Green/Duwamish River Watershed Pollutant Loading Assessment Technical Approach

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Abbreviations

ARAR	Applicable or Relevant and Appropriate Requirements
BCM	Bed Composition Model
BEHP	Bis(2-ethylhexyl) phthalate
BHC	Benzene Hexachloride
BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
Boeing	Boeing Company (aircraft manufacturing)
BSAF	Biota-Sediment Accumulation Factors
CCC	Criterion Continuous Concentration
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
cm	Centimeter
CM	Conceptual Model
CMC	Criteria Maximum Concentration
cm/yr	Centimeters per Year
COCs	Contaminants of Concern
cPAHs	Carcinogenic Polycyclic Aromatic Hydrocarbons
Consent Order	Administrative Order and Settlement Agreement on Consent
CSL	Sediment Cleanup Screening Level
CSM	Conceptual Site Model
CSO	Combined Sewer Overflow
CWA	Clean Water Act
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
DMR	Discharge Monitoring Report
EAAs	Early Action Areas
DYMBAM	Biodynamic Model of Bioaccumulation
dw	Dry Weight
Ecology	Washington State Department of Ecology
EFDC	Environmental Fluid Dynamics Code
EIM	Environmental Information Management System
EPA	U.S. Environmental Protection Agency
ERA	Ecological Risk Assessment
ET	Evapotranspiration
FCM	Food Chain Model
FOVA	First Order Variance Analysis
FS	Feasibility Study
FWM	Food Web Model
GIS	Geographic Information System
Green WQA	Green River Water Quality Assessment
HAP	Hazardous Air Pollutants
HEC	Hydrologic Engineering Centers
HHRA	Human Health Risk Assessment

HPAHs	High Molecular Weight Polycyclic Aromatic Hydrocarbons
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program – Fortran
HUC	Hydrologic Unit Code
IQUAL	Impervious Quality Constituent
KCFCD	King County Flood Control District
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
LPAHs	Low Molecular Weight Polycyclic Aromatic Hydrocarbons
LSPC	Loading Simulation Program- C++
LTST	Long-Term Stormwater Treatment System
µg/kg	Micrograms per Kilogram
MDAS	Mining Data Analysis System
mg/kg	Milligrams per Kilogram
MOU	Memorandum of Understanding
MS4	Municipal Separate Storm Sewer Systems
MTCA	Model Toxics Control Act
NAWQA	National Water-Quality Assessment
NCDC	National Climatic Data Center
ng/kg	Nanograms per Kilogram
NHD	National Hydrography Dataset
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NRWQC	National Recommended Water Quality Criteria
NTR	National Toxics Rule
NWS	National Weather Service
PAHs	Polycyclic Aromatic Hydrocarbons
OC	Organic Carbon
PARIS	Permitting and Reporting Information System
PBDE	Polybrominated Diphenylethers
PBBs	Polybrominated Biphenyls
PCBs	Polychlorinated Biphenyls
PCDDs	Polychlorinated Dibenzo-Dioxins
PCDFs	Polychlorinated Dibenzo-Furans
PLA	Pollutant Loading Assessment
POTWs	Publicly Owned Treatment Works
PP	Proposed Plan
ppm	Parts per Million
PQUAL	Pervious Quality Constituent
PRGs	Preliminary Remediation Goals
PSAMP	Puget Sound Assessment and Monitoring Program
QA	Quality Assurance

RAL	Remedial Action Level
RAO	Remedial Action Objectives
RBTC	Risk-Based Threshold Concentrations
RCHRES	ReaCHes/REServoirs module
RI	Remedial Investigation
RM	River Mile
ROD	Record of Decision
SCAPs	Source Control Action Plans
SCAs	Source Control Areas
SCWG	Source Control Work Group
SIZ	Sediment Impact Zone
SMS	Sediment Management Standards
SQS	Sediment Quality Standards
SSO	Sanitary Sewer Overflow
STAR	Sediment Transport Analysis Report
STATSGO	State Soil Geographic Database
STM	Sediment Transport Model
STORET	STOrage and RETrieval
SUSTAIN	System for Urban Stormwater Treatment and Analysis IntegratioN
SVOC	Semivolatile Organic Compound
SWAMP	Sammamish-Washington, Analysis, and Modeling Program
SWMM	Storm Water Management Model
TCDD	Tetrachlorodibenzodioxin
TDS	Total Dissolved Solids
TEF	Toxic Equivalency Factor
TEQ	Toxic Equivalent
TIC	Total Inorganic Carbon
TMDL	Total Maximum Daily Load
TOC	Total Organic Carbon
Toolbox	TMDL Modeling Toolbox
TSS	Total Suspended Solids
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VGP	Vessel General Permit
VOC	Volatile Organic Compound
WAC	Washington Administrative Code
WDFW	Washington Department of Fish and Wildlife
WLAs	Waste Load Allocations
WQC	Water Quality Criteria
WRIA	Water Resource Inventory Area
ww	Wet Weight

Executive Summary

The Green/Duwamish River watershed provides habitat for wildlife, birds and fish, including three fish species listed as "threatened" under the Endangered Species Act: Puget Sound Chinook, Puget Sound Steelhead, and Bull Trout. The Green/Duwamish River watershed includes the land surrounding the Green River and the Duwamish River, as well as the land surrounding all of the tributaries that drain to the Green/Duwamish River, including the Black River, Springbrook Creek, Mill Creek, Soos Creek, Jenkins Creek, Covington Creek, Newaukum Creek, and Crisp Creek.

The downstream area of the watershed, known as the Lower Duwamish Waterway (LDW), is now largely an engineered channel. Decades of industrial activity in the lower watershed have contaminated portions of the groundwater, soil and sediment with a variety of pollutants. Remediation of contaminated groundwater, soil and sediment is being planned, is under-way, or has been completed at numerous locations along the LDW under federal and state authorities. A large-scale Superfund in-waterway cleanup, involving sediment dredging, capping and other remediation techniques, will occur over the next ten years in the lower five-miles of the river.

In contrast to the site-specific focus of state and federal clean-up programs, the Clean Water Act (CWA) looks broadly at the cumulative water quality effect of pollutants in impaired watersheds. This CWA requirement is implemented through a series of steps, beginning with development of state water quality standards. Water quality standards establish the "uses" of a waterbody, and commonly include fishing, shellfish harvesting, swimming and the ability to support aquatic life. Each state adopts criteria to protect the designated uses. CWA Section 303(d) requires that states identify those waterbodies where the water quality criteria (and therefore the "uses") are not being met. This list of impaired waters is referred to as the 303(d) list.

Ecology has identified impairments in the water column, fish tissue and sediment in the Green/Duwamish River watershed. While the in-waterway cleanup and source control efforts will substantially improve the quality of LDW sediments and surface water, and reduce the seafood consumption risk by about 90%, some CWA-based impairments may remain following the LDW cleanup. Both the U.S. Environmental Protection Agency (EPA) and the Washington Department of Ecology (Ecology) recognize the need for a scientific approach that can predict short and long-term improvements in water and sediment quality, and can subsequently predict the level of contamination in fish tissue over time, as different cleanup and restoration scenarios are implemented.

As illustrated in Figure ES-1, state and federal efforts to clean up historical contamination and to restore water quality in the Green/Duwamish River watershed are complimentary efforts aimed at a common goal: protecting human health and the environment. Remediation of contaminated sediments, soil and groundwater in the LDW will help restore water quality, while reduction of pollutant loading throughout the watershed will help protect sediment quality and aquatic habitat in the LDW. Ultimately, successfully integrating state and federal efforts to improve both water and sediment quality will make the most progress toward attaining designated uses, including reducing the bioaccumulation of toxics in the food chain.

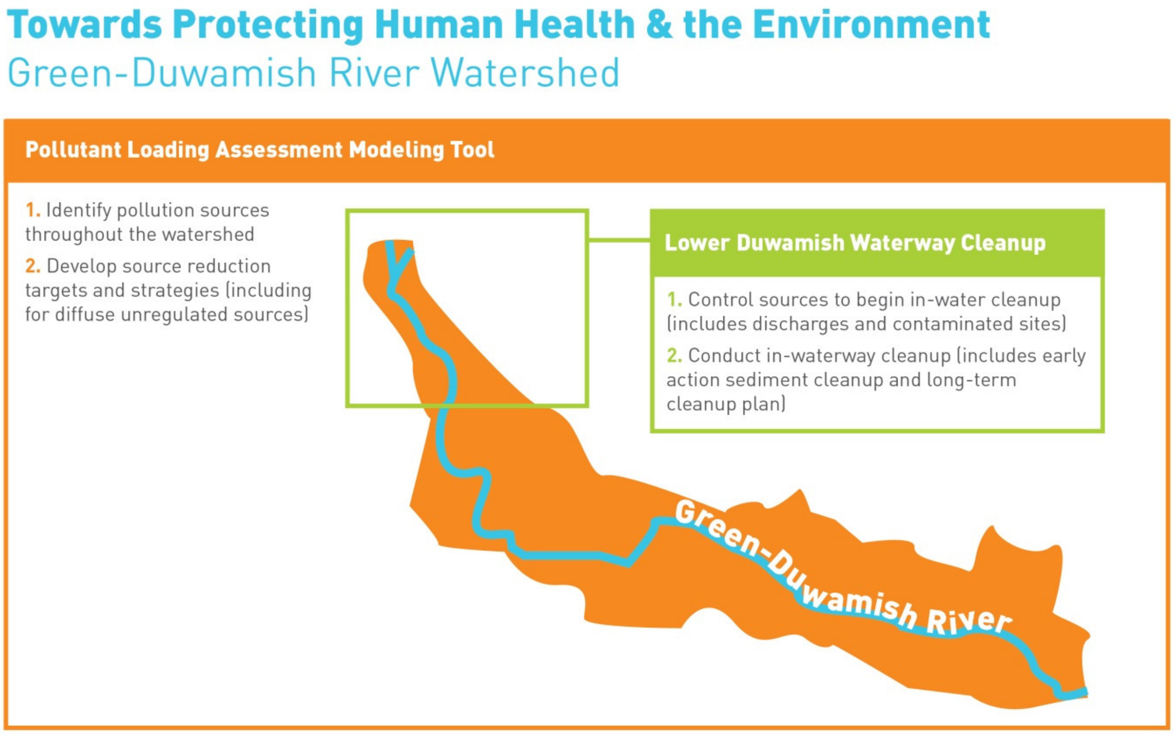

Figure ES-1: The Clean Water Act-based Pollutant Loading Assessment and LDW cleanup activities are complimentary efforts aimed at a common goal: protecting human health and the environment

The purpose of this report is to outline a proposed comprehensive and quantitative geographically-based pollutant loading assessment (PLA) tool for the Green/Duwamish River watershed, the essential elements of which are described below. A considerable amount of monitoring, modeling, cleanup and restoration work has already been done by local governments, interested parties and regulatory agencies (e.g., Ecology, 2012b; AECOM, 2012a). This report identifies these previous and ongoing efforts, and is designed to incorporate these efforts into a proposal for future work in a way that best represents the complex dynamics of the Green/Duwamish River watershed.

The proposed PLA tool can be used to integrate current and ongoing cleanup and source control efforts in the watershed, with the ultimate goal of protecting human health and the environment throughout the watershed. The PLA tool is designed to assist governments, businesses, and residents with each of the following needs:

- Understand the pollutant loading associated with point sources and the uncontrolled release of chemical pollution from diffuse sources throughout the watershed.
- Compare different pollutant reduction alternatives to allow for more informed decision-making.
- Predict the resulting short and long term improvements in fish tissue, water column and sediment quality throughout the watershed.
- Minimize recontamination of post cleanup sediments and improve the effectiveness of natural recovery.
- Support adaptive management over time in response to measured progress in meeting water quality targets.

The proposed tool consists of a linked watershed/receiving water/food web modeling system that will accurately reflect the hydrology, hydrodynamics, and source loadings to the Green/Duwamish River watershed. The recommended models include the LSPC[1] watershed model, the EFDC[2] receiving water model, and the Arnot and Gobas and DYMBAM[3] food-web models. The PLA tool will also represent, in a scientifically rigorous manner, sediment transport, resuspension and sedimentation, as well as the dominant processes affecting the transformations and transport of toxic pollutants throughout the watershed, including dissolved and particulate phases of pollutants.

There are three important distinctions between the recommended technical approach and previous approaches developed for the LDW: 1) given that ongoing sources of pollution are located throughout the watershed, a broad geographic scale is a necessary expansion to previous technical analyses, 2) the recommended model framework includes contaminant transport and transformation processes, and an expanded suite of pollutants, and 3) the recommended model framework has the ability to model and predict water quality.

Development of the PLA tool will benefit from the involvement of tribal governments, federal, state and local governmental agencies, as well as area businesses and other interested parties. An initial review found some gaps in water quality data available to support model calibration and validation. Despite these data gaps, EPA and Ecology believe initial modeling efforts can start soon (e.g. during the period of additional data collection and/or compilation). Ecology expects development of the PLA to begin in the fall of 2014, and expects that completion of the modeling tool will take several years due to the complexity of the natural processes in the watershed and the wide range of interested parties.

[1] Loading Simulation Program - C++
[2] Environmental Fluid Dynamics Code
[3] Biodynamic Model of Bioaccumulation

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1 Purpose and Context

The Green/Duwamish River watershed (Figure 1-1), located near Seattle, Washington, has historically provided habitat for fish, birds, and wildlife with its marshes and mudflats, but development has increasingly stressed the lower region of the basin and reduced the natural environment. In the 1890s, raw sewage and stormwater emptied into the Duwamish River, Elliott Bay, and Puget Sound. In the early 1900s, with the expansion of waterway commerce, industrial development and pollutants associated with this waste were also introduced to these waterbodies. During this time the estuary tidelands were filled in and the river was modified to serve the growing industrial and port activities.

The downstream area, known as the Lower Duwamish Waterway (LDW), is now a largely engineered channel. Conditions subsequently continued to deteriorate; however, the 1960s saw increased environmental awareness and action, with treatment plants to address industrial effluent and sewage. Contaminated soil, groundwater, and sediment remediation efforts are being conducted along with habitat restoration. Since the turn of the century, regional agencies have emphasized current and future actions, with both sediment investigation and cleanup as well as source control activities (Section 1.4).

Considerable resources have been utilized to characterize and prioritize these cleanup, restoration, and source control efforts. This technical approach is designed to build upon these efforts, wherever possible, and ultimately present recommendations for a comprehensive pollutant loading assessment (PLA). The purpose of the PLA is two-fold:

- To minimize recontamination of post-cleanup sediments from incoming loads from the entire drainage area, including lateral loads to the LDW.
    - To improve the effectiveness of the sediment remedial action (because Monitored Natural Recovery relies on cleaner sediments depositing over the more contaminated sediments over time).
- To address water, sediment, and tissue quality impairments (i.e., 303(d) listings under the Clean Water Act [CWA]) in the Green/Duwamish River watershed, including the LDW, as appropriate, to attain designated uses.

The remainder of this section provides context for this effort and defines the specific project objectives, presents an overview of the study area, identifies the 303(d)-listed impairments, describes previous and ongoing activities, and presents a brief overview of the organization of this technical approach.

