRV (mg/kg dw soil)	LOECs Available, range and selected TRV (mg/kg dw soil)	Background Concentrations	NOEC HQs (range and selected[c] TRV/mean conc)	LOEC HQs (range and selected TRV/mean conc)
Lead	9.3-330 (158)	9.0-5,000 (100)	21-30,000 (125)	0.10U-24[d]; 29.6[e]; 20[f]	0.0019-37 (1.6)	0.00030-16 (1.3)
Mercury	0.090-0.37 (0.25)	na [g]	na [g]	0.010-0.28[d]; 0.0944[e]; 0.15[f]	0.60-2.5 (1.7) [h]	0.60-2.5 (1.7) [h]
PCBs	0.020-9.4 (1.7)	10-1,000 (20)	40-1,000 (327)	0.0031-0.050U[d]; 0.047[f]	0.000020-0.94 (0.090)	0.000020-0.24 (0.0050)
Zinc	56-155 (133)	10-2,500 (20)	25-5,000 (40)	15-101J[e]; 132.5[e]; 103[f]	0.022-16 (6.7)	0.011-6.2 (3.3)

U – Undetected

J – Estimated

[a] Concentrations of COPC within 50 m of marsh habitat (per USFWS designation) (n=7 stations: DR013, DR014, DR061, DR263, DR264, DR270, DR271; see RI Maps 2-5a through 2-5k)

[b] Nondetects were treated as half the detection limit in the 95% UCL mean calculations

[c] Selection of a TRV for plants is discussed in Section A.6.2

[d] PTI (1991) (range of concentrations from Puget Sound sediment reference areas)

[e] Ecology (1994) (maximum concentration in Puget Sound region natural soil background)

[f] PTI (1991) (proposed Puget Sound reference area performance standard [i.e., sites with concentrations lower than these standards are suitable for reference area classification])

[g] No acceptable studies were identified for mercury and plants

[h] Proposed reference area performance standard used in place of NOEC or LOEC because no TRVs were available (i.e., HQ was based on a comparison to background concentration rather than a TRV)

The primary uncertainties associated with the plant assessment are the relevance of the available toxicity data, particularly for lead, which had concentrations in marsh sediments greater than background concentrations (Table 5-14). Due to the relatively small sediment dataset available for marsh areas, estimating exposure of COPCs to plants is also somewhat uncertain. Based on the HQ calculations and the uncertainties, none of the COPCs are recommended for further assessment for plants in the Phase 2 ERA. However, the utility and feasibility of collecting more data to refine the lead assessment will be evaluated during development of the Phase 2 RI work plan.

Table 5-14. Summary of primary uncertainties in plant risk characterization

ISSUE	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK CONCLUSIONS	FEASIBILITY TO FILL DATA GAP
Exposure Assessment					
Use of sediment data alone to estimate exposure	medium	possibly underestimated	estimate exposure through water	low	medium
Use of limited marsh dataset	medium	accuracy unknown	collect additional sediment data	medium	high
Impact of potential restoration projects	medium	overestimated in areas to be restored	assess during planning of potential projects	low	low
Effects Assessment					
Soil vs. sediment toxicity data	high	accuracy unknown	develop alternative TRVs	medium	low
Relevance of plants studied in literature	medium	accuracy unknown	develop alternative TRVs	medium	low
Large range of NOECs and LOECs reported in literature	high	possibly overestimated	assess risks using median TRV	high	medium

Level of uncertainty key: **low** = large or relevant dataset
medium = small dataset or limited information
high = very limited data

Potential effect key: **low** = unlikely to result in a change of HQ from less than 1 to greater than 1 (or vice versa)
medium = could result in a change of HQ from less than 1 to greater than 1 if worst-case scenario is used (scenario is viewed as unlikely)
high = HQ could change from less than 1 to greater than 1 (or vice versa) using a scenario that is conservative but more reasonable than the worst-case scenario

Feasibility key: **low** = high budget or difficult research study would be required to address uncertainty
medium = issue could be resolved with a mid-level field sampling event or research study or a detailed assessment of literature
high = issue could be resolved with additional literature search or through limited field sampling

5.6 CONCLUSIONS

Based on available data, the Phase 1 ERA evaluated risks from sediment-associated chemicals to benthic invertebrates, crab, fish, and wildlife species that may reside or forage in the LDW for at least a portion of their lives. Although there is relatively little suitable habitat presently available for rooted aquatic plants within the LDW, risks to this group were also evaluated. Based on risk estimates and assessments of uncertainty, ROC/COPC pairs are recommended for further assessment in the Phase 2 ERA, as summarized below, and data needs were identified. ROC/COPC pairs for the Phase 2 ERA will be determined in the Phase 2 problem formulation based on Phase 1 results, analysis of additional data collected in Phase 2, and methods described in the Phase 2 RI work plan.

For benthic invertebrates, 70% of the area in the LDW had no exceedances of sediment quality standards or guidelines for any chemical based on detected concentrations, and thus risk to benthic invertebrates in those areas appears to be low. The likelihood of effects is higher in the 10% of the area in the LDW with exceedances of CSLs or MLs for at least a single chemical, and risk in areas with sediment chemical concentrations between the SQS (or SL) and the CSL (or ML) is uncertain. The potential for adverse effects on the benthic invertebrate community is thus recommended for further evaluation in Phase 2. In addition, the potential for adverse effects from TBT is recommended for further evaluation in Phase 2, as is the potential effect of sediment-associated chemicals on crab, even though risk to crab appears to be low.

For fish, preliminary risk estimates indicate that sediment-associated copper, arsenic, and PCBs may result in adverse effects because exposure estimates were greater than the lowest relevant effects data. Although not exceeding concentrations associated with an adverse effect (i.e., only a “no effect” concentration was exceeded), risks from mercury, PAHs, and TBT are also recommended for further investigation in Phase 2 for at least one fish ROC. Evaluations of arsenic related to background or regional risk for arsenic are also recommended for consideration in Phase 2, following EPA (2002b) guidance. Site-specific work with English sole suggested the potential for adverse effects on reproduction compared to reference areas. However, linking these effects to individual chemicals is highly uncertain and will be discussed in the Phase 2 ERA.

For wildlife, none of the preliminary exposure estimates resulted in dietary doses greater than those associated with adverse effects. However, data from heron eggs, another line of evidence, indicated that risks from PCBs should be further evaluated. In addition to PCBs, potential issues from sediment-associated arsenic, lead, and mercury are also recommended for further evaluation in Phase 2.

The aquatic plant assessment in Phase 1 was highly uncertain, primarily as a result of the questionable applicability and wide range of available toxicity data. Only potential issues associated with lead exposure were identified for consideration in the development of the Phase 2 work plan.

In addition to providing input to the Phase 2 ERA and identifying data gaps, the Phase 1 ERA provided information used in the identification of candidate sites for early remedial action. Although risk estimates to fish, wildlife, and plants did not reach the level required to trigger the identification of additional areas in the LDW for early action,[90] these receptors will benefit from any remedial action that results in lower concentrations of chemicals in surface sediments, particularly those chemicals discussed above. Risks to benthic invertebrates (as indicated by sediment standard or guideline exceedances) were used directly in the candidate site identification process, and risks to these species will also be reduced through early remedial action.

6.0 Summary of the Phase 1 HHRA

This section summarizes the Phase 1 (scoping-phase) HHRA that was conducted as part of the Phase 1 RI. The complete HHRA is in Appendix B. The Phase 1 HHRA was based on existing data only. Data gaps identified as part of the Phase 1 HHRA will be filled prior to conducting the baseline HHRA during the Phase 2 RI. This section summarizes the key components of the HHRA, including the data evaluation, the conceptual site model and exposure assessment, the toxicity assessment, the risk characterization, and the uncertainty assessment.

6.1 DATA EVALUATION

People may be exposed to chemicals found in LDW sediments either through direct exposure to sediment or indirectly through seafood consumption. Accordingly, both tissue and sediment chemistry data are relevant for this HHRA.

The available sediment and tissue chemistry data are described in Sections 2.3.1 and 2.3.5, respectively. Only surface sediment chemistry data were used in the HHRA because it was assumed that people are unlikely to be exposed to deeper sediments given the primarily depositional nature of the LDW hydrodynamic environment (see Section 4.4). Further information will be collected and analyses will be conducted on sediment fate and transport in Phase 2. Surface sediment samples were collected from both subtidal and intertidal[91] areas of the LDW. Some of the sediment samples previously collected were from areas that have been subsequently dredged. Consequently, the data from these samples are not relevant for assessing current conditions since the sediment no longer exists in the LDW. Table D-1 (Appendix D) lists the samples that were excluded from the HHRA for this reason.

Tissue chemistry data have been collected for chinook and coho salmon, English sole, crabs, mussels, and perch (Table 2-5). Only data from composite samples for crab (edible meat and hepatopancreas), English sole fillets, perch fillets, and mussels were used in this HHRA.

Adult salmon data were not utilized in the HHRA because there is unlikely to be a relationship between site-related contamination and chemical concentrations in adult salmon tissue. Salmon feed very little as adults once they enter rivers and streams,

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[90] For a fish or wildlife ROC/COPC pair to trigger site identification, the LOEC- or LOAEL-based HQ has to exceed 10 (Windward 2002).

[91] The elevation dividing intertidal and subtidal locations was –2 ft mean lower low water (MLLW).

and diet is probably the primary exposure pathway to sediment-related chemicals. Because salmon returning to the Duwamish estuary were exposed to site-related chemicals only very briefly as juveniles, the contribution of this exposure to adult body burdens is insignificant (O'Neill et al. 1998).

Part of the data evaluation process involves assessing the suitability of existing data for use in the risk assessment. The key considerations include how well existing data reflect site-related contamination and expected human exposure conditions at the site, and data adequacy as reflected by QA/QC results. As described in greater detail in Section B.2.3.1.1 of Appendix B, more sediment samples were collected in areas near suspected contaminant sources. The small amount of available intertidal sediment chemistry data between Slip 4 and Kellogg Island do not appear to adequately characterize the expected human exposure in that area. Additional data on this topic will be collected during Phase 2.