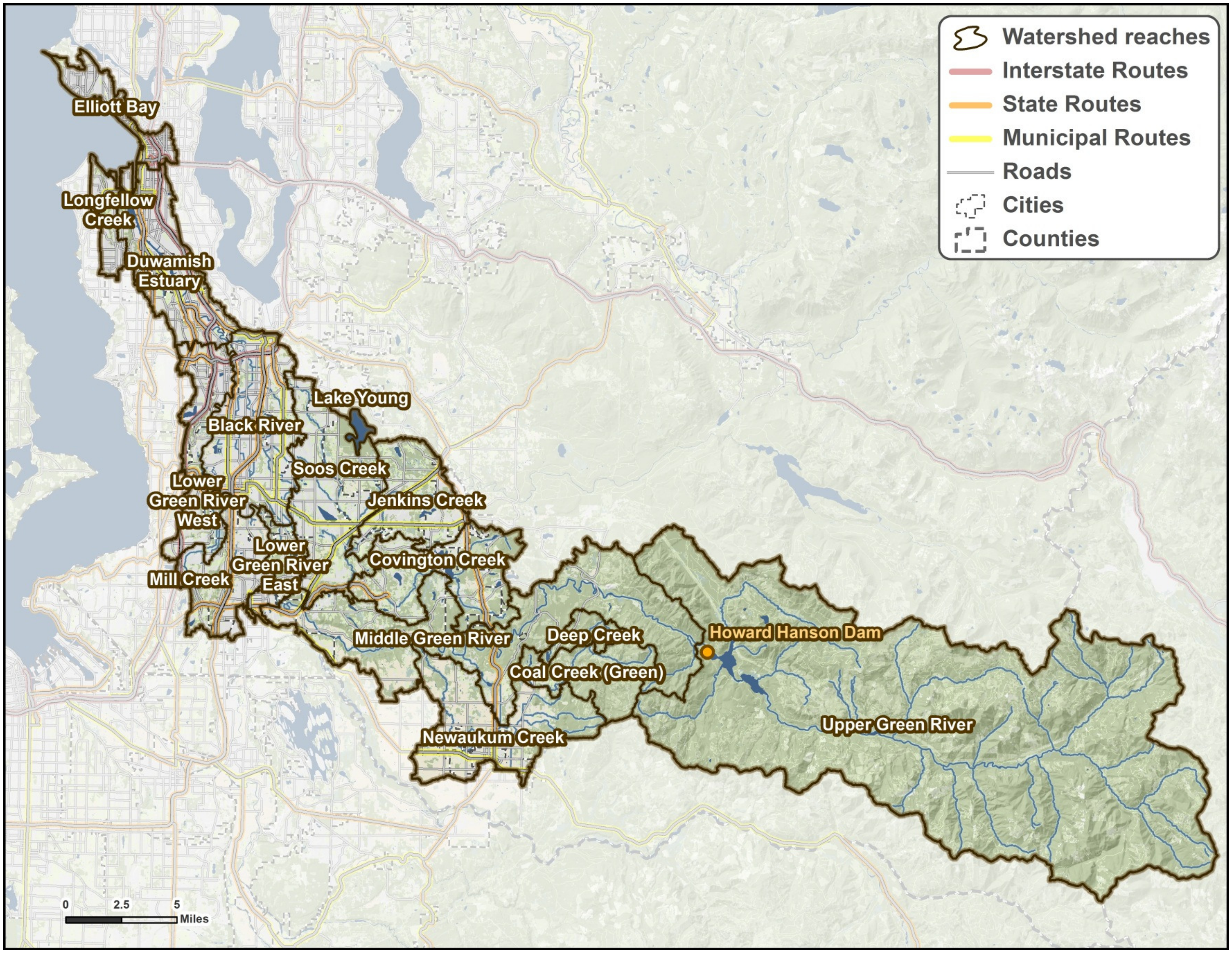


Figure 1-1. Green/Duwamish River study area

1.1 Objectives and Rationale

The Green/Duwamish River watershed (Figure 1-1) is a complex river system with multiple historical and on-going sources of pollution. The Green/Duwamish River watershed (referred to throughout this document as the *study area*) is identified on Washington's 303(d) list as being impaired for over 50 different pollutants (including both toxic and conventional parameters) and total maximum daily loads (TMDLs) have been developed for conventional pollutants such as ammonia, fecal coliform, total phosphorous, temperature, and dissolved oxygen (Ecology, 2013a) (Section 1.3). Portions of the study area are also on the National Priorities List and are in various stages of sediment cleanup under the Superfund or Washington State Model Toxics Control Act (MTCA) programs (Section 1.4). The objective of this technical approach is to develop a comprehensive and quantitative geographically-based loading assessment tool that considers existing watershed and receiving water conditions, as well as ongoing and future Superfund and MTCA cleanup efforts. Such a tool can be used to minimize recontamination of post-cleanup sediments from incoming loads from the entire drainage area, including all lateral loads to the LDW, improve the effectiveness of the sediment remedial action and address CWA water, sediment, and tissue quality impairments in the Green/Duwamish River watershed, including the LDW, as appropriate, to attain CWA designated uses. A loading assessment tool can also help identify required load reductions from various sources in the watershed and the receiving waters; and can be used to estimate loadings during and after sediment cleanup.

A comprehensive and quantitative geographically-based loading assessment tool that considers existing watershed and receiving water conditions, as well as ongoing and future sediment cleanup efforts, can be used to minimize recontamination of post-cleanup sediments from incoming loads, improve the effectiveness of the sediment remedial action, and to address water, sediment, and tissue quality impairments in the Green/Duwamish River watershed, including the LDW, to attain designated uses.

Specific projects objectives are to:

- Develop a tool that can address 303(d)-listed impairments in both the Green/Duwamish River watershed and the LDW.
- Develop sediment, water, and tissue relationships so that concentrations resulting from cleanup work in one media can be compared to concentrations in another media.
    - Determine a site specific equilibrium partitioning coefficient for polychlorinated biphenyls (PCBs).
- Develop a tool that can be used on a site-specific/discharge-specific basis in the LDW to evaluate reasonable potential to cause or contribute to a violation of water quality standards.
    - Identify pollutant loading from lateral discharges to the LDW.
    - Provide the ability to add a discharge within a grid cell.
- Develop a tool to identify cumulative pollutant loading from the watershed upstream of the LDW.
- Develop a tool to predict bioaccumulation of pollutants in the food web.
- Develop a tool to predict improvement in sediment, water, and fish tissue expected to occur as a result of management actions (i.e., sediment cleanup, specific source control actions).
- Develop a tool to evaluate the effectiveness of sediment cleanup and associated source control efforts in meeting water quality standards.

Developing a loading assessment tool for the study area requires comprehensive consideration of all previous and planned cleanup efforts, and all on-going sources and transport pathways of pollution.

United States Environmental Protection Agency (EPA) and Washington State Department of Ecology (Ecology) have stated that recontamination of LDW sediments after the Superfund cleanup is likely due to "ongoing and unidentified sources" and "the impacts of atmospheric pollutant deposition on stormwater quality" (among other causes) (Flint and Thomas, 2013). Consideration and quantification of atmospheric deposition, actionable sources, and ubiquitous pollutant levels is therefore needed to minimize additional pollutant loads that can cause recontamination of the remediated sediments and impair water quality. Given that many ongoing sources are located in the study area, a broad geographic scale is a necessary expansion to previous technical analyses. Ultimately, this approach is designed to address the following pollutants of concern:

- Primary human health risk drivers identified in EPA's Proposed Plan (PP) for the LDW Superfund Cleanup (EPA, 2013)
  - PCBs
  - Arsenic
  - Carcinogenic polycyclic aromatic hydrocarbons (cPAHs)
  - Dioxins/furans
- Ecological risk drivers identified in EPA's PP for the LDW Superfund Cleanup (EPA, 2013)
  - Dioxins/furans
  - Metals
  - Other Semivolatile Organic Compounds (SVOCs)
  - PAHs
  - Phthalates
- Other Sediment Management Standards (SMS) chemicals listed in the PP to protect benthic life
- Over 50 pollutants on the 2012 303(d) list (Section 1.3)

The primary Superfund human health risk drivers, also called the Contaminants of Concern (COCs), are a subset of the pollutants on Washington's 2012 CWA 303(d) list. They are of critical importance to the Superfund cleanup and associated source control activities; therefore, special emphasis is placed on these pollutants in this technical approach.

Pollutants of Concern:

- *Primary human health risk drivers:*
  - *PCBs, arsenic, cPAHs, dioxins/furans*
- *Ecological risk drivers:*
  - *Dioxins/furans, metals, SVOCs, PAHs, Phthalates*
- *Other SMS chemicals to protect benthic life*
- *50+ pollutants on the 2012 303(d) list*

A primary focus of this technical approach has been to identify previous modeling, data collection, and cleanup efforts that can be expanded upon[4] or utilized directly as part of the proposed comprehensive framework. Specifically, this technical approach was designed to incorporate previous and ongoing efforts and to fit these into a more comprehensive geographic and analytical tool that includes the direct modeling of dissolved and particulate contaminant concentrations in surface water, pore water, and sediments of the LDW and Green/Duwamish River, linkage to a food web model (FWM), and watershed-based loading inputs from the Green/Duwamish River upgradient of the LDW. This framework can then be used to determine the pollutant loading for all CWA 303(d)-listed impairments that would result in the attainment of designated uses in the Green/Duwamish River watershed.

The proposed comprehensive framework can be thought of as an umbrella encompassing previous or ongoing modeling, data collection, and cleanup efforts, while filling in any identified gaps in sources, pathways (including lateral loading), and previous model configurations to best represent complex

[4] It should be noted that arsenic, PCBs, cPAHs (as a group), and dioxin/furan were the only contaminants evaluated for the Feasibility Study (FS) using the modeling outputs for sediment dynamics in the LDW. Specifically, these contaminants were not directly modeled but calculated within a spreadsheet based on the results for spatial sediment dynamics predicted by EFDC/STM model along with a contaminant concentration developed from the assumption that all contaminants are only associated with particulates and that the upstream, lateral, and in-stream initial concentration conditions can be assigned to the three sediment types traced by the EFDC/STM models, except for PCBs for the FWM.

dynamics of the Green/Duwamish River watershed. To support LDW cleanup efforts, the framework looks at the upgradient watershed as well as lateral or direct inputs to the LDW itself. Figure 1-2 illustrates this proposed structure. Many of the data collection, modeling and technical analysis, or cleanup efforts to date have focused on a particular area or on specific pollutants. The proposed loading assessment tool builds upon these efforts in many ways:

- Additional pollutants will be considered, other than arsenic, cPAHs, dioxin/furans, and PCBs, to address other 303(d)-listed impairments and contaminants of concern.
- The geographic scope is expanded to ensure that other sources are managed to accomplish project goals.
- Thorough analysis of available data and information to verify results of the assessment tool. Data gaps will be identified and evaluated and data collection recommendations will be made considering potential benefits associated with additional data collection or use of surrogate parameters.
- Green/Duwamish River watershed loadings, including lateral loadings, and possible management practices for point and nonpoint sources will be evaluated to determine how they affect pollutant loads in the receiving waters, including the LDW.
- Direct modeling of contaminant source, transformations, and fate in both the water column and sediments will be performed to support technical evaluations of potential management actions.
- A direct model linkage and dynamic simulation of long-term water, porewater, and sediment concentrations will be developed to reduce assumptions and simplifications used in the application of the Arnot and Gobas FWM for the LDW[5], which will improve ecological risk assessments (ERAs) for future conditions. This effort utilizes a recalibrated Environmental Fluid Dynamics Code (EFDC) model to predict dissolved and particulate PCBs based on a partition coefficient to support the FWM.[6] The tool will include more rigorous modeling of PCBs, metals, and other contaminants to predict sediment-associated contaminants in multiple classes, pore water concentrations, and water column concentrations in the LDW, and link a FWM.

An end goal of this PLA is to provide a tool to quantify loadings from a comprehensive suite of sources and/or pathways to minimize recontamination of post-cleanup sediments, improve effectiveness of the Superfund remedy, and address 303(d)-listed impairments in the Green/Duwamish River watershed. Therefore, the estimated load reductions associated with previous, ongoing, and future sediment cleanup efforts can be calculated in conjunction with improvements from other ongoing programs, such as National Pollutant Discharge Elimination System (NPDES) permits and air quality management efforts, resulting in measureable improvements to the water, sediment, and tissue quality of the LDW and the larger Green/Duwamish River watershed.

[5] Windward Environmental, 2010. Appendix D: Food Web Model for the LDW.
[6] Windward Environmental, 2010. Appendix D: Food Web Model for the LDW-Attachment 3 EFDC Calibration Process for Predicting PCB Water Concentrations in LDW.

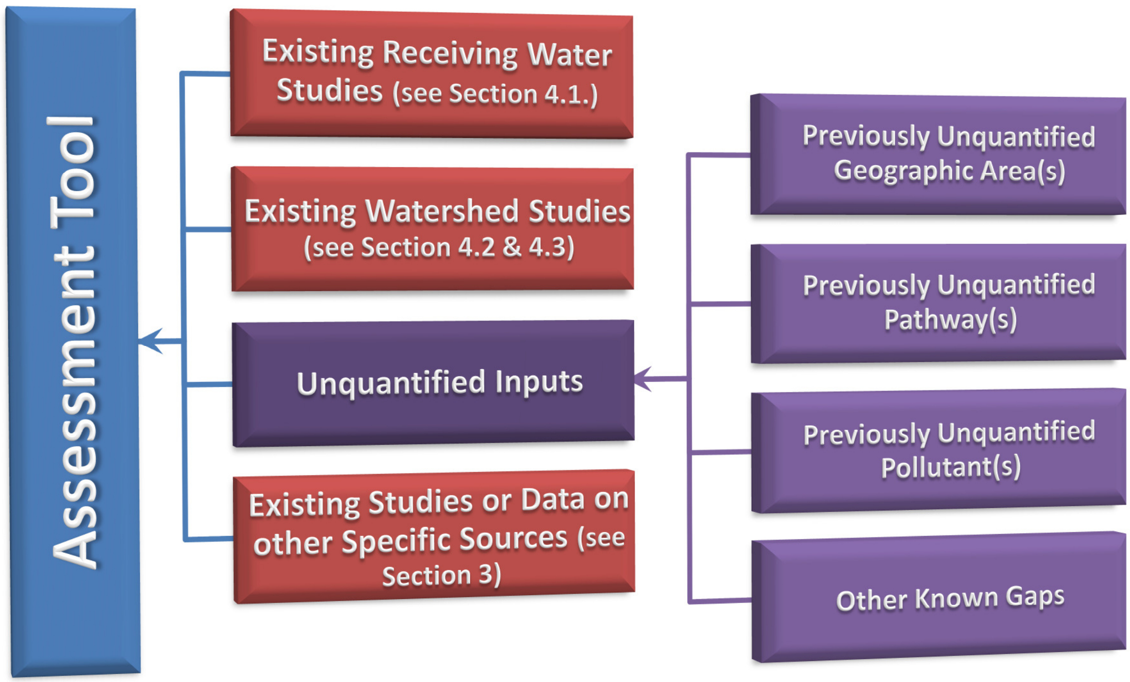


Figure 1-2. Framework for the comprehensive and quantitative assessment tool

1.2 Study Area Overview

> ***Two Modeling Scales:***
> - *Receiving Water: LDW*
> - *Watershed: Green/Duwamish River watershed*

The Green/Duwamish River flows for over 90 miles from the Cascade Mountains before discharging into Elliott Bay near the City of Seattle in northwest Washington State (Figure 1-1). This drainage, which makes up most of Water Resource Inventory Area (WRIA) 9, includes the direct lateral flows to the LDW, and represents the complete *study area.* Modeling of the watershed and LDW is proposed at two general scales for the PLA: the LDW receiving water and the Green/Duwamish River watershed. The approach is designed to address sources throughout the Green/Duwamish River watershed that affect water, sediment, and tissue quality in the LDW, address the CWA 303(d)-listed impairments throughout the watershed, and minimize recontamination of sediments in the LDW. The geographic scope is discussed and illustrated below for both the LDW and the Green/Duwamish River watershed.