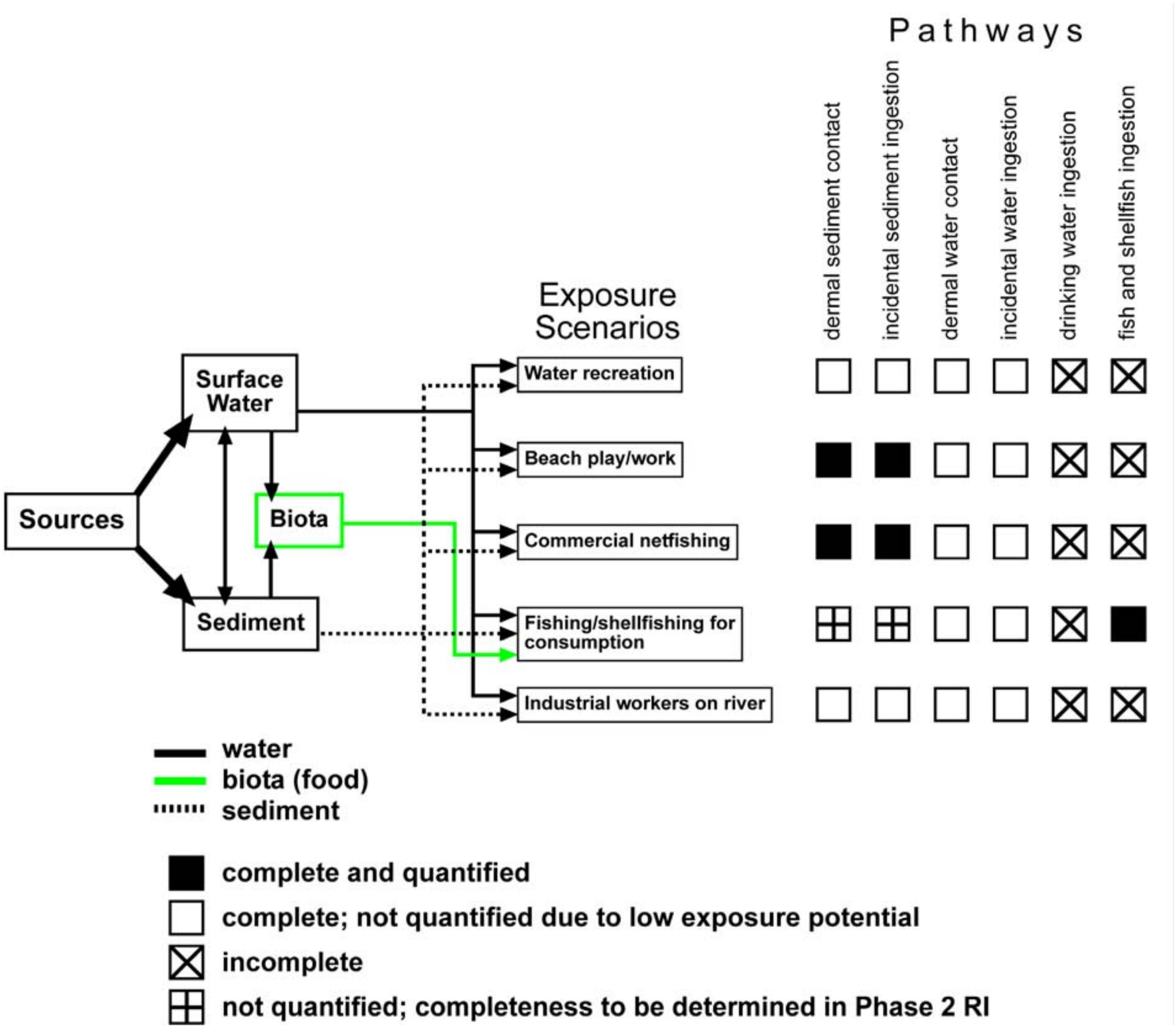
6.2 EXPOSURE ASSESSMENT

The exposure assessment in Appendix B described scenarios in which people may come in contact with COPCs from contaminated sediment and provided equations and parameters so that such exposure can be quantified.

6.2.1 Selection of exposure pathways

The first step in the exposure assessment was to select exposure scenarios to evaluate quantitatively. Exposure scenarios evaluated previously for the LDW, including Harbor Island, are summarized in Table B-4 in Appendix B. Two exposure scenarios, consumption of seafood by recreational anglers and exposure to sediment by commercial fishermen, were evaluated in more than one previously conducted risk assessment and are also included in this HHRA.

The conceptual site model is a graphical representation of chemical sources, transport mechanisms, exposure routes, and potentially exposed populations (Figure 6-1). Five exposure pathways are represented in Figure 6-1, corresponding to potentially exposed populations described in Section 2.6. Each pathway includes a potential direct exposure route (i.e., incidental sediment ingestion or dermal contact) or indirect exposure route (i.e., ingestion of seafood) to COPCs in contaminated sediments. Each pathway is discussed in greater detail in Section B.3.2 of Appendix B.



Exposure Scenarios	dermal sediment contact	incidental sediment ingestion	dermal water contact	incidental water ingestion	drinking water ingestion	fish and shellfish ingestion
Water recreation	☐	☐	☐	☐	☒	☒
Beach play/work	■	■	☐	☐	☒	☒
Commercial netfishing	■	■	☐	☐	☒	☒
Fishing/shellfishing for consumption	⊞	⊞	☐	☐	☒	■
Industrial workers on river	☐	☐	☐	☐	☒	☒

■ complete and quantified
☐ complete; not quantified due to low exposure potential
☒ incomplete
⊞ not quantified; completeness to be determined in Phase 2 RI

Figure 6-1. **Conceptual site model for Phase 1 human health risk assessment**

Table 6-1 lists the exposure pathways that were selected for quantitative evaluation. Separate exposure scenarios for seafood consumption by tribal members and Asian and Pacific Islanders (API) were included. These scenarios were intended to be more health-protective than scenarios that specifically addressed recreational seafood consumption, so risks for the latter scenario were not quantified in the Phase 1 HHRA. Similarly, the beach play exposure scenario was considered more health-protective than a scenario that included workers that may come in contact with intertidal sediments, so only risks for the former scenario were quantified. Exposure pathways that are primarily water-based, such as swimming and other recreational uses, and exposure pathways for industrial workers (not including commercial fishermen) were not quantitatively evaluated in this HHRA. However, risks associated with surface water contact were considered in this assessment. Specifically, risk estimates for swimming presented in the King County Water

Quality Assessment HHRA (King County 1999a) were summarized and included in the risk characterization section. Additional details on the King County analysis are provided in the HHRA subappendix B1. The King County assessment suggested that risks from these scenarios were well within acceptable levels identified by EPA.[92]

Risk estimates for the industrial worker scenario are likely to be much lower than estimates for the other pathways listed on Table 6-1, so this scenario was not evaluated further.

Table 6-1. Exposure pathways included in the Phase 1 HHRA

ACTIVITY	ROUTE/EXPOSURE MEDIUM	GROUP
Fishing	Consumption of seafood	tribal and API adults and tribal children
Commercial netfishing	Incidental ingestion of sediment Dermal contact with sediment	adults adults
Beach play	Incidental ingestion of sediment Dermal contact with sediment	children children

API - Asian and Pacific Islanders

6.2.2 Screening and evaluation of chemicals of potential concern (COPCs)

Many different chemicals have been measured in both sediment and tissue collected from the LDW. In accordance with EPA (1997a) guidelines, where unacceptable risk has been related to a specified concentration (risk-based concentration or RBC), risk-based screening was conducted to determine which chemicals should be evaluated in the Phase 1 HHRA. For detected chemicals with RBCs, the maximum detected concentration was compared to the applicable RBC. Detection limits were also evaluated relative to the RBCs for chemicals whose maximum detected concentrations did not exceed the RBCs and for chemicals that were undetected. Screening was conducted separately for intertidal sediment (beach play scenario), intertidal and subtidal sediment (netfishing scenario), and tissue chemistry (seafood consumption scenario) data.

EPA has not developed RBCs specifically for sediment, but soil RBCs provide a health-protective means to evaluate scenarios that include incidental ingestion and dermal contact with sediment because the RBCs assume more frequent contact with soil than would be expected for sediment. Soil RBCs developed by EPA Region 9 (1999c) were used to screen data for sediment COPCs. EPA (1999c) contains soil RBCs for both industrial and residential scenarios. Residential RBCs were applied to the beach play scenario and industrial RBCs were applied to the netfishing scenario. Fish tissue RBCs developed by EPA Region 3 (EPA 2000a) were used for the fishing scenario. The Region 3 RBCs were modified to account for site-specific differences,

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[92] The highest excess cancer risk estimate from incidental ingestion and direct contact with water due to swimming in the LDW was 4 in 1,000,000 including estimates for both adults and children. All hazard quotients were less than 1 for both adults and children (King County 1999b).

including a higher consumption rate, exposure frequency, body weight, and exposure duration.

Forty-three chemicals were identified as COPCs for one or more scenarios; ten chemicals were identified for all three scenarios (Table 6-2). Of these COPCs, 22 were never detected in either sediment or tissue (or both) and were included because detection limits were elevated above risk-based concentrations (RBCs). These 22 COPCs were evaluated in the uncertainty assessment. Seventeen chemicals were selected as COPCs for the netfishing scenario, three of which were based on comparison of detection limits with RBCs. Twenty-nine COPCs were selected for the beach play scenario, six of which were based on elevated detection limits. Thirty-one COPCs were identified for the seafood consumption scenario, nineteen of which were based on elevated detection limits.

Table 6-2. Selection of chemicals of potential concern for Phase 1 HHRA[a]

CHEMICAL	NETFISHING SCENARIO		BEACH PLAY SCENARIO		SEAFOOD CONSUMPTION SCENARIO	
	SELECTED AS COPC?	RATIONALE	SELECTED AS COPC?	RATIONALE	SELECTED AS COPC?	RATIONALE
1,2,3-Trichloropropane	No	24 of 44 DLs < RBC	Yes	all DLs > RBC	No	not analyzed
1,2-Diphenylhydrazine	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
2-Nitroaniline	No	1 of 525 DLs > RBC	Yes	68 of 184 DLs > RBC	No	no RBC available
2,3,7,8-TCDD TEQ	Yes	max detection > RBC	Yes	max detection > RBC	No	not analyzed
3,3'-Dichlorobenzidine	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
Aldrin	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
Alpha-BHC	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
Aluminum	Yes	max detection > RBC	Yes	max detection > RBC	No	not analyzed
Antimony	Yes	max detection > RBC	Yes	max detection > RBC	No	26 of 27 DLs < RBC
Arsenic	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
Barium	No	max detection < RBC	Yes	max detection > RBC	No	not analyzed
Benzidine	Yes	all DLs > RBC	Yes	all DLs > RBC	Yes	all DLs > RBC
Beta-BHC	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
bis(2-chloroethyl)ether	No	7 of 527 DLs > RBC	Yes	29 of 186 DLs < RBC	Yes	all DLs > RBC
bis(2-ethylhexyl)phthalate	No	max detection < RBC	No	max detection < RBC	Yes	max detection > RBC
bis-chloroisopropyl ether	No	all DLs < RBC	No	all DLs < RBC	Yes	27 of 30 DLs > RBC
Cadmium	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
Carcinogenic PAHs	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
Chlordane	No	max detection < RBC	No	max detection < RBC	Yes	all DLs > RBC
Chromium	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
Copper	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
DDTs (total)	No	max detection < RBC	Yes	max detection > RBC	Yes	max detection > RBC
Dieldrin	Yes	max detection > RBC	Yes	max detection > RBC	Yes	all DLs > RBC
gamma-BHC	No	max detection < RBC	No	max detection < RBC	Yes	11 of 20 DLs > RBC
Heptachlor	No	max detection < RBC	No	max detection < RBC	Yes	all DLs > RBC

CHEMICAL	NETFISHING SCENARIO		BEACH PLAY SCENARIO		SEAFOOD CONSUMPTION SCENARIO	
	SELECTED AS COPC?	RATIONALE	SELECTED AS COPC?	RATIONALE	SELECTED AS COPC?	RATIONALE
Heptachlor epoxide	No	max detection < RBC	Yes	max detection > RBC	Yes	all DLs > RBC
Hexachlorobenzene	No	max detection < RBC	Yes	max detection > RBC	Yes	all DLs > RBC
Hexachlorobutadiene	No	all DLs < RBC	No	all DLs < RBC	Yes	27 of 30 DLs > RBC
Iron	Yes	max detection > RBC	Yes	max detection > RBC	No	not analyzed
Lead	Yes	max detection > RBC	Yes	max detection > RBC	Yes	alternate eval. method used
Manganese	Yes	max detection > RBC	Yes	max detection > RBC	No	not analyzed
Mercury	No	max detection < RBC	Yes	max detection > RBC	Yes	max detection > RBC
Nickel	No	max detection < RBC	Yes	max detection > RBC	No	max detection < RBC
N-Nitrosodimethylamine	Yes	all DLs > RBC	Yes	all DLs > RBC	Yes	all DLs > RBC
N-Nitroso-di-n-propylamine	No	12 of 527 DLs > RBC	Yes	68 of 186 DLs > RBC	Yes	all DLs > RBC
PCBs (total-calc'd)	Yes	max detection > RBC	Yes	max detection > RBC	Yes	max detection > RBC
Pentachlorophenol	No	max detection < RBC	No	max detection < RBC	Yes	all DLs > RBC
Silver	No	max detection < RBC	Yes	max detection > RBC	No	max detection < RBC
Thallium	Yes	max detection > RBC	Yes	max detection > RBC	No	not analyzed
Toxaphene	No	all DLs < RBC	No	all DLs < RBC	Yes	all DLs > RBC
Tributyltin as ion	No	max detection < RBC	No	max detection < RBC	Yes	max detection > RBC
Vanadium	No	max detection < RBC	Yes	max detection > RBC	No	max detection < RBC
Zinc	No	max detection < RBC	Yes	max detection > RBC	Yes	max detection > RBC

DL = detection limit, RBC = risk-based concentration

[a] COPCs identified based on elevated detection limits were quantitatively evaluated in the uncertainty assessment.