1.2.1 Lower Duwamish Waterway

The LDW is of particular interest for this PLA as it is the focus of many source control and sediment cleanup efforts. It is a five-mile, 441-acre waterbody located at the terminus of the Green/Duwamish River watershed. The LDW is defined as the stretch of water between the turning basin near S. 102nd Street Bridge and the southern end of Harbor Island (Figure 1-3). It is a stratified saltwater wedge estuary affected by both tidally-influenced Puget Sound saltwater and freshwater inflows from the Green/Duwamish River watershed. It is a navigable waterway and supports associated boat traffic and robust industrial commerce. Additionally, the waterway serves as a migratory pathway for numerous fish, including the threatened Puget Sound Chinook salmon and bull trout. Several neighborhoods are also located nearby (South Park and Georgetown), with a mix of residential, commercial, recreational, and industrial activities.

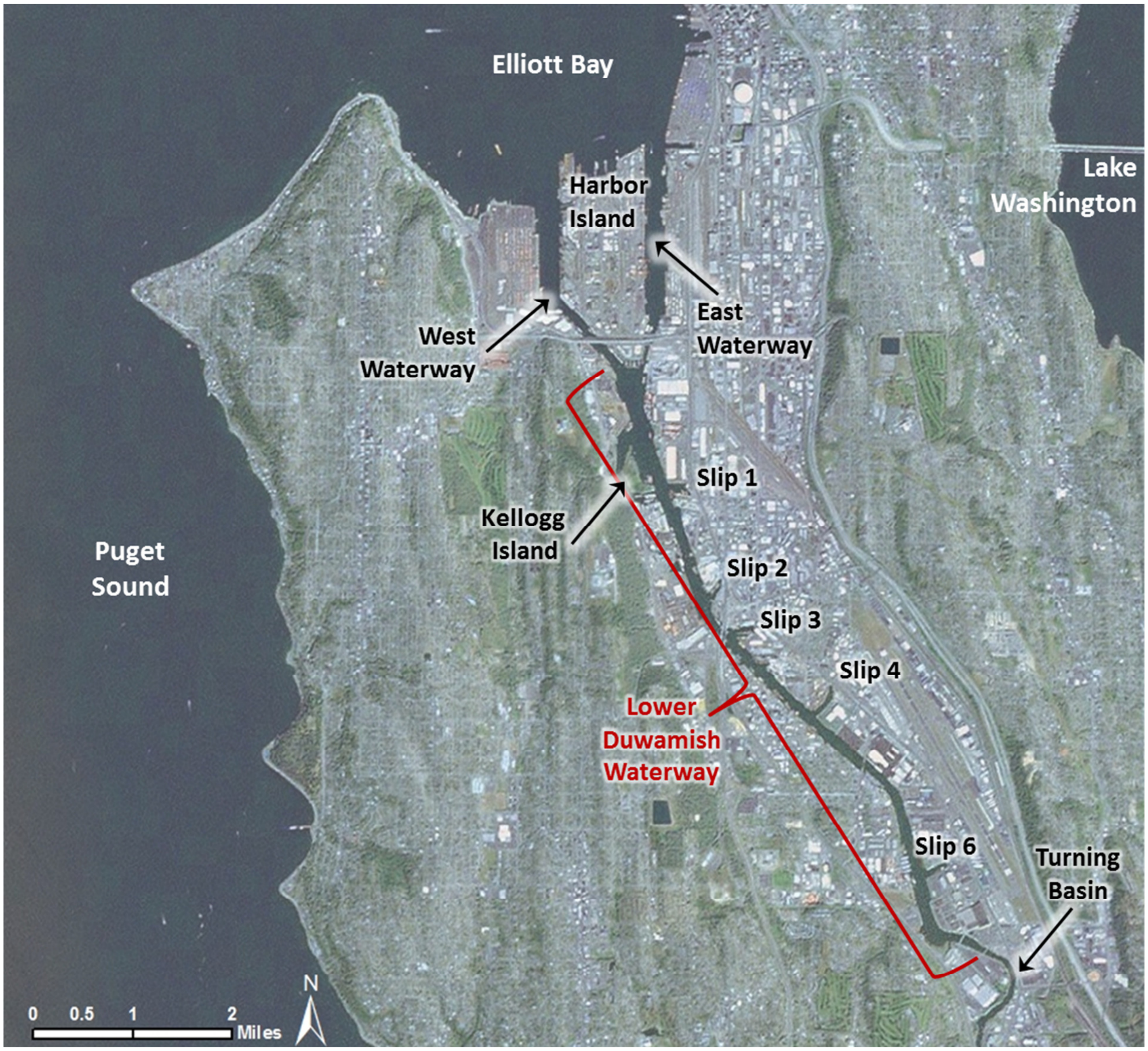


Figure 1-3. Extent of the Lower Duwamish Waterway

1.2.2 Green/Duwamish River Watershed

The LDW is at the mouth of the Green/Duwamish River watershed (Figure 1-1). Consistent with geographic information system (GIS) layers from King County, the Green/Duwamish River watershed area has been divided into four primary subwatersheds for consideration in this technical approach[7]:

- *Duwamish Estuary* (Figure 1-4) from Elliott Bay/Harbor Island to river mile (RM) 11.0 at Tukwila near the confluence with the Black River (22 square miles of industrial and residential

[7] The King County website (http://www.kingcounty.gov/environment/watersheds/green-river.aspx), among other sources, provides considerable additional background information on the watershed including historical changes.

areas; includes lateral loading to portion of the Duwamish River downstream of the Black River as well the LDW);

- *Lower Green River* (Figure 1-4) from Tukwila (RM 11.0) to Auburn Narrows (RM 32.0) (nearly 64 square miles of residential, industrial, and commercial);
- *Middle Green River* (Figure 1-5) from Auburn Narrows (RM 32.0) to the Howard Hanson Dam (RM 64.5) (nearly 180 square miles of residential, forest, and agricultural land uses); and
- *Upper Green River* (Figure 1-6) from the Howard Hanson Dam to the headwaters (220 square miles of mostly forested land).

Tributaries in these subwatersheds include the Black River, Mill Creek, Soos Creek, Jenkins Creek, Covington Creek, Newaukum Creek, and many other smaller creeks.

LDW is located in the Duwamish Estuary subwatershed and direct loading from this area will be quantified along with loadings from the upstream subwatersheds (Lower, Middle, and Upper Green). Loads to the East and West Waterways will also be included as these loads impact the LDW due to tides; however, details on cleanup efforts in and around the East and West Waterways and Elliott Bay will not be included.

The LDW is located within the Duwamish Estuary subwatershed. Direct loading from this subwatershed to the LDW (which is the receiving waterbody of primary concern) and additional combined sewer overflow (CSO) loading from the sewershed will be considered in this technical approach along with the comprehensive loadings from sources in the three upstream subwatersheds (Lower, Middle, and Upper Green subwatersheds). This watershed-based geographic representation allows for quantification of all sources associated with LDW and other Green/Duwamish River watershed impairments and provides connectivity to Elliott Bay. Loads from the land or via direct discharges to the East and West Waterways will also be included into the technical approach as these loads impact conditions in the LDW due to tidal processes. Ultimately, the connection to downstream receiving waters streamlines expansion of the approach to address impairments in the East and West Waterways as well as Elliott Bay in the future; however, specific details on other cleanup efforts in and around these waterbodies will not be included in this technical approach. Representation of these areas associated with the technical approach is discussed in Section 5.