6.2.3 Selection of exposure parameters

The scenarios evaluated in this HHRA are consistent with EPA's guidelines for estimating the reasonable maximum exposure (RME) expected to occur under both current and future land-use conditions (EPA 1989). EPA defines the RME as the highest exposure that is reasonably expected to occur at a site. A central tendency (CT) exposure, reflecting more typical conditions compared to the RME, was also created for the netfishing scenario.

Exposure to contaminated sediment or seafood is expressed as the chronic daily intake (CDI).[93] The CDI is calculated based on site-specific data for chemical concentrations, exposure frequency, exposure duration, body weight, and averaging time. The equations for estimating the CDI for each COPC are given in Section B.3.4 of the Phase 1 HHRA. That section also lists the selected values for all the exposure parameters, which were selected from EPA guidance and derived from site-specific information to best represent specific potentially exposed populations. Values for the commercial netfishing scenario were based on data collected from the Muckleshoot Tribe, which operates a commercial netfishing operation within the LDW. Values for the seafood consumption scenario were based on data collected from the Suquamish Tribe, which utilizes the area adjacent to the LDW as part of its usual and accustomed fishing area. Specifically, a consumption rate of 84 grams per day of seafood was assumed, based on consumption rates for seafood from the entire Puget Sound, apportioned among fish species that may be consumed from the LDW (16 g/day for pelagic species and 15 g/day for benthic species), of crabs (45 g/day), and mussels (7.8 g/day). An additional scenario was evaluated using seafood consumption data collected from Asian and Pacific Islanders that fish in King County. The presence of habitat for crabs and shellfish and their harvestability in the LDW will be further evaluated during the Phase 2 RI, and consumption rates may be modified at that time. Values for the beach play exposure parameters were based primarily on best professional judgment, and should be recognized as highly speculative. Consistent with EPA (1989) risk assessment guidance, health-protective estimates were selected for all exposure scenarios to avoid underestimating risks. Consequently, risks may be overestimated for many individuals.

Site-specific chemical data were used in the CDI equation via a parameter called the exposure point concentration (EPC). EPCs were calculated for each COPC. The EPC is the assumed concentration to which all individuals in a given scenario are exposed over the assumed exposure duration. EPCs for the sediment scenarios were based on spatially-weighted average concentrations calculated in the GIS (see Section B.3.4.3 of

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[93] Although chronic daily intake technically refers to oral exposure only, this term is also used in the HHRA to refer to dermal exposure, which is technically an absorbed dose, not intake. For this HHRA, the adjustment between orally administered doses and dermally administered doses was made by adjusting the oral toxicity values (SFs and RfDs), as appropriate, according to EPA (2001) guidance. Additional details on this topic are provided in Appendix Section B.3.4.2.

Appendix B). The area over which the netfishing EPCs were calculated included the entire LDW. EPCs for the beach play scenario were based only on intertidal sediment data because children playing on the beach are expected to have little or no exposure to subtidal sediment.

EPCs for the seafood consumption scenario were also developed for each COPC, but the data on which they were based were first grouped by species in what is known as the market basket approach. In this approach, CDIs are calculated independently for diet components, which are then summed to yield an overall CDI for risk calculations. This approach provides a more accurate method for calculating the CDI when consumption rates and chemical concentrations vary by diet component (i.e., benthic fish, pelagic fish, mussels, crabs, and clams).

6.3 TOXICITY ASSESSMENT

Quantitative toxicity estimates for each COPC are derived by EPA using toxicity studies conducted on animals or epidemiological studies with humans following occupational exposure or accidental environmental exposure. The toxicity value for chemicals with non-cancer effects is called the reference dose (RfD). The RfD is an estimate, with uncertainty spanning perhaps an order of magnitude or greater, of the daily exposure to the human population, including sensitive sub-populations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. The toxicity value for chemicals that may cause cancer in humans is called the cancer slope factor (SF). The SF represents a plausible upper-bound estimate of the probability of response per unit intake of a chemical over a lifetime. The RfDs and SFs for all COPCs are given in Section B.4 of Appendix B. A toxicological profile of each COPC is also provided in Appendix B.

6.4 RISK CHARACTERIZATION

Carcinogenic risks and noncarcinogenic health effects are evaluated separately in HHRAs due to fundamental differences in their critical toxicity values. For chemicals with carcinogenic effects, the risk of cancer is proportional to dose with the assumption that there is no threshold. In other words, there is never a zero probability of cancer risk when exposed to these chemicals at any concentration. Carcinogenic risk probabilities are calculated by multiplying the estimated exposure level (CDI, in mg/kg-day) by the cancer SF (in kg-day/mg) for each chemical.

Cancer risk is expressed as a lifetime excess cancer risk. This concept assumes that the risk of cancer from a given chemical is in “excess” of the background risk of developing cancer (i.e., approximately 1 in 3 chances during a lifetime according to the American Cancer Society).

In assessing carcinogenic risks posed by a site, EPA establishes an excess cancer risk of 1×10^{-6} (1 chance in 1 million) as a “point of departure” for establishing remediation goals. Where the cumulative cancer risk to an individual based on the

RME for current and future land use is less than 1 x 10^{-4} (1 chance in 10,000), and the noncarcinogenic hazard index (see below) is less than 1, action generally is not warranted unless there are adverse environmental effects. Excess cumulative cancer risks between 1 x 10^{-6} and 1 x 10^{-4} may or may not be considered acceptable, depending on site-specific factors such as the potential for exposure, technical limitations of remediation, and data uncertainties.

Cancer risks are presented in the format of XE-Y, where X is an integer between 1 and 9, E represents an exponent (base 10), and Y is the value (negative) of the exponent. For example, 1E-5 is equivalent to 1 x 10^{-5} or 1 in 100,000. Cancer risks are presented with only one significant figure to acknowledge the uncertainty in the underlying cancer slope factors.

Chemicals with noncarcinogenic health effects are generally not toxic below a certain threshold; a critical chemical dose must be exceeded before health effects are observed. The potential for noncarcinogenic health effects is represented by the ratio of a chemical's exposure level (CDI, in mg/kg-day) and the route-specific RfD (in mg/kg-day), and is expressed as a hazard quotient (HQ).

The HQ is accepted by EPA as a way to quantify the potential for noncarcinogenic health effects (EPA 1989). HQs are not risk probabilities; the probability an adverse effect will occur does not usually increase linearly with the calculated value. An HQ greater than 1 may indicate a potential adverse health effect from a chemical exposure, although the same HQ may not equate to the same potential for adverse health effects for all chemicals. HQs for individual COPCs with similar toxicological endpoints may be summed to yield a hazard index (EPA 1989).

The cancer risk and non-cancer hazard estimates are summarized for all exposure scenarios in Table 6-3. Chemical-specific risk and HQ estimates are provided only for detected chemicals identified as COCs (i.e., those exceeding a cancer risk estimate of 1E-6 or an HQ of 1). The highest cancer risks and non-cancer hazard estimates were calculated for the seafood consumption pathways. The impact of risks posed by non-detected chemicals is evaluated in the HHRA (Appendix B, Section 6.3). Additional work will be conducted in Phase 2 to determine how to better characterize risks posed by non-detected chemicals.

Table 6-3. Summary of risk characterization for the Phase 1 HHRA

			CANCER RISK				NONCANCER HQS			
MEDIUM	EXPOSURE MEDIUM	EXPOSURE SCENARIO	CHEMICAL	INGESTION	DERMAL	EXPOSURE ROUTE TOTAL	CHEMICAL	INGESTION	DERMAL	EXPOSURE ROUTE TOTAL
Sediment	Sediment	Netfishing, adult RME	Arsenic	3E-6	1E-6	4E-6				
			Total	4E-6	3E-6	7E-6	Total [a]	0.04	0.03	0.07
		Netfishing, adult CT	Total	1E-6	9E-7	2E-6	Total [a]	0.02	0.02	0.04
		Beach play, Kellogg Island	Arsenic	2E-6	4E-7	2E-6				
			TCDD	1E-6	3E-7	1E-6				
			Total	4E-6	1E-6	5E-6	Total [a]	0.21	0.16	0.37
		Beach play, southeast	Arsenic	2E-6	4E-7	2E-6				
			TCDD	1E-6	3E-7	1E-6				
			Total	4E-6	2E-6	6E-6	Total [a]	0.37	0.25	0.62
		Beach play, southwest	Arsenic	2E-6	3E-7	2E-6				
			TCDD	1E-6	3E-7	1E-6				
			Total	4E-6	1E-6	5E-6	Total [a]	0.25	0.19	0.44
		Swimming, highly exposed adults[b]	Arsenic	4E-7	7E-7	1E-6 [c]				
			Total	5E-7	8E-7	2E-6 [c]	Total [a]	0.001	0.002	0.004 [c]
		Swimming, highly exposed children[b]	Arsenic	4E-7	4E-6	4E-6 [c]				
			Total	4E-7	5E-6	6E-6 [c]	Total [a]	0.012	0.13	0.15 [c]
Sediment	Fish/ shellfish tissue	Consumption, adult tribal RME	Arsenic	1E-3		1E-3	Arsenic	3.2		3.2
			cPAHs	1E-4		1E-4				
			PCBs	3E-4		3E-4	PCBs	10		10
			Total	2E-3		2E-3	Total [a]	15		15
		Consumption, child tribal RME	Arsenic	4E-4		4E-4	Arsenic	10		10
			cPAHs	3E-5		3E-5	PCBs	24		24
			PCBs	8E-5		8E-5	TBT	1.3		1.3
							Mercury	2.8		2.8
			Total	5E-4		5E-4	Total [a]	40		40
		Consumption, adult API RME	Arsenic	6E-5		6E-5				
			cPAHs	6E-6		6E-6				
			PCBs	2E-5		2E-5				
							Mercury	1.3		1.3
			Total	9E-5		9E-5	Total	1.8		1.8

Note: Exposure route total chemical-specific cancer risk and HQ estimates less than 1E-6 and 1, respectively, are not shown in this table. See Section B.5.3 for all estimates.

cPAH = carcinogenic PAHs (TEQ)

[a] Total is for all chemicals, regardless of toxicological endpoint.

[b] Risk characterization results as reported by King County (1999b).

[c] Totals include estimates from ingestion and dermal contact with both water and sediment. Estimates for water are not shown individually because they are several orders of magnitude lower than estimates shown for sediment exposure.

The total cancer risk estimate was 2E-3 for the adult tribal RME scenario.[94] Total cancer risks for the direct sediment exposure pathways (e.g., netfishing and beach play) were greater than 1E-6, but less than 1E-4. Based on the exposure scenarios evaluated in the Phase 1 HHRA, the following chemicals were identified as COCs: PCBs, arsenic, carcinogenic PAHs, TCDD TEQs, TBT, and mercury. The results of the Phase 1 HHRA will be used in analyses conducted to identify candidate sites for early remedial action.

6.5 UNCERTAINTY ANALYSIS

There is a degree of uncertainty in any quantitative risk assessment. The exposure and toxicity assumptions used for this risk assessment, which were based on EPA guidance, current scientific literature, and best scientific judgment, are inherently uncertain. This section summarizes some of the key uncertainties in this risk assessment, and presents recalculated risk estimates based on alternate exposure assumptions.

Table 6-4 lists some of the key uncertainties in the Phase 1 HHRA. Each uncertainty is characterized qualitatively as low, medium, or high (see footnote to table for explanation of descriptors). Table 6-4 also characterizes each uncertainty by the impact on risk characterization of additional data collection or an alternate analysis, the feasibility of collecting additional data or conducting additional analyses, and whether risk estimates included in the risk characterization section are likely to be underestimates or overestimates. Additional data may be collected as part of the data gaps analysis during the Phase 2 RI to reduce some of the uncertainties identified below.

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[94] A child RME scenario and an adult central tendency (CT) scenario were also evaluated for fish consumption, but risks were lower.