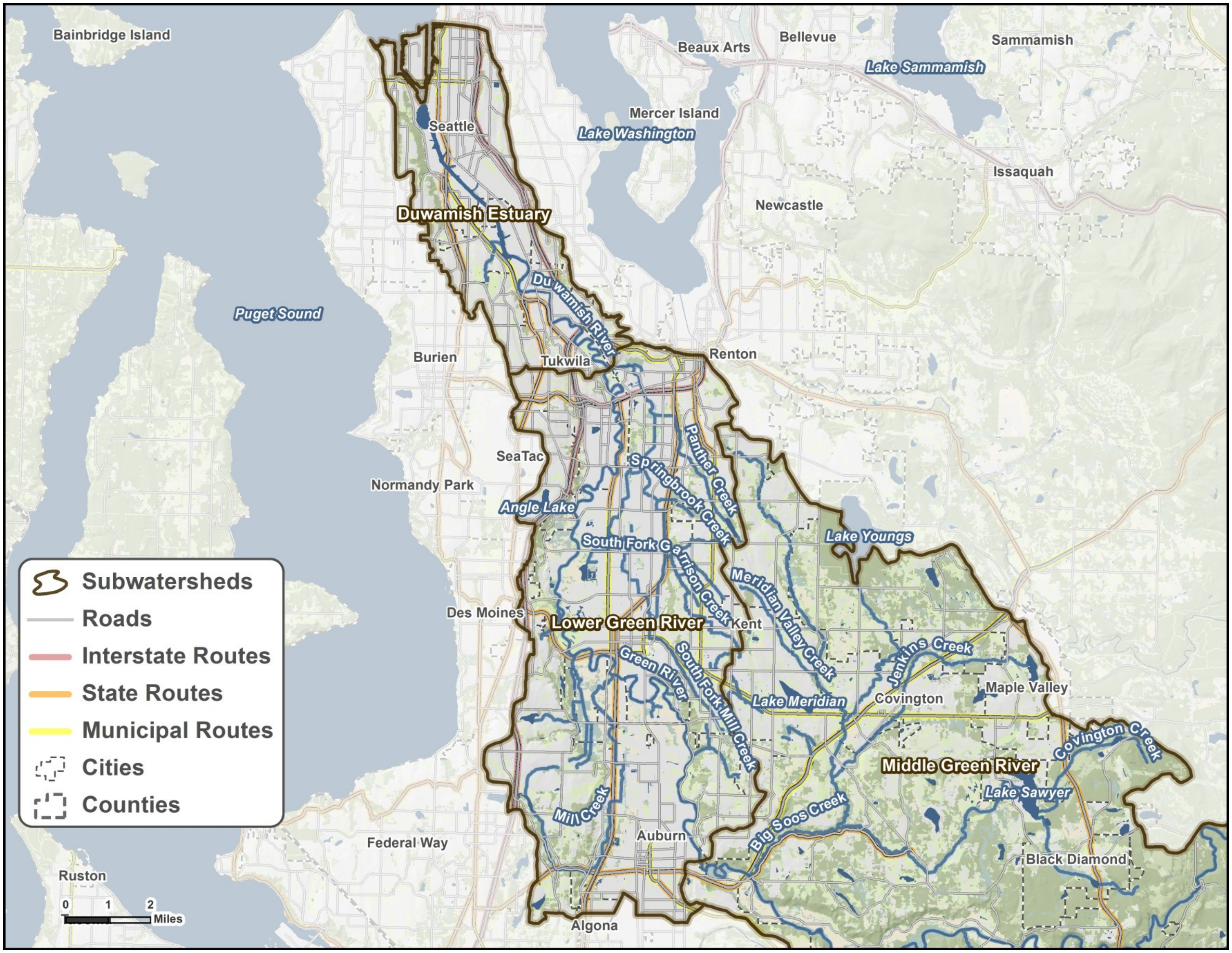


Figure 1-4. Duwamish Estuary and Lower Green River subwatersheds

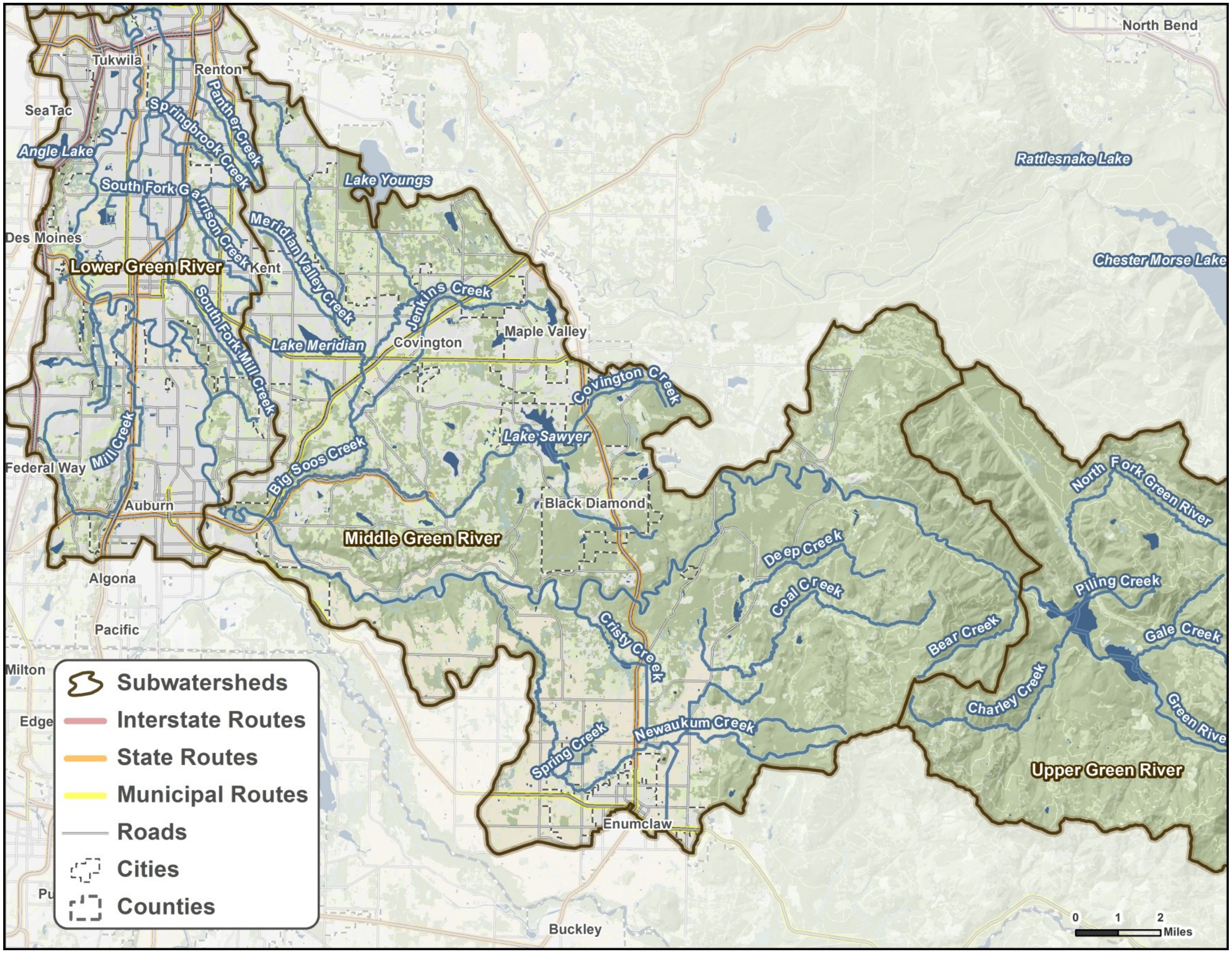


Figure 1-5. Middle Green River subwatershed

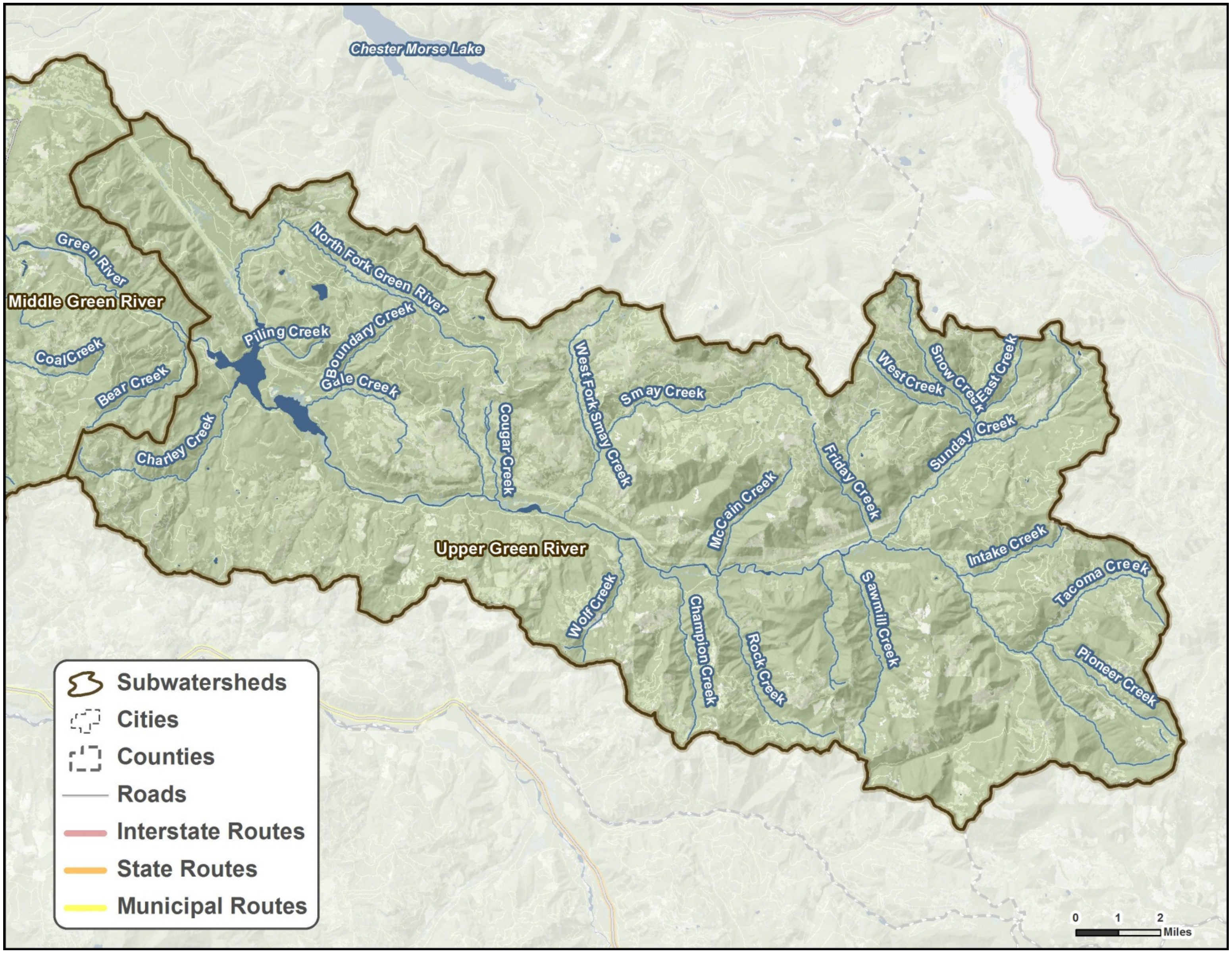


Figure 1-6. Upper Green River subwatershed

1.3 Clean Water Act 303(d) Listings and Impairments

The federal CWA, adopted in 1972, requires that all states restore their waters to be "fishable and swimmable." Section 303(d) of the CWA established a process to identify and clean up polluted waters. Every two years, all states are required to perform an assessment of the quality of surface waters in the state, including all rivers, lakes, and marine waters where data were available. Ecology compiles its own water quality data, and invites other groups to submit water quality data they have collected using appropriate scientific methods (note: the term *water quality* also encompasses sediment and tissue for these assessments) (Ecology, 2013a). It should be noted that the determination of COCs under Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) is governed by a separate and distinct process that is not identical to the assessment of designated uses under the CWA.

The assessed waters under the CWA are placed into one of five categories that describe the status of water quality. The final assessment is formally submitted to the EPA for approval. Waters in Category 5 are those for which Ecology has data showing that water quality standards have been violated for one or more pollutants, and there is no TMDL or pollution control plan established (Ecology, 2013a). TMDLs are required for the waterbodies in this category. Category 5 waters constitute the 303(d) list of impaired waters for the State. Ecology's assessment of which waters to place on the 303(d) list is guided by federal laws, state water quality standards, and Water Quality Program Policy 1-11 (the Policy on the Washington State Water Quality Assessment). This policy describes how the standards are applied and requirements for the data used.

Categories 1 through 4, including three subcategories of Category 4, are used to supplement other water quality efforts in the State, as well as to communicate the known State water conditions to the public. These category assignments are not subject to EPA approval. Categories 1-3 designate waters that are not known to be impaired due to meeting tested criteria, being a water of concern, or lacking sufficient data for listing. Category 4 designates waters that are impaired but do not require a TMDL because they either have an existing approved TMDL, have a Pollution Control Program, or are impaired by a non-pollutant.

There are 73 waterbody segment-pollutant combinations on the 2012 category 4 list in the study area. These include impairments for sediment and water for 50 pollutants. These impairments are summarized in Table 1-1 along with their associated parameter group. Conventional parameters, nutrients, and bacteria have the largest number of listings (all in water), while PAHs are associated with more impairments than other pollutant groups in sediment. The 22 Category 4A water impairments have been addressed by the following TMDLs: Duwamish/Green Ammonia-N TMDL, Fauntleroy Creek fecal coliform TMDL, Green River TMDL, Newaukum Temperature TMDL, and the Sawyer Lake total phosphorus TMDL. It is believed that the 51 Category 4B sediment impairments included in the 2012 assessment, all of which are located downstream of the LDW, will be addressed by other pollution controls. In this case, those pollution controls include CERCLA, or MTCA Record of Decision (ROD) Consent Decrees, or associated remedial actions for the following sites in the East or West Waterway: Harbor Island East Waterway, Harbor Island West Waterway Lockheed Shipbuilding Co. Yard 1, and Southwest Harbor Project Lockheed Yard 2.

Table 1-1. 2012 Category 4A and 4B impairment count by pollutant for sediment and water in the study area

Impaired Waterbodies[1]	Parameter	Parameter Group	Number of Impairments
4A Water Impairments			
Duwamish Waterway, Green River	Ammonia-N	Nutrients	3
Fauntleroy Creek	Bacteria	Bacteria	1
Green River, Newaukum Creek	Temperature	Conventionals	17
Sawyer Lake	Total Phosphorus	Conventionals	1
4B Sediment Impairments			
East Waterway	1,2,4-Trichlorobenzene	Other SVOCs	1
East Waterway	1,2-Dichlorobenzene	Other SVOCs	1
East Waterway	1,4-Dichlorobenzene	Other SVOCs	1
East Waterway	2,4-Dimethylphenol	Other SVOCs	1
East Waterway	2-Methylnaphthalene	PAHs	1
East Waterway	2-Methylphenol	Other SVOCs	1
East Waterway	4-Methylphenol	Other SVOCs	1
East Waterway	Acenaphthene	PAHs	1
East Waterway	Acenaphthylene	PAHs	1
East Waterway	Anthracene	PAHs	1
East Waterway	Arsenic	Arsenic	2
East Waterway	Benz[a]anthracene	PAHs	1
East Waterway	Benzo[a]pyrene	PAHs	1
East Waterway	Benzo[ghi]perylene	PAHs	1
East Waterway	Benzofluoranthenes, Total (b+k+j)	PAHs	1
East Waterway	Bis(2-Ethylhexyl) Phthalate	Phthalates	2
East Waterway	Butyl benzyl phthalate	Phthalates	1
East Waterway	Cadmium	Metals	1
East Waterway	Chromium	Metals	1
East Waterway	Chrysene	PAHs	1
East Waterway	Copper	Metals	1
East Waterway	Dibenzo[a,h]anthracene	PAHs	1
East Waterway	Dibenzofuran	Other SVOCs	1
East Waterway	Dibutyl phthalate	Phthalates	1
East Waterway	Diethyl phthalate	Phthalates	1
East Waterway	Dimethyl phthalate	Phthalates	1

Impaired Waterbodies[1]	Parameter	Parameter Group	Number of Impairments
East Waterway	Di-N-Octyl Phthalate	Phthalates	1
East Waterway	Fluoranthene	PAHs	1
East Waterway	Fluorene	PAHs	1
East Waterway	Hexachlorobenzene	Other SVOCs	1
East Waterway	Hexachlorobutadiene	Other SVOCs	1
East Waterway	High Molecular Weight Polycyclic Aromatic Hydrocarbons (HPAHs)	PAHs	1
East Waterway	Indeno(1,2,3-cd)pyrene	PAHs	1
East Waterway	Lead	Metals	1
East Waterway	Low Molecular Weight Polycyclic Aromatic Hydrocarbons (LPAHs)	PAHs	1
East Waterway	Mercury	Metals	1
East Waterway	Naphthalene	PAHs	1
East Waterway	N-Nitrosodiphenylamine	Other SVOCs	1
East Waterway	PCB	PCBs	1
East Waterway	Pentachlorophenol	Other SVOCs	1
East Waterway	Phenanthrene	PAHs	1
East Waterway	Phenol	Other SVOCs	1
East Waterway	Pyrene	PAHs	1
East and West Waterways	Sediment Bioassay	Bioassay	6
East Waterway	Silver	Metals	1
East Waterway	Zinc	Metals	1

[1] Impairments in the East and West waterways are identified on Ecology's 2012 Integrated Report as "Duwamish Waterway." Clarification provided in this table.

Chapter 1 of the policy, *Assessment of Water Quality for the Clean Water Act Section 303(d) and 305(b) Integrated Report* (Ecology, 2012a), describes how waterbody segments will generally be assessed to determine attainment with surface water quality standards (WAC 173-201A) and SMS (WAC 173-204) defined in the Washington Administrative Code (WAC). Generally numeric and narrative data are used for assessment purposes, depending on the parameter. Newly submitted data are added to previously assessed data that are less than ten years old. Data older than ten years are used only if no more recent data exist to conduct the assessment. Older data must also meet all Quality Assurance (QA) requirements at the time of submittal, and are compared against the current policy to make the assessment decision. Data older than ten years are used whenever necessary to determine historical natural conditions. Listings from previous assessment cycles are not reassessed according to this policy unless more recent information associated with the parameter and waterbody segment is made available.

Waterbody segments can be listed as impaired due to the following pollutants (and listings can be associated with water, sediment, and/or tissue matrices, depending on the pollutant):

- Bacteria

- Contaminated Sediments
- Dissolved Oxygen
- pH
- Total Phosphorus in Lakes
- Temperature
- Total Dissolved Gas
- Toxic Substances
- Turbidity

Chapter 2 of the policy, *Ensuring Credible Data for Water Quality Management* (Ecology, 2006) describes the QA measures, guidance, regulations, and existing policies that help ensure the credibility of data and other information used in agency actions based on the quality of state surface waters.

The designation of fresh or marine water is determined from salinity measurements based on the WAC 173-201A-260(e) rules outlined below; the exact line along the Duwamish River and LDW shifts but the boundary between freshwater and marine is generally located upstream of the turning basin near S. 102nd Street Bridge (Figure 1-3).

***WAC 173-201A-260**:*

(e) In brackish waters of estuaries, where different criteria for the same use occurs for fresh and marine waters, the decision to use the fresh water or the marine water criteria must be selected and applied on the basis of vertically averaged daily maximum salinity, referred to below as "salinity."

(i) The fresh water criteria must be applied at any point where ninety-five percent of the salinity values are less than or equal to one part per thousand, except that the fresh water criteria for bacteria applies when the salinity is less than ten parts per thousand; and

(ii) The marine water criteria must apply at all other locations where the salinity values are greater than one part per thousand, except that the marine criteria for bacteria applies when the salinity is ten parts per thousand or greater.

Starting with the 2010 Water Quality Assessment, Ecology began using a rotating assessment system to alternate between marine and freshwater assessments due to the high volume of new data and the time required to properly assess these data. The 2010 cycle focused on marine waters, while the next cycle will focus on freshwater. With the exception of the LDW, all waterbodies in the Green/Duwamish River watershed addressed in this technical approach are freshwater. The designation of fresh or marine water is determined from salinity measurements outlined in *Water Quality Standards for Surface Waters of the State of Washington* (WAC 173-201A-260(e)). While the exact line between the Duwamish River and LDW shifts depending on the salinity monitoring data which will vary with tidal influence, Table 602 in WAC 173-201A defines the fresh water boundary as the Duwamish River from its mouth south of a line bearing 254 degrees true from the NW corner of berth 3, terminal No. 37 to the Black River (RM 11.0). Ecology indicates a true delineation of the freshwater and marine boundary will be somewhere upstream of the turning basin near S. 102nd Street Bridge (see Figure 1-3 for the location of the turning basin). For the purposes of this technical approach, the Duwamish River (downstream of the Black River confluence) is considered freshwater to the turning basin. Downstream of the turning basin, the LDW, including the East and West Waterways, are considered marine. The marine designation from the turning basin to the mouth is consistent with the criteria Superfund has applied for cleanup efforts. Sediment standards are determined by the salinity in pore water and the delineation of fresh pore water to marine pore water will be similar to that of surface water. Future analysis of salinity data will be needed to specifically define the freshwater/marine delineation for the purpose of applying the appropriate criteria and managing discharges.

The Washington Water Quality Assessment (i.e., 305(b) and 303(d) reports) fulfills the state's obligation to submit an integrated report to meet the CWA requirements of sections 305(b) and 303(d). EPA approved Washington's most recent 303(d) list on December 21, 2012. Given that EPA approval occurred in late 2012, the 2010 process was merged into the 2012 assessment for tracking purposes by Ecology. This assessment was based on mostly new, readily available, water quality data for marine waters; data for freshwaters will be assessed in the next listing cycle. Washington State's Water Quality Assessment and 303(d) list are available on Ecology's website (http://www.ecy.wa.gov/programs/wq/303d/index.html).

There are over 250 waterbody segment-pollutant combinations on the 2012 303(d) list in the study area. These include impairments for sediment, tissue, and water for over 50 pollutants. These listings are summarized in Table 1-2 along with their associated parameter group. Conventional parameters and bacteria have the largest number of listings (all in water), while PAHs are associated with more impairments than other pollutant groups in sediment and tissue.

Table 1-2. Impairment count by pollutant for sediment, water, and tissue in the study area

Parameter	Parameter Group	Number of Impairments by Matrix[1]			Total
		Sediment	Tissue	Water	
2,3,7,8-TCDD	Dioxin/Furan		3		3
2-Methylnaphthalene	PAHs	1			1
4,4'-DDD	Pesticides		1		1
4,4'-DDE	Pesticides		1		1
4,4'-DDT	Pesticides		1		1
4-Methylphenol	Other SVOCs	1			1
Acenaphthene	PAHs	2			2
Alpha-BHC	Pesticides		1		1
Anthracene	PAHs	3			3
Arsenic	Metals	3			3
Arsenic, Inorganic	Metals		4		4
Bacteria	Bacteria			42	42
Benzo[a]anthracene	PAHs	2	1		3
Benzo[a]pyrene	PAHs	3	6		9
Benzo[b]fluoranthene	PAHs		6		6
Benzo[ghi]perylene	PAHs	3			3
Benzo[k]fluoranthene	PAHs		6		6
Benzofluoranthenes, Total (b+k+j)	PAHs	3			3
Benzoic Acid	Other SVOCs	1			1
Bis(2-Ethylhexyl) Phthalate	Phthalates	3	2		5
Butyl benzyl phthalate	Phthalates	2			2
Cadmium	Metals	4			4
Chromium	Metals	3			3
Chrysene	PAHs	3	6		9
Copper	Metals	3		3	6
Dibenzo[a,h]anthracene	PAHs	3	5		8
Dibenzofuran	Other SVOCs	2			2
Dibutyl phthalate	Phthalates	1			1
Dieldrin	Pesticides		2		2
Dimethyl phthalate	Phthalates	1			1
Di-N-Octyl Phthalate	Phthalates	1			1
Dissolved Oxygen	Conventional			29	29
Fluoranthene	PAHs	3			3
Fluorene	PAHs	2			2

Parameter	Parameter Group	Number of Impairments by Matrix[1]			Total
		Sediment	Tissue	Water	
Hexachlorobenzene	Other SVOCs		1		1
HPAHs	PAHs	3	1		4
Indeno(1,2,3-cd)pyrene	PAHs	3	6		9
Lead	Metals	3			3
LPAHs	PAHs	3			3
Mercury	Metals	4			4
Naphthalene	PAHs	1			1
PCB	PCBs	3	6		9
pH	Conventional			2	2
Phenanthrene	PAHs	3			3
Phenol	Other SVOCs	2			2
Pyrene	PAHs	3			3
Sediment Bioassay	Bioassay	30			30
Silver	Metals	3			3
Temperature	Conventional			10	10
Total Chlordane	Pesticides		1		1
Total Phosphorus	Nutrients			3	3
Toxaphene	Pesticides		1		1
Zinc	Metals	3			3
Total		**117**	**61**	**89**	**267**

[1] Blank cells indicate no Category 5 listing for that matrix-pollutant combination.

Table 1-3 through Table 1-5 summarize the number of sediment, tissue, and water impairments, respectively, in the study area. These are based on a count of unique Listing ID Numbers from the 303(d) list and, for many waterbodies, these tables present the sum of impairments in multiple geographic segments within that waterbody. These tables also identify the initial year the waterbody was listed for that pollutant and a generalized parameter group for each of the specific sediment and tissue pollutants (note: the water pollutants are bacteria, conventional, metals, or nutrients). These listings are also illustrated in Figure 1-7 through Figure 1-10 for the Duwamish Estuary, Lower, Middle, and Upper Green River subwatersheds, respectively (presented from downstream to upstream).

Table 1-3. Summary of Category 5 sediment impairments in the study area

Parameter	Parameter Group	Number of Listed Segments	First Year Listed
Waterbody: Lower Duwamish Waterway			
2-Methylnaphthalene	PAHs	1	2012
4-Methylphenol	Other SVOCs	1	2012
Acenaphthene	PAHs	2	2012
Anthracene	PAHs	3	2012
Arsenic	Metals	3	2012
Benzo[a]anthracene	PAHs	2	2012
Benzo[a]pyrene	PAHs	3	2012

Parameter	Parameter Group	Number of Listed Segments	First Year Listed
Benzo[ghi]perylene	PAHs	3	2012
Benzofluoranthenes, Total (b+k+j)	PAHs	3	2012
Benzoic Acid	Other SVOCs	1	2012
Bis(2-Ethylhexyl) Phthalate	Phthalates	3	2012
Butyl benzyl phthalate	Phthalates	2	2012
Cadmium	Metals	4	2008
Chromium	Metals	3	2012
Chrysene	PAHs	3	2012
Copper	Metals	3	2012
Dibenzo[a,h]anthracene	PAHs	3	2012
Dibenzofuran	Other SVOCs	2	2012
Dibutyl phthalate	Phthalates	1	2012
Dimethyl phthalate	Phthalates	1	2012
Di-N-Octyl Phthalate	Phthalates	1	2012
Fluoranthene	PAHs	3	2012
Fluorene	PAHs	2	2012
HPAHs	PAHs	3	2012
Indeno(1,2,3-cd)pyrene	PAHs	3	2012
Lead	Metals	3	2012
LPAHs	PAHs	3	2012
Mercury	Metals	4	2008
Naphthalene	PAHs	1	2012
PCB	PCBs	3	2012
Phenanthrene	PAHs	3	2012
Phenol	Other SVOCs	2	2012
Pyrene	PAHs	3	2012
Sediment Bioassay	Bioassay	30	2008
Silver	Metals	3	2012
Zinc	Metals	3	2012
Total		**117**	**2008**

Table 1-4. Summary of Category 5 tissue impairments in the study area

Parameter	Parameter Group	Number of Listed Segments	First Year Listed
Waterbody: Lower Duwamish Waterway			
2,3,7,8-TCDD	Dioxin/Furan	1	2012
Arsenic, Inorganic	Metals	4	2012
Benzo[a]anthracene	PAHs	1	2012
Benzo[a]pyrene	PAHs	6	2012
Benzo[b]fluoranthene	PAHs	6	2012

Parameter	Parameter Group	Number of Listed Segments	First Year Listed
Benzo[k]fluoranthene	PAHs	6	2012
Bis(2-Ethylhexyl) Phthalate	Phthalates	2	2012
Chrysene	PAHs	6	2012
Dibenzo[a,h]anthracene	PAHs	5	2012
Dieldrin	Pesticides	1	2012
Indeno(1,2,3-cd)pyrene	PAHs	6	2012
PCB	PCBs	2	2004
Waterbody Total		**46**	**2004**
Waterbody: Duwamish River			
4,4'-DDD	Pesticides	1	2004
4,4'-DDE	Pesticides	1	2004
4,4'-DDT	Pesticides	1	2004
Alpha-BHC	Pesticides	1	2004
PCB	PCBs	1	2004
Waterbody Total		**5**	**2004**
Waterbody: Meridian Lake			
2,3,7,8-TCDD	Dioxin/Furan	1	2008
Dieldrin	Pesticides	1	2008
Hexachlorobenzene	Other SVOCs	1	2008
PCB	PCBs	1	2008
Total Chlordane	Pesticides	1	2008
Toxaphene	Pesticides	1	2008
Waterbody Total		**6**	**2008**
Waterbody: Sawyer Lake			
2,3,7,8-TCDD	Dioxin/Furan	1	2008
PCB	PCBs	1	2008
Waterbody Total		**2**	**2008**
Waterbody: Duwamish East and West Waterways[1]			
HPAHs	PAHs	1	2004
PCB	PCBs	1	1998
Waterbody Total		**2**	**1998**
Total Tissue Impairments		**61**	**1998**

[1] Impairments will not be addressed as part of the technical approach; however, they are related to the study area due to tidal influences.

Table 1-5. Summary of Category 5 water impairments in the study area

Waterbody[1]	Bacteria		Copper		Dissolved Oxygen		pH		Temperature		Total Phosphorus		Total Number of Listings
	Number of Listed Segments	First Year Listed	Number of Listed Segments	First Year Listed	Number of Listed Segments	First Year Listed	Number of Listed Segments	First Year Listed	Number of Listed Segments	First Year Listed	Number of Listed Segments	First Year Listed	
Angle Lake	1	2004											**1**
Big Soos Creek	3	1996			2	1996			1	2008			**6**
Black River	2	1996			1	1996							**3**
Covington Creek	1	2004			1	2008							**2**
Crisp Creek	2	1998											**2**
Duwamish River							2	1996	1	2008			**3**
Lower Duwamish Waterway	1	1996			1	1996							**2**
Fenwick Lake											1	2004	**1**
Gale Creek									1	1996			**1**
Green River	3	1996			5	1996							**8**
Hill (Mill) Creek	5	1998	1	2004	4	1998			1	1998			**11**
Jenkins Creek	1	1996											**1**
Little Soos Creek	2	1996			1	1996			2	2004			**5**
Little Soosette Creek	3	1998			2	1996							**5**
Longfellow Creek	3	1998			1	2004							**4**
Meridian Lake	1	1998									1	1996	**2**
Mullen Slough	2	1998			2	1998			1	1998			**5**
Newaukum Creek	6	1996	2	2004	3	1996							**11**
Ravensdale Creek									1	2004			**1**
Smay Creek									1	1996			**1**
Soosette Creek	1	2004											**1**
Springbrook (Mill) Creek	1	2004			1	1996							**2**
Unnamed Creek (Tributary to Newaukum Creek)	1	1998			3	2008			1	2008			**5**
Unnamed Creek (WDF# 09.0046)	1	1998			1	1998							**2**
Unnamed Pond											1	2008	**1**
Wilderness Lake	1	2004											**1**
Duwamish West Waterway[2]	1	2008			1	1996							
Total	**42**	**1996**	**3**	**2004**	**29**	**1996**	**2**	**1996**	**10**	**1996**	**3**	**1996**	**89**

[1] Blank cells indicate no Category 5 listing for that waterbody-pollutant combination.

[2] Impairments will not be addressed directly as part of the technical approach; however, they are related to the study area due to tidal influences.

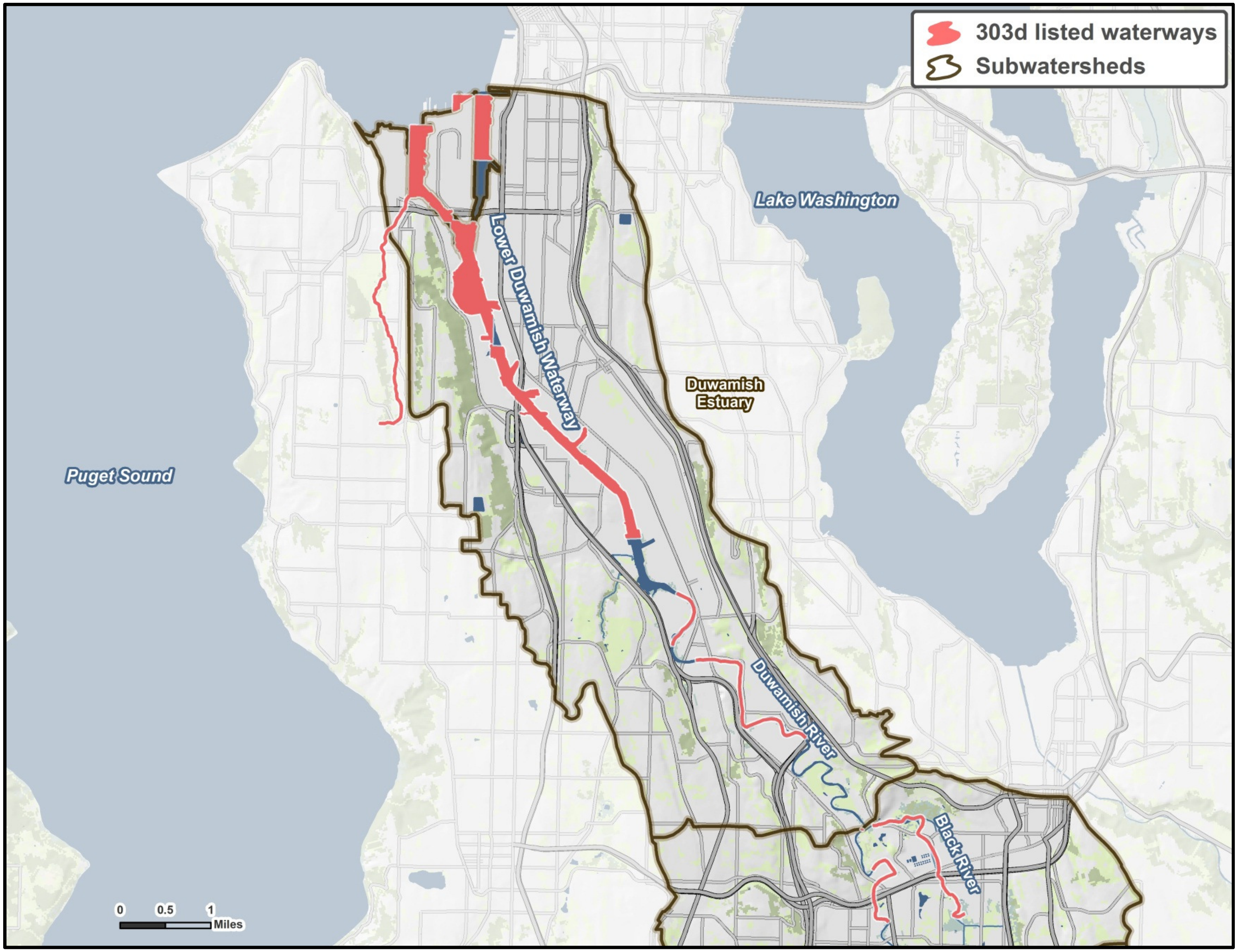


Figure 1-7. 303(d) listings in the Duwamish Estuary subwatershed

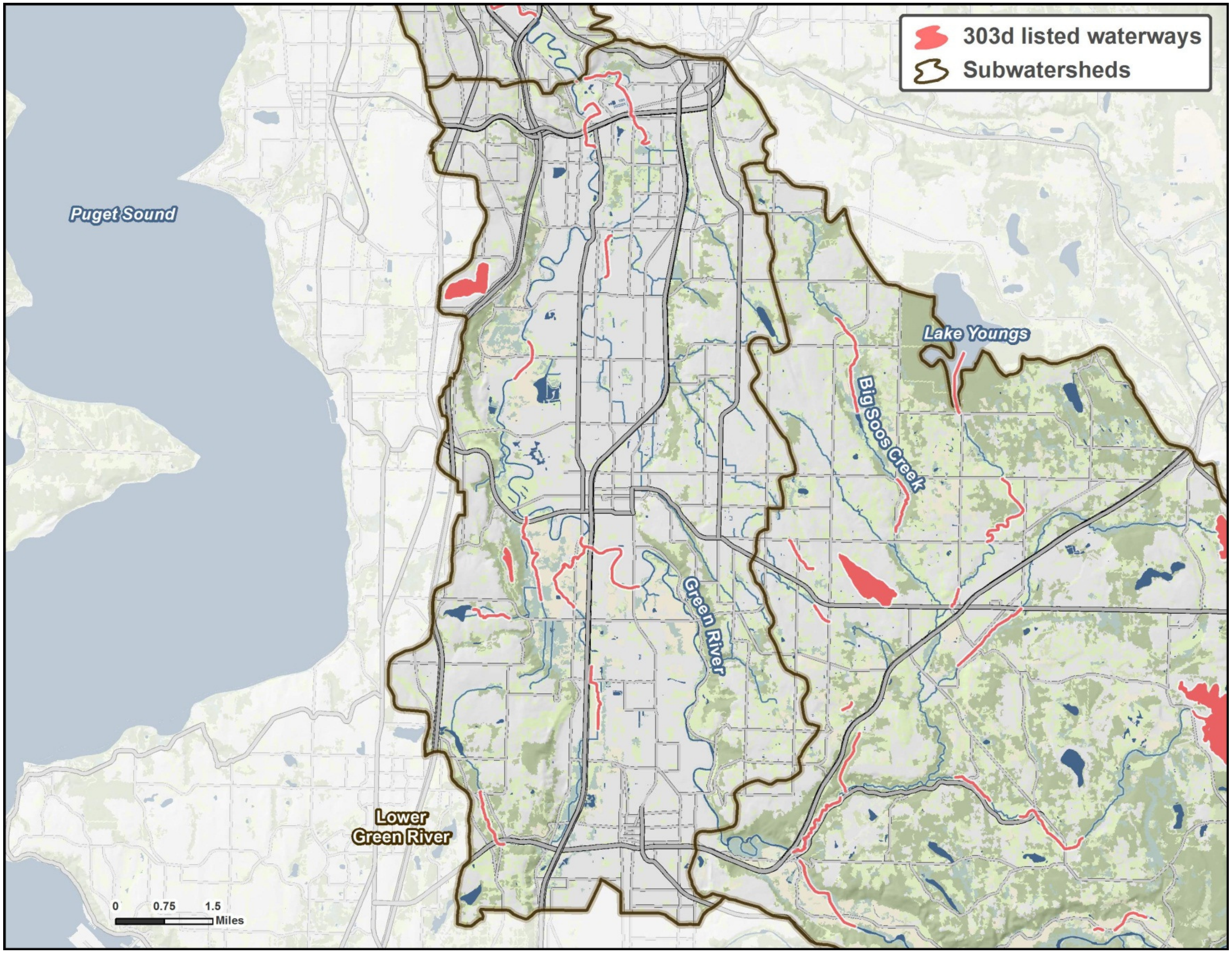


Figure 1-8. 303(d) listings in the Lower Green River subwatershed

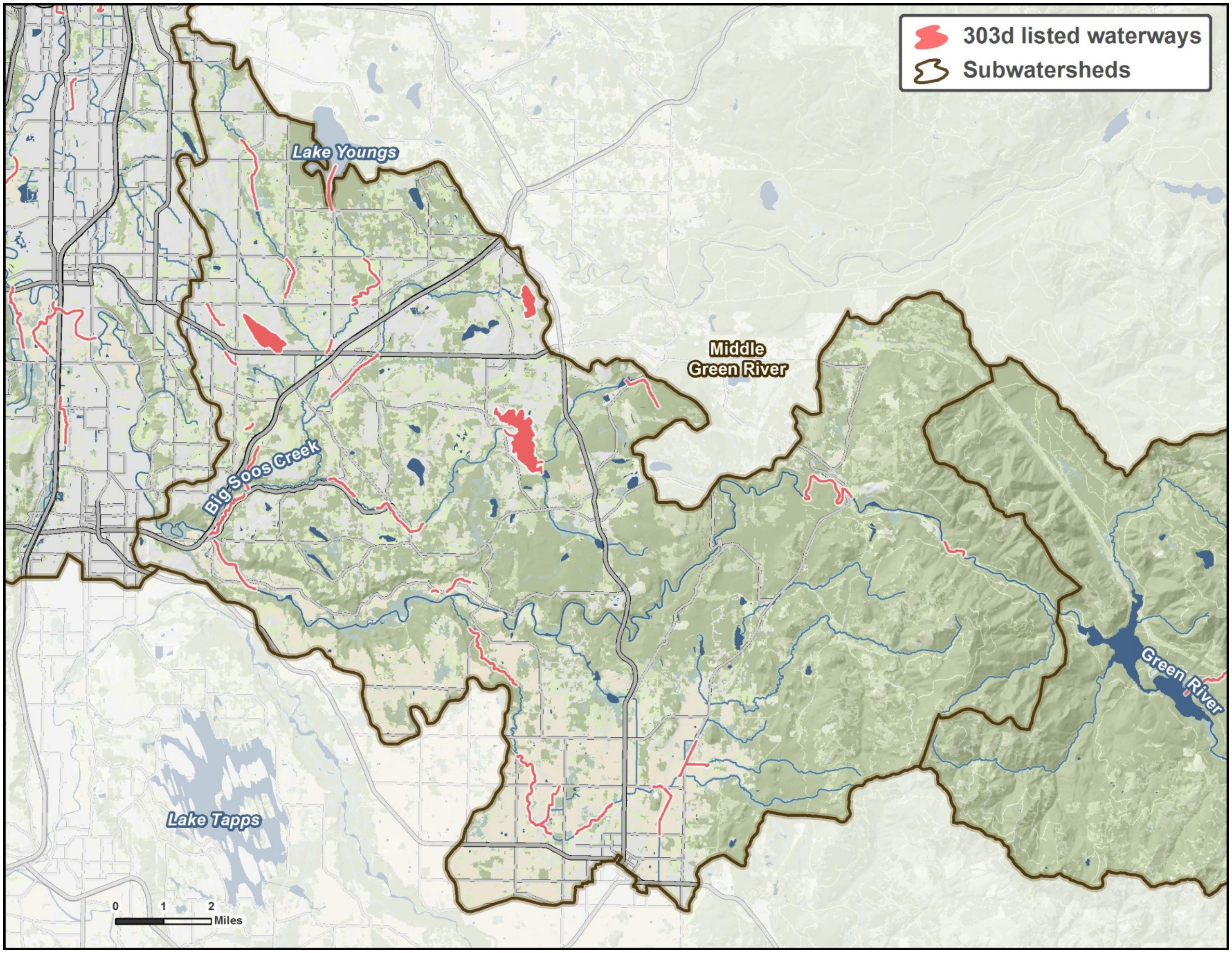


Figure 1-9. 303(d) listings in the Middle Green River subwatershed

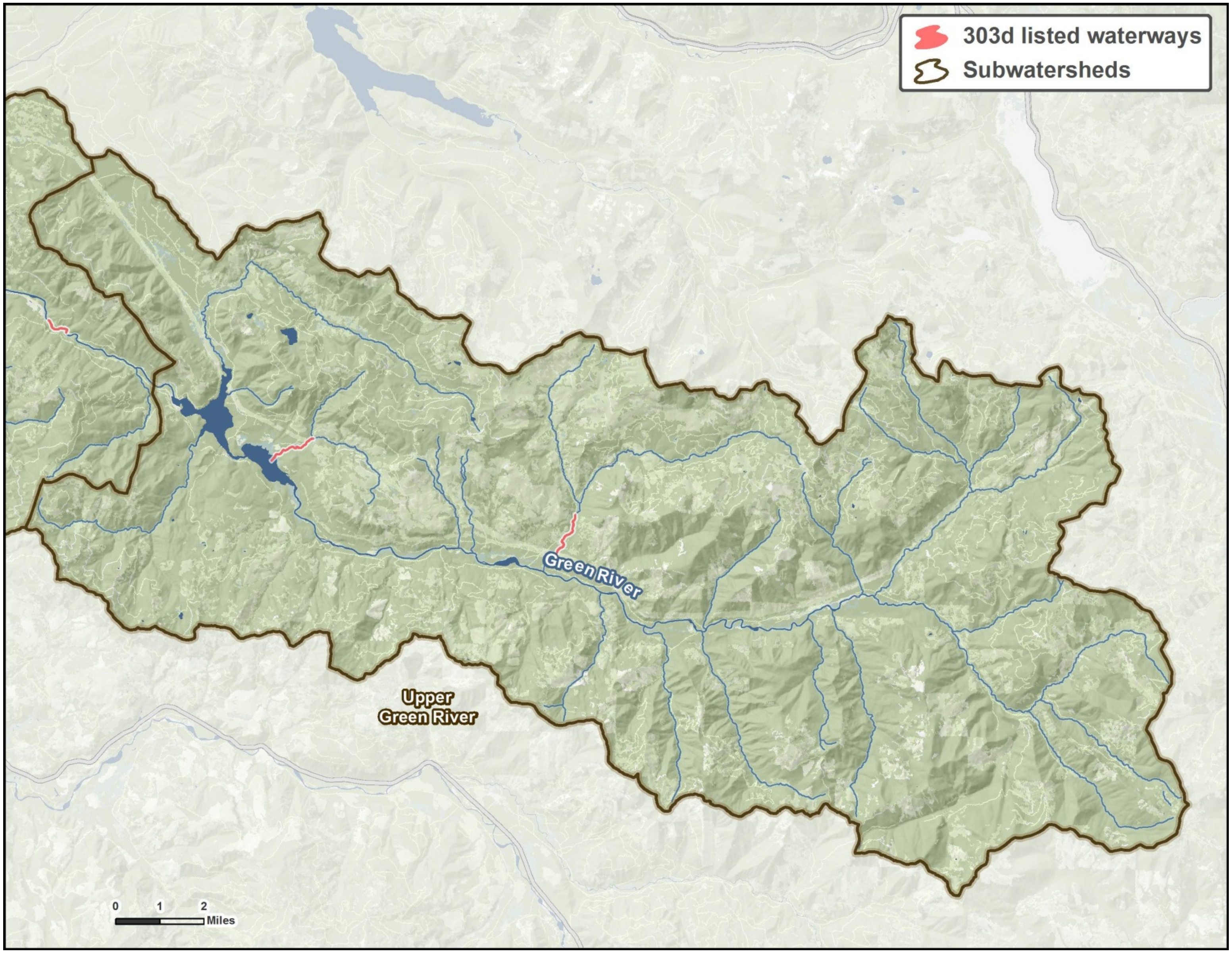


Figure 1-10. 303(d) listings in the Upper Green River subwatershed

When evaluating the study area impairments geographically, there are numerous creeks and several lakes impaired throughout the Lower and Middle Greek River subwatersheds (Figure 1-8 and Figure 1-9, respectively) and just two creeks in the mostly open Upper Green River subwatershed (Figure 1-10). Some of these impairments are being addressed through separate efforts (or have been addressed, but have not yet been delisted), so this approach is designed to address any remaining impairments. In the Duwamish Estuary subwatershed (Figure 1-7), impairment areas are illustrated for the Duwamish East and West Waterways (on either side of Harbor Island). These impairments include tissue and water listings (Table 1-4 and Table 1-5, respectively) and are included in this section because they impact water, sediment, and tissue quality in the LDW due to tidal processes (in addition, tissue listings may be based on fish that move between the East and West Waterways and the LDW). The Duwamish East and West Waterway impairments will not be addressed as part of this technical approach because they require a more detailed analysis of their associated Superfund sites (including Harbor Island).

***Impairment Summary*:**

- *Sediment: 117 listings for 36 different toxic compounds; all downstream of the turning basin*
- *Tissue: 61 listings for 20 different toxic compounds; includes LDW, East and West Waterways, Duwamish River, and two lakes in Middle Green River subwatershed*
- *Water: 89 listings for bacteria, conventional pollutants, metals, and nutrients (six different pollutants); includes five lakes, one slough, Duwamish River, LDW, West Waterway, and many creeks located throughout study area*

All of the sediment listings (Table 1-3) are associated with the LDW and the earliest listing was in 2008. Pollutants include a suite of toxic compounds and sediment bioassay impairments (note: no sediment impairments have been identified upstream of the turning basin). Similar toxic compounds are associated with the tissue listings in the LDW, Duwamish River, Meridian Lake, Sawyer Lake, and the Duwamish East and West Waterways (Table 1-4). Most of the tissue listings originated in 2008 or more recently, except for PCBs in the LDW (2004), various pollutants upstream of the LDW in the Duwamish River (2004), and the listings in the East (2004 for HPAHs) and West (1998 for PCB) Waterways. The Category 5 listings for water are distributed throughout the study area and include bacteria, conventional pollutants, metals, and nutrients. Original listings for many of these date back to 1996 or 1998.

Data from the past 10 years are generally considered in a listing decision. It is assumed that impairments added to the 303(d) list in 2008 or later meet all credible data requirements from Ecology (as part of Water Quality Program Policy 1-11). This includes all of the sediment impairments presented in Table 1-3 and many of the tissue impairments (Table 1-4). Data used in the decisions for the tissue listings from 2004 and 1998 were evaluated (Table 1-4). Most of the data were based on Washington Department of Fish and Wildlife (WDFW) Puget Sound Assessment and Monitoring Program (PSAMP) data. The 1998 impairment for PCBs in the Duwamish West Waterway was based on mussel samples from 1995, which exceeded the Ecology National Toxics Rule (NTR)-based criteria, while the 2004 assessments (also compared to this criteria) included more than 24 exceedances in fish tissue samples from 1992-2000. Alternatively, fish exposed to xenobiotics such as PAHs exhibited hepatic necoplasms and lesions, which led to the 2004 Duwamish East Waterway listing for HPAHs. The 2004 Duwamish River PCB and pesticides listings used older fish tissue data from 1984 that were compared to Ecology NTR-based criteria.

While some of the data used for assessment purposes were older, these impairments were still kept on the 303(d) list on subsequent listing cycles, so data to support delisting is likely not available. However, it is important to acknowledge that these older data are of limited use when compared against the newer data from the remedial investigation (RI) and feasibility study (FS) and Water Program Policy 1-11. Continued data collection and assessment is imperative as ongoing and future cleanup and source control activities will result in changes to sediment and water chemistry (which should reduce tissue concentrations over time); thereby, potentially changing the category designation in the 305(b) assessment or supporting delisting.

In many cases, these waterbodies were listed as impaired on the 303(d) list after the LDW was already characterized as a Superfund Site and Ecology Hazardous Site (Section 1.4). This is likely due to the abundance of data collected subsequent to Superfund designation. It is also important to note that the Superfund program rejected some data in the LDW that were used to identify 303(d) impairments due to a focus on human health risk drivers or COCs (see below); therefore, the LDW has some 303(d) listings, particularly for pesticides, that are not included in the Superfund assessment and PP. In addition to the full suite of 303(d)-listed pollutants presented above, the Superfund PP identified pollutants that are the primary human health risk-drivers based on the human health risk assessment (HHRA) conducted as part of the RI as well as ecological risk drivers (EPA, 2013; see Section 1.1).

The human health risk drivers were selected based on estimates of lifetime excess cancer risks that exceeded 1×10^{-6} or a non-cancer hazard quotient of 1 for an adult tribal consumer. The following contaminants exceeded these risk thresholds but were not selected as risk drivers for human health for the following reasons:

1. Bis(2-ethylhexyl) phthalate (BEHP) and pentachlorophenol - insignificant contributors (< 1%) to the total risk estimate and they were rarely detected in Lower Duwamish Watery Group (LDWG) tissue samples. BEHP was selected as a risk driver for ecological risk.
2. Tributyltin and vanadium slightly exceeded a hazard quotient of 1 for only one seafood consumption scenario, the child tribal scenario. Child tribal exposure parameters have considerable uncertainty.
3. Eleven organochlorine pesticides (i.e., dichlorodiphenyltrichloroethane [DDT], aldrin, alpha-benzene hexachloride [BHC], beta-BHC, carbazole, total chlordane, dieldrin, gamma-BHC, heptachlor, heptachlor epoxide, and hexachlorobenzene) - Contaminant concentrations in tissue are uncertain due to analytical interference with the quantification of organochlorine pesticides from the presence of PCB congeners. Most of the pesticides had low detection frequencies.

The human health and ecological risk drivers are the primary pollutants driving selection of the technical approach; however, the approach being proposed here is flexible and can address all 303(d)-listed pollutants, as available data allow, or utilize appropriate, conservative surrogate parameters. Specifically, many of the other listed pollutants have similar (or identical) sources to those human health and ecological risk drivers (EPA, 2013).

1.4 Lower Duwamish Waterway Cleanup Activities

The LDW evolved over the past several decades from a natural estuary to a channelized waterway. Industrial and commercial development expanded as Seattle grew, especially in the early 1900s. Pollution sources in the Green/Duwamish River watershed were documented as early as 1945 and in the past several decades, the LDW has been extensively studied (Flint and Thomas, 2013).

EPA conducted a study in 1999 on LDW contaminants and, subsequently, the five-mile stretch was placed on the EPA National Priorities List (i.e., Superfund) in 2001 and on the Ecology Hazardous Sites List in 2002. Superfund is the nickname of CERCLA, passed in 1980. It identifies hazardous sites and requires cleanup by responsible parties. In the LDW Superfund Site, the contaminants include PCBs, dioxins/furans, cPAHs, and arsenic, as well as 41 other contaminants and are associated with a history of industrial use and waste (EPA, 2013).

In 2000, EPA and Ecology entered into an Administrative Order of Consent with LDWG, which is made up of King County, the Port of Seattle, the City of Seattle, and the Boeing Company (Boeing). Under this agreement, the LDWG was required to perform a RI (Windward Environmental, 2010) and to propose a FS for cleanup (AECOM, 2012a). EPA subsequently developed the PP, which presents EPA’s preferred alternative to clean up contamination in the LDW Superfund Site, while a ROD will ultimately be developed (anticipated in 2014) to select the final remedy (EPA, 2013).

In April 2002, EPA and Ecology signed an interagency Memorandum of Understanding (MOU) dividing federal and state work responsibilities for the LDW. This MOU was revised in 2004 to reflect ongoing work in the LDW. Under the MOU, EPA is the lead for the sediment investigation work and Ecology is the lead for coordinating and implementing the source control work.

A Phase 1 RI was prepared based on previously existing information in 2003. The Phase 1 RI also facilitated the identification of early action areas (EAAs). EAAs are areas identified for management actions (to be completed prior to starting construction of the selected remedy for the LDW) to reduce unacceptable risks in surface sediments. The early cleanup efforts comprise 29 acres in five EAAs: Duwamish/Diagonal, Terminal 117, Slip 4, Boeing Plant 2/Jorgenson Forge, and Norfolk CSO.

Additional details on the LDW source control and cleanup activities are provided below. These historical and ongoing actions were considered during development of the technical approach. In addition, innumerable activities are occurring upstream of the LDW (e.g., TMDLs and cleanup actions); these activities will be considered, as appropriate, under this PLA.

1.4.1 Superfund LDW-Specific Source Control and Cleanup

As presented in the Superfund PP for the LDW, the strategy to address contamination and associated risks in the LDW has three components (EPA, 2013):

1. Source control
2. EAAs
3. LDW-wide in-waterway cleanup

These three components are described in more detail below.

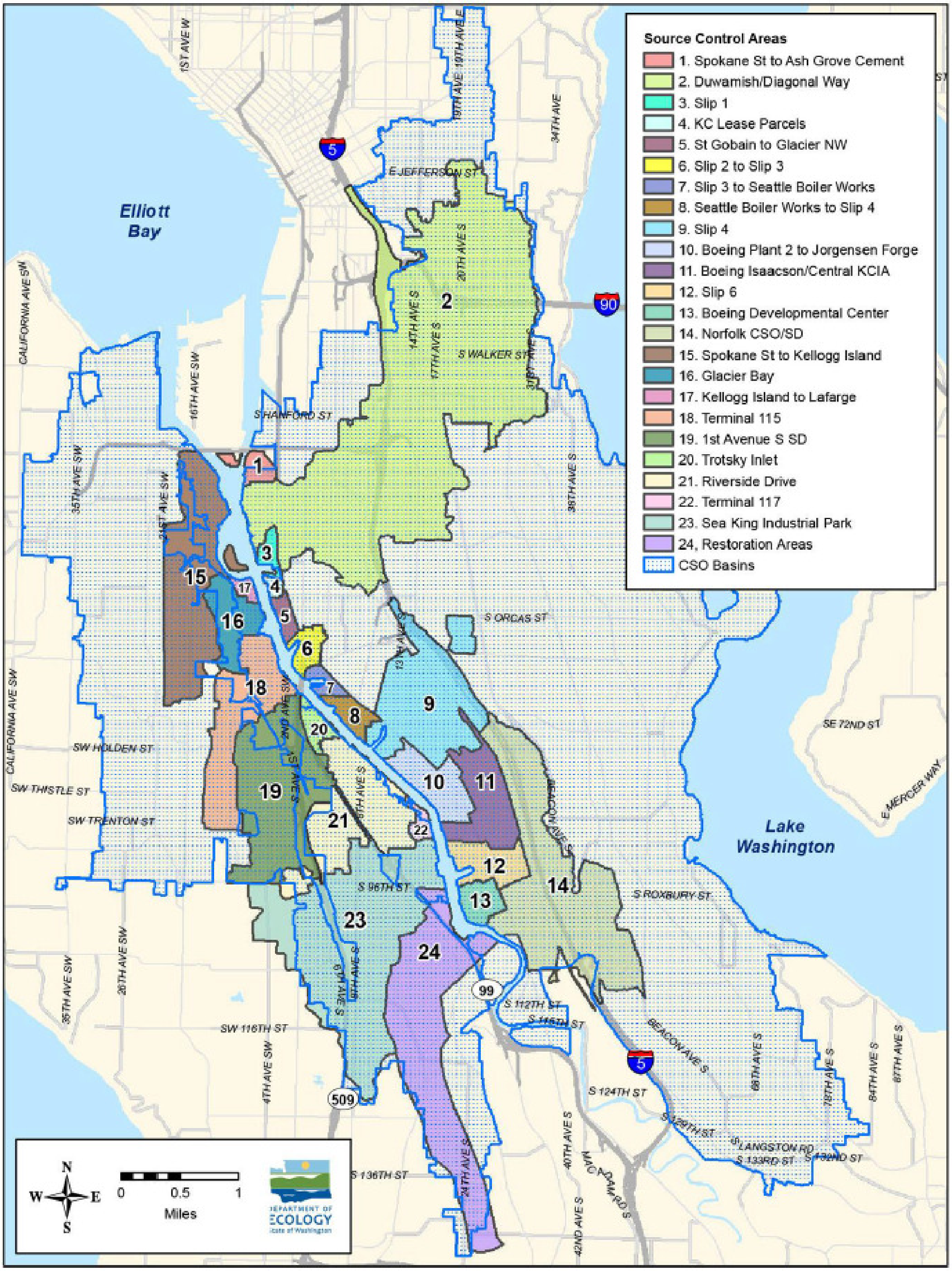
1.4.1.1 Source Control

Ecology is leading the Source Control Work Group (SCWG) that coordinates source control efforts by public agencies (Ecology, EPA, City of Seattle, and King County) as well their respective roles and responsibilities for source control work in the LDW. As part of the initial source control efforts (2002-2013), Ecology developed the LDW Source Control Strategy (Ecology, 2004 and 2012b) and Source Control Action Plans (SCAPs) for 24 Source Control Areas (SCAs) that drain to the LDW. The SCAs as well as the CSO service area (together referred to as the LDW Source Area) are illustrated in Figure 1-11. The SCAP for each SCA describes available existing information and any data gaps, and identifies potential sources of sediment contaminants and actions needed to control them. It also evaluates whether ongoing sources are present that could recontaminate sediments after in-water cleanup work.

Ongoing or planned source control activities that reduce loading to the LDW can be incorporated into a comprehensive approach through different scenarios and the results can inform future source control efforts and characterize changes over time (Section 5).

The 2012 Source Control Strategy prioritizes actions for each SCA into the following categories:

- High (needs to be cleaned up before sediment cleanup);
- Medium (can be completed before or at the same time as sediment cleanup); or
- Low (can be completed as resources are available because source is likely not critical to preserving the cleanup) (Ecology, 2012b; Flint and Thomas, 2013).



Source: Ecology, 2012b

Figure 1-11. LDW Source Control Areas

Continuing source control activities will lead to a reduced loading of contaminants to the LDW. The source control efforts are active, well-documented, and frequently updated. Ecology's Toxic Cleanup Program provides specific information on each of the SCAs via its website, including the Existing Information and Identification of Data Gaps Reports, SCAPs, and Source Control Status Reports (http://www.ecy.wa.gov/programs/tcp/sites_brochure/lower_duwamish/lower_duwamish_hp.html). In addition, other agencies are performing source control work in the LDW area, such as Seattle Public Utilities, King County, and the Port of Seattle (Flint and Thomas, 2013).

Despite the source control efforts, some recontamination is expected to occur. Given that the previous modeling efforts do not account for all of the sources and pathways to the LDW (Flint and Thomas, 2013), a more comprehensive approach will help quantify the potential for recontamination and identify associated sources. Ongoing or planned source control activities that reduce loading to the LDW can be incorporated in such an approach through different scenarios and the results can help inform future source control efforts and characterize changes over time (Section 5).

1.4.1.2 Early Action Areas

The Phase 1 RI identified areas that warranted early cleanup actions due to their high levels of contamination EAAs. Five areas were designated as EAAs, including two areas cleaned up by King County and another area cleaned up by the City of Seattle. The SCAs draining to these areas also have published SCAPs to control additional loading to the EAAs. The EAAs are identified below along with a summary of the planned and completed activities:

- ***Duwamish/Diagonal CSO/Storm Drain (SD)***: A 7-acre area was dredged and capped by King County in 2003 and 2004 (68,000 cubic yards). This effort addressed PCBs, mercury, bis(2-ethylhexyl)phthalate, and butyl benzyl phthalate. Subsequently, a 6-in layer of clean sand was placed over an area with elevated PCB concentrations following cleanup.
- ***Slip 4***: In October 2011 – January 2012, PCB-contaminated sediments were dredged (approximately 10,000 cubic yards) and 3.4 acres were capped with clean fill material by the City of Seattle. This cleanup was performed under an EPA Administrative Order and Settlement Agreement on Consent (Consent Order).
- ***Boeing Plant 2/Jorgensen Forge***: Beginning in 2013, areas of sediment contamination adjacent to Boeing Plant 2 and Jorgensen Forge are being cleaned up. . Source control actions in the upland facilities have already been completed. Both of these early actions are expected to be completed by 2015.
- ***Terminal 117***: In 2014, PCB-contaminated sediments were cleaned up by the Port of Seattle and City of Seattle as part of an EPA Consent Order issued in June 2011. In 1996 and 2006, soils in the upland portion of Terminal 117 were removed by the Port of Seattle and additional upland cleanup will be completed by the City of Seattle in 2015.
- ***Norfolk CSO***: In 1999, King county dredged over 5,000 cubic yards of PCB-contaminated sediment from the Norfolk CSO EAA and then backfilled the area with clean sediment (an additional contaminated inshore area was also excavated and capped in 2003 by Boeing under Ecology's Voluntary Cleanup Program).

EPA is the lead agency for this sediment investigation and cleanup work. In total, the EAAs cover 29 acres and cleanup will be completed before the Preferred Alternative, as described in the PP, is implemented. Cleanup at these five EAAs addresses some of the highest levels of contamination in the LDW (it is estimated that EAA cleanup will reduce the overall LDW surface area-weighted average sediment PCB concentration by 50 percent) (EPA, 2013).

1.4.1.3 LDW-wide In-Waterway Cleanup

After addressing EAAs, cleanup of the remaining contamination in the LDW is addressed by EPA's Preferred Alternative in the Superfund PP, which is subject to change before finalized in the ROD (EPA, 2013). This cleanup effort, for which EPA is the lead agency with support from Ecology, also includes long-term monitoring to measure success of the remedy. The proposed cleanup is based on four goals, or Remedial Action Objectives (RAOs), which identify the risks to be reduced (i.e., reduce the risk to human or ecological health). There are two numeric criteria presented in the PP: Preliminary Remediation Goals (PRGs) that are long-term goals and Remedial Action Levels (RALs) that trigger cleanup action in specific areas (these also allow for Monitored Natural Recovery in other areas with lower contamination levels). The cleanup alternatives list actions that must be taken if these numeric criteria are exceeded.

Cleanup alternatives include a combination of dredging or capping (with clean material) contaminated sediments or enhanced natural recovery (i.e., adding six to nine inches of clean material, and possible amendment with activated carbon or other substances, to areas with moderate contamination). The PP identifies the conditions that influence the methods of active cleanup. The proposed cleanup addresses 156 acres of contaminated sediment and will take an estimated seven years to implement with an additional ten years to further reduce contaminants concentrations through natural recovery. The Monitored Natural Recovery areas add 256 acres to the total cleanup area (EPA, 2013).

1.4.1.4 Dredging and Capping Events

Historical dredging and capping events have reduced contaminated sediments in the LDW through maintenance dredging of the navigation channel, dredging of berthing areas and contaminated sediment dredging followed by capping actions. Similar efforts have been conducted in the East and West Waterways.

1.5 Document Organization

This introductory section (**Section** 1) provides a geographical and regulatory context to interpret and evaluate the information presented throughout the rest of this technical approach document. The remainder of this report is divided into five additional sections as well as two supplementary appendices, as described below.

- **Section 2 – Conceptual Model.** In Section 2, detailed conceptual models (CMs) are presented. These CMs identify sources and pathways that may contribute pollutant loading to various segments in the study area and are referred to throughout the subsequent sections of this document as they provide a visual representation of the processes considered during development of the technical approach.
- **Section 3 – Data Assessment.** Available data are discussed in Section 3 (and **Appendix A**), focusing on the spatial and temporal resolution of existing data and how these data represent the sources and/or pathways of the CMs and then inform the technical approach recommendations.
- **Section 4 – Existing Models.** Section 4 presents a review of available receiving water, watershed, and bioaccumulation modeling studies and how they tie to the CM and technical approach.
- **Section 5 – Technical Approach.** The final technical section (Section 5) synthesizes the information previously presented to provide a recommended technical approach for the PLA utilizing previous studies and data to create a quantitative and comprehensive tool to evaluate the attainment of designated uses under the CWA and minimize recontamination of remediated sediments.
- **Section 6 – Numeric Targets.** To support future assessment efforts, a suite of potentially relevant numeric targets associated with the CWA 303(d)-listed pollutants are presented in

Section 6 (and **Appendix B**). Some of these targets are linked to the Superfund PRGs used for cleanup efforts (EPA, 2013) and applicable or relevant and appropriate requirements (ARARs), others focus more specifically on the restoration of CWA designated uses in the impaired waterbodies (Section 1.3), and some targets are used for non-regulatory screening purposes only. Wherever possible, multiple targets for the same pollutant-matrix combination are presented side-by-side for a straight-forward comparison. Note that goals and targets developed under CERCLA may differ from those associated with attaining Washington's designated uses under the CWA.

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2 Conceptual Model

The CMs for the Green/Duwamish River watershed and LDW guide the overall approach to this PLA. It is important for the CMs to represent the dominant sources of contaminants or other substances that affect water quality in the target environments. It is recognized that there are substantial challenges and complexities in representing this system, and it is emphasized that the CMs must be scientifically-grounded, coupled to advanced hydrologic system balancing, represent various contaminants (organic contaminants, metals, and major water quality variables) in realistic transport and transformation pathways, and be able to represent receptor exposures for a variety of management or risk scenarios. To evaluate pollutants effectively on an integrated watershed scale, source loadings from across the watershed must be coupled to an understanding of (1) reactive transport representing the dominant pathways and (2) transformations by which source contaminants affect the quality of both natural and managed ecosystems (Figure 2-1). The CMs also provides a guide for application of the technical approach and subsequent implementation activities including:

- Evaluation of hydrologic variations due to time variable weather patterns and the related transport in surface water;
- Consideration of transient saturation or unsaturated condition of the surface/subsurface;
- Examination of time variable chemical loadings of organics, metals, and major ions from industrial, urban, agricultural, and various natural pollutant sources in the watershed;
- Review of physical, biogeochemical interactions and receptor exposure within various environments;
- Review of previous modeling results with a broad range of spatial and temporal scales, simulated pathways, and represented constituents; and
- Evaluation of source reduction and watershed management scenarios for water quality control.

The development of the CMs considered the context for natural and anthropogenic sources of pollutants, chemical migration pathways, chemical transformations, and fate. The CMs for the project is based on a comprehensive evaluation of existing information concerning the observed resource impacts and degradation as affected by a variety of pollutant sources and pathways (Figure 2-2). Existing information for the Green/Duwamish River watershed and the LDW was used to develop the CMs to address pollutant loading from various sources and pathways including industrial and other point sources, agricultural runoff, stormwater point and nonpoint sources, natural sources (e.g., forests), atmospheric deposition, and others. The pollutants associated with these sources are varied and will require a comprehensive approach regarding the pathways for pollutant migration to waterways, migration within the waterways, and chemical transformations that will all affect the fate within the surface waters and the ultimate impairments and degradation of environmental quality. As previously noted, the end goal is the development of a PLA tool to evaluate ways to address 303(d)-listed impairments in the Green/Duwamish River watershed, and to quantify loadings from a comprehensive suite of sources and pathways to minimize recontamination of post-cleanup sediments in the LDW and improve the effectiveness of the Superfund in-waterway cleanup.

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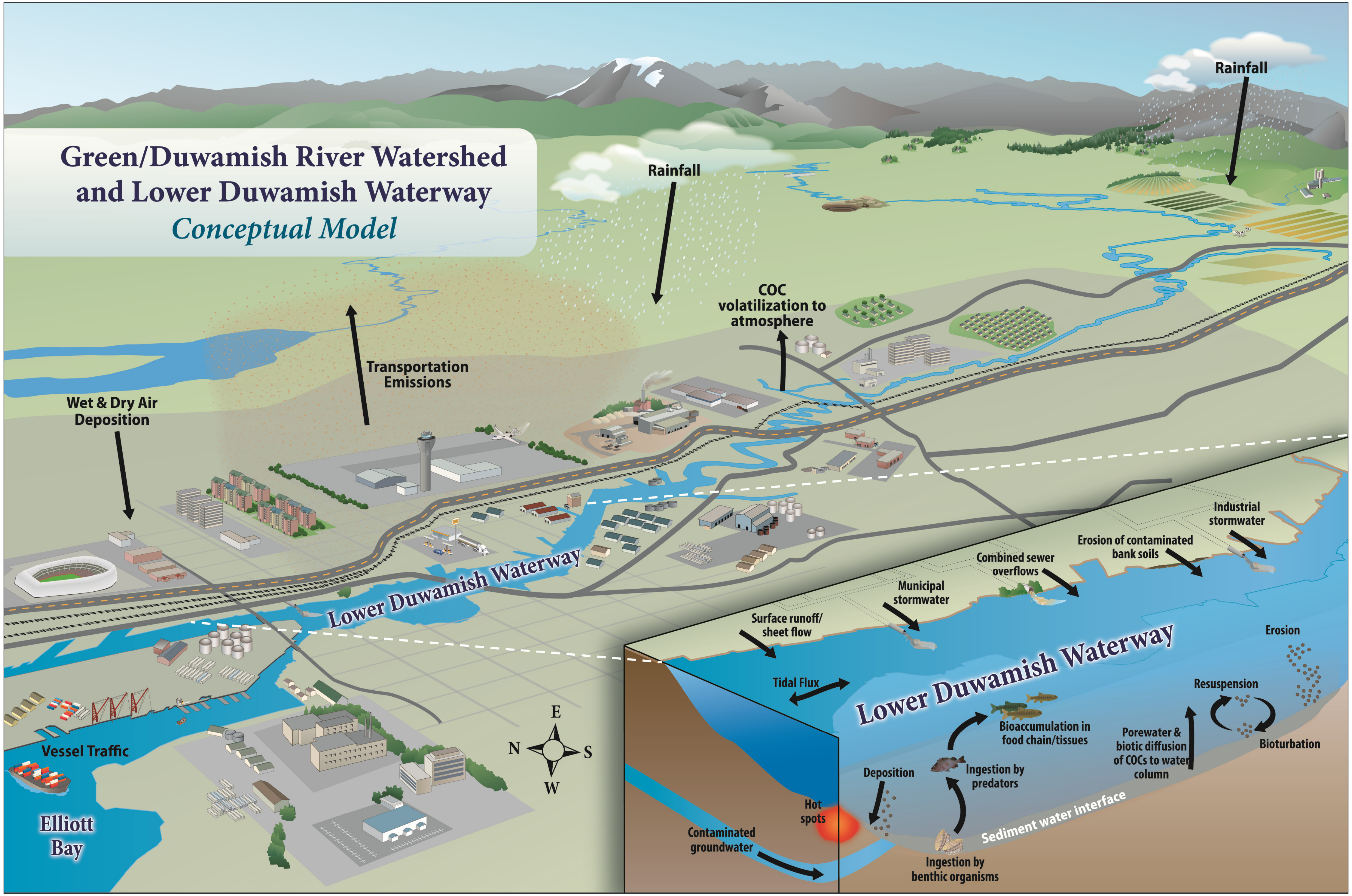

Figure 2-1. Conceptual model for the Green/Duwamish River watershed and LDW

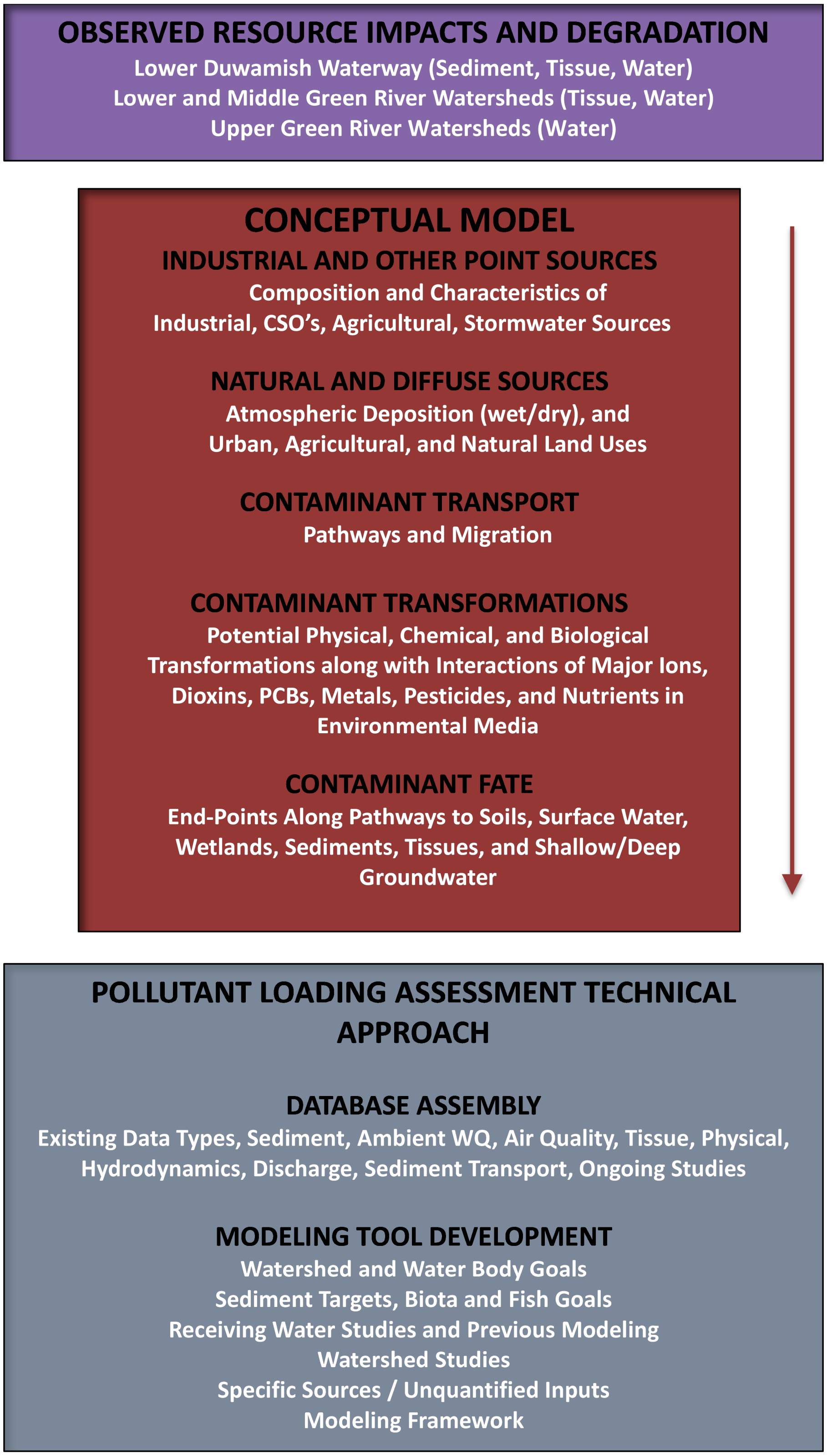

Figure 2-2. Conceptual model components for the Green/Duwamish River watershed and the LDW

Previous modeling activity in the LDW and Green River (discussed further in Section 4) has included portions of the CM components identified in Figure 2-2; however, the models may have been defined to address only a subset of constituents, portions of the pathways, or only physical transport of water and sediments. In addition, chemical transformations may have been simulated empirically rather than mechanistically, due to uncertainty in available data for loadings, composition, or transformations in specific media. During the development of the tools, dominant processes controlling the migration, transformations, and fate of chemicals must be included to manage future load reduction activity and potential recontamination issues.

For example, common practice for modeling metals in surface waters, such as the Green River and LDW, has been to treat each metal as an independent state variable subject only to transport and sorption. One approach described sorption reactions using apparent partition coefficients, which reflect the combined effects of the aqueous chemistry. The apparent coefficients are sometimes, but not usually, based upon field measurements. A second approach has been to estimate the apparent partition coefficients for the modeling activity using geochemical equilibrium models and incorporating site-specific water chemistry for the range of conditions expected. The former approach neglects interactive effects, and the latter approach, while preferable, has limited predictive capability in situations where the modeled chemistry is variable, particularly under future loading and chemical conditions. For example, conditions may vary from complete sorption to complete desorption within as little as one-half a pH unit for some metals, making the range of the apparent partition coefficients large. Sorption is also dependent on the sorbate-sorbent ratio such that considerable error may arise in the estimation of sorption using simple coefficients when conditions are, in fact, highly variable.

Contaminated sediments are an important aspect of chemical management in the LDW. While sediments affect water quality through the "sorption" of pollutants from the water column, contaminated sediments may also result in negative toxic effects of both elevated sediment/pore water concentrations as well as release previously bound contaminants from sediments to the water column.

However, the environmental impacts of chemicals present in the aquatic environment are largely related to exposure to bioavailable forms of the contaminant. The bioavailable forms will be determined by the net result of the suite of interacting phenomenon governing the environmental partitioning (fate). For example, adsorption, hydrolysis, photolysis, biodegradation and volatilization processes are important for a given organic contaminant while adsorption, complexation, hydrolysis, chemical precipitation and redox processes are important in the environmental fate of a toxic metal (arsenic, cadmium, chromium, copper, lead, mercury, silver, and zinc). The extent to which each process exerts an influence on the exposure concentration will largely determine the actual toxicity of the chemical in the receiving water. For the majority of chemicals of interest, the interactions of dissolved forms of the chemicals with solids (suspended or bed region) is a major fate-influencing process and the degree to which this occurs must be represented in the model development process.

The CM guides the development of tools that are able to predict the environmental distribution of important chemicals on both spatial and temporal scales, and to do so with particular emphasis on the water column concentrations. The complexities of representing watershed processes and instream processes is illustrated by examining loading processes in the watershed with the fate and transport issues within the receiving water. Predicting water column concentrations requires a consideration of the interactions of water column contaminants with both bed sediments and suspended particulates as a critical component in the assessment. It is also important to realize that this project includes both watershed-scale and receiving water-scale modeling that will inform management activities. The existing and future data collected as part of this and other efforts should aid in a better understanding of important watershed issues, such as:

- addressing a variety of pollutants, with primary focus on the primary human health pollutants,
- addressing a watershed with mixed land uses and wide variety of pollutant sources,

- providing accurate representation of rainfall events and stormwater runoff,
- characterizing sediment conditions and concentrations of pollutants,
- representing sediment transport dynamics, deposition, and scour,
- identifying the controlling instream reactions for modeled pollutants, and
- representing a variety of pollutant transport mechanisms (e.g., groundwater and surface water advection, atmospheric deposition, volatilization) and sources (e.g. diffuse sources and point sources).

2.1 Green/Duwamish River Watershed Conceptual Model

The watershed CM not only addresses the physical and chemical processes within the Green/Duwamish River watershed itself, but also integrates with the LDW CM by supplying inputs of hydrology, sediment, and pollutants representing upstream sources (Figure 2-1). As such, it must address pollutants and impairments within the watershed as well as the LDW. The watershed CM is composed of the following broad considerations:

- Spatial considerations, which define the spatial extent of the watershed and the stream flow pathways,
- Hydrologic considerations, which describe meteorological inputs and flow response from the watershed, and
- Pollutant considerations, which encompass all pollutant sources and transport pathways to the watershed. Pollutants include COCs, nutrients, bacteria, and any other parameters needed to represent impairments in the Green/Duwamish River watershed and the LDW.

2.1.1 Spatial Considerations

Spatial considerations describe the physical configuration of the land areas and their relationship to receiving streams. The Green/Duwamish River watershed is comprised of many smaller subwatersheds that cumulatively contribute flow to the Green and Duwamish Rivers. Subwatersheds drain to receiving streams and lakes. The streams and lakes combine into a flow network representing all of the minor and major waterbodies within the watershed, including major tributaries (e.g., Black River, Mill Creek, Soos Creek, Jenkins Creek, Covington Creek, Newaukum Creek) and the Green River itself. The lower Green River includes numerous levees intended to address flooding risk.

Each subbasin is composed of contributing land areas. Land unit representation should be sensitive to the features of the landscape including land use, impervious features, soils, and slope. In urban areas, it is important to understand the division of land use into pervious and impervious components. In rural areas, vegetative cover is more important. Division of pervious land cover by soil hydrologic group to distinguish infiltration processes is typically useful. Slope might also be an important factor where steep slopes are prevalent: high slopes influence runoff and moisture storage processes.

The hydrologic response unit (HRU) concept provides a way to describe landscape variability using discrete units. Landscapes possess an identifiable spatial structure, with corresponding patterns of runoff and stream chemistry that are strongly influenced by climate, geology, and land use. An HRU is defined as a unit of land with relatively homogenous hydrologic properties, typically based primarily on land use/land cover. Soil properties and slope are also frequently considered. When considering land use and its effect on hydrology and pollutant loading, it is helpful to draw a distinction between *land use* and *land cover*. “Land use” refers to how a piece of land is used or managed by its owner. For instance, a group of parcels may be assigned a land use of “single family residential.” The entire land area is used for human habitation and other typical activities (lawn mowing and fertilization, yards receiving pet waste, etc.). “Land cover,” on the other hand, refers to the type of vegetated or impervious surface present on the land.

Areas with single-family residential land use are made up of several land covers, including managed pervious surfaces (lawns, landscaped areas, etc.), impervious surfaces (roofs, driveways, sidewalks, roads), and possibly forest in rural areas. The