Table 6-4. Summary of uncertainties identified in Phase 1 HHRA

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Exposure Assessment						
Background chemical concentrations	Medium	Very slightly to greatly overestimated	Discount risk estimates for chemicals with concentrations not different from background	High	High	Risk estimates do not account for contribution from natural background or from sources outside the LDW, which are likely to be as great or greater for some chemicals such as arsenic and dioxins/furans
Detection limits for all EPCs in sediments	Low	Accuracy unknown for chemicals that were never detected	Collect more sediment data with lower detection limits	Low	High	One-half detection limit used in calculations
EPCs for fish and shellfish	High	Accuracy unknown, may over- or underestimate risks	Collect additional data	Unknown	High	Based on small number of samples
Identical tissue COPCs for each market basket component	Medium	Greatly overestimated for some chemicals	Conduct COPC screening separately for each market basket fraction	High	High	Some COPCs (e.g., PAHs) accumulate differently in fish compared to shellfish, so identifying identical COPCs for each market basket component may not be appropriate
EPCs for perch	High	Underestimated because most chemicals not analyzed in perch	Collect additional data	Medium	High	Only three chemicals analyzed in perch
EPCs for mussels	Low	Statistical methods make no difference to overall risk estimates	Collect additional mussel chemistry data	Low	High	Additional work on the presence of harvestable LDW mussel populations will be conducted. If harvestable populations are present, the need for additional mussel chemistry data will be evaluated.
EPCs for PCBs in sediment derived from different analytical methods	Medium	Excluding NOAA HPLC/PDA data slightly increases risk estimate	Exclude NOAA data	Low	High	Existing non-NOAA PCB data suggest risks from direct exposure to sediment-associated PCBs are insignificant

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Seafood ingestion rates	High	Greatly overestimated for tribal populations for current conditions. The degree of overestimation for tribal populations under future conditions is uncertain, but likely lower than current conditions. API community members harvest fish from the LDW, but it is uncertain to what degree consumption rates from EPA's 1999 API study overestimate LDW-specific API consumption rates.	Collect additional data that reflects habitat suitability to support harvestable fish and shellfish populations	High	Low	Current site usage may not reflect future site usage

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Clam consumption not included in market basket approach	Medium	If harvestable populations of clams are present, chemical concentrations in those clams are similar to concentrations in non-anadromous LDW fish, and the estimated clam consumption rate is similar to upper-end rates reported in the Suquamish Tribe (2000) study, then the current risk estimate is greatly underestimated	Collect additional data on clam abundance and chemistry	Medium	Medium	Existing data suggest suitable clam habitat is rare in LDW, but additional data collection on topic is necessary

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Fraction of intake obtained from site	High	For most individuals, the fraction of seafood intake obtained from the site is likely to be moderately to greatly overestimated. There may be a small population that currently practices subsistence seafood harvest from the LDW. The representativeness for the future use scenario is unknown. For the beach play scenario, the fraction of intake from the site is unknown.	Collect additional data that reflects site-specific usage and habitat suitability to support beach play and harvestable populations of fish and shellfish	High	Medium	Default assumption of 1 due to lack of site-specific data
Representativeness of existing tissue chemistry data for all potentially exposed populations	Medium to High	Underestimated for some consumers (e.g., those who consume crab hepatopancreas and perch)	Collect additional data for different tissue types and/or use alternate exposure assumptions for different populations	Unknown	Medium	Existing data indicate that fillets are the primary parts of the fish consumed. However, API community members, particular within the Hmong community, consume other fish parts, including heads, bones, eggs, and organs. Use of fillet data in risk estimates will underestimate risks for people who consume other parts of the fish with potentially higher concentrations of COPCs.
Exposure area used for beach play scenario	Medium	Accuracy unknown, high uncertainty	Collect additional data on site usage and habitat suitability to support beach play	Unknown	Medium	Relationship between areas where intertidal chemistry data exist and human use occurs is uncertain

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Spatial coverage of sediment chemistry data	Low	Low	Research past industrial activities to determine if likely chemical sources have been adequately characterized	Unknown	Medium	Available information does not suggest there are large sources that have not been characterized, but some gaps in spatial coverage may exist
Toxicity Assessment						
Chemicals without toxicity values	Low	Underestimated to unknown degree	Develop additional toxicity values	Medium	Low	Risk estimates not made for these chemicals
Tissue chemistry data for dioxins/furans and PCB congeners	Medium	Moderately underestimated	Collect additional data	High	Medium	No data are available for these chemicals, which are highly toxic and may be found in fish tissue
Cancer slope factor for PCBs	Medium	Moderately overestimated	Additional congener data unlikely to change approach for tissue exposure, but different slope factor may be applicable for sediment ingestion if more highly chlorinated congeners are uncommon	High	Medium	Most health protective slope factor probably not applicable for all PCB congeners
Arsenic speciation	Medium	Moderately overestimated	Collect additional data on arsenic species present in tissue	Medium	Medium	10% value for inorganic arsenic as required by EPA may overestimate exposure, but it accounts for the uncertainty in the toxicity of dimethyl arsenic acid
Chromium speciation	Medium	Moderately overestimated	Collect additional data on chromium species present in sediment and tissue	Low	Medium	RfD for hexavalent chromium used for total chromium; chromium not identified as COC

PARAMETER	LEVEL OF UNCERTAINTY	EFFECT OF UNCERTAINTY ON RISK ESTIMATE	POTENTIAL MEANS TO DECREASE UNCERTAINTY	POTENTIAL IMPACT ON RISK ESTIMATES	FEASIBILITY	COMMENT
Risk Characterization						
Risk estimates for chemicals that were never detected	High	Greatly overestimated if these COPCs are not present, uncertain if these COPCs are present	Collect additional data with lower detection limits	Unknown	Low	Many of the chemicals that were never detected have no known LDW source, so lower detection limits may not be helpful. Additional research on past industrial practices will be conducted to determine if uncharacterized sources may exist.

7.0 Conclusions

The Phase 1 RI report presents the findings of the first phase of a two-phase approach that is being used to investigate the LDW. The report was aimed at addressing three questions:

1. Based on existing data, what are the risks to human health and the environment associated with sediment-associated chemicals in the LDW?
2. Are there areas within the LDW that might be candidates for early remedial action?
3. What additional information is needed to understand the nature and extent of chemical distributions in the LDW and characterize risks to human health and the environment sufficiently to make final remedial decisions in the LDW?

The Phase 1 RI directly answers the first question while providing the information and analysis that is needed for the last two questions. Two additional reports immediately following the RI will directly address the last two questions.

7.1 NATURE AND EXTENT OF CHEMICAL CONTAMINATION

Approximately 1,200 surface sediment samples, 230 subsurface sediment samples, and 225 fish and shellfish tissue samples have been collected from the LDW and analyzed for metals and organic compounds since 1990. Overall, the historical data provide a sufficient characterization of the nature and extent of chemical contamination in the LDW to identify candidate sites for early action. One of the more significant findings is that chemicals in sediment are not uniformly distributed throughout the LDW, but rather generally occur in discrete locations. Areas of the LDW with elevated concentrations are well defined and are separated by sections of the river in which chemical concentrations are low.

General categories of potential sources include historical land use and disposal practices, industrial or municipal releases (including both permitted and unpermitted wastewater and stormwater discharges), spills or leaks, atmospheric deposition, and waste disposal either on land or in landfills. Available evidence suggests that chemicals currently found in the sediments are largely the result of historical practices dating back many years. In more recent years, there have been well-documented efforts to either eliminate or substantially reduce releases of chemicals to the LDW from multiple sources. Data were evaluated to assess potential groundwater sources of chemicals to the LDW at 12 sites identified by EPA and Ecology for the purposes of this Phase 1 RI. Chemicals in groundwater do not appear to be a concern to the LDW with respect to potential accumulation in sediment or as a source (e.g., in seeps) except at a few sites currently being investigated through other programs.

Existing data indicate that almost all sediment transported into the LDW from upstream sources is deposited in the upper reaches of the LDW near Turning Basin 3. Based on an evaluation of multiple bathymetry surveys, water depths generally are stable or decrease with time, indicating a predominantly depositional or dynamic equilibrium environment. Transport of resuspended sediment occurs on a local scale as a result of episodic events such as propeller scour. Bottom currents are rarely high enough to initiate motion of bedded sediments; thus, transport of resuspended sediment does not appear to be a system-wide phenomenon.

7.2 RISK ASSESSMENTS

Some site-specific data were available on the use of the site and its resources by humans, as well as information on the distribution and use of the site by aquatic organisms and wildlife. The results of the Phase 1 RI indicate that there was sufficient environmental data available for the LDW to undertake an initial assessment of risks to human health and the environment and to make recommendations on candidate sites for early remedial action. The risks for some exposure scenarios and receptors estimated in this RI are high enough to suggest that remedial action may be warranted in some portions of the LDW:

- For the HHRA, estimated cancer risks in the LDW were found to be highest for the seafood consumption scenario, while the cancer risks for the other exposure scenarios (netfishing and beach play) were much lower. Noncancer hazard quotients greater than levels of potential concern were only noted for the seafood consumption scenario.
- For the ERA, certain areas in the LDW were predicted to pose unacceptable risks to benthic invertebrates based on comparison to CSLs. In addition, based on preliminary exposure estimates, the potential for adverse effects was predicted for select fish and wildlife species; specific links between dietary exposure and sediment cleanup recommendations have not yet been made.

7.3 CANDIDATE SITES FOR EARLY ACTION

One objective of the Phase 1 studies was to determine if discrete areas within the LDW could be identified as candidates for early remedial action. The analysis and conclusions presented in the Phase 1 RI show that remediation of selected areas within the LDW on an expedited schedule will reduce risks to human health or the environment. While the distributions of chemicals within the sediments were found to be highly variable, discrete areas (in some cases near known or suspected sources) have higher chemical concentrations than other areas. Risks associated with these discrete areas are considered to be sufficiently high that initiation of remedial action without waiting for the results of the Phase 2 RI is warranted.

The next step in the Phase 1 process is to prepare a memorandum that recommends candidate sites for potential early remedial action based on the results of this RI report and its risk assessments. EPA and Ecology will review the proposed candidate sites, and may enter into negotiations with one or more LDWG members and/or other parties to perform early remedial actions outside of the RI/FS process.

7.4 PHASE 2 DATA REQUIREMENTS

Based on the Phase 1 RI and RAs, critical data needs are proposed in a data gaps memorandum prepared as part of Phase 1, and will be described further in a Phase 2 RI work plan. Taken together, the RI and risk characterizations and the uncertainty analyses conducted as part of the risk assessments provide the basis for proposing data needs to further evaluate estimates of risk. Additional investigations will be conducted as part of Phase 2 to fill critical data gaps regarding the nature and extent of chemical distributions and biological effects within the LDW. References to some of these investigations are included in this RI report; those that are not mentioned specifically will be described in the Phase 2 RI work plan. The results of these investigations will be incorporated into a Phase 2 RI that will contain a baseline (Phase 2) HHRA and ERA and a residual risk assessment. An important part of this assessment is to examine how much the early remedial actions are likely to reduce overall risks. The baseline risk assessments will support a determination of the need for further sediment remediation within the LDW, based on standard risk management practices.

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Appendices to this Remedial Investigation are published at separate volumes as detailed below; titles are included here for reference purposes

Oversize Maps and Tables (separate volume)

Oversize maps and tables, including all GIS maps created for this Remedial Investigation, are published as a separate 11 x 17” volume.

Appendix A: Ecological Risk Assessment (separate volumes)

Published as a separate document in two volumes: an 8½ x 11” text volume and an 11 x 17” volume of color GIS maps

Appendix B: Human Health Risk Assessment (separate volume)

Published as a separate document in one volume (8½ x 11”).

Appendix C: Data Management Procedures Related to GIS Maps (separate volume with Appendices D, E, and F)

Appendices C, D, E, and F are published as a single volume.

Appendix D: Summary Statistics for Sediment, Porewater, and Tissue Samples (separate volume with Appendices C, E, and F)

Appendices C, D, E, and F are published as a single volume.

Appendix E: Lists of Potential Sources (separate volume with Appendices C, D, and F)

Appendices C, D, E, and F are published as a single volume.

Appendix F: Duwamish River Waste Disposal and Dredge Fill Sites (separate volume with Appendices C, D, and E)

Appendices C, D, E, and F are published as a single volume.

Appendix G: Groundwater Pathway Assessment (separate volumes)

Published as a separate document in two volumes: an 8½ x 11” text volume and an 11 x 17” volume of oversize maps (oversize volume available in hard copy only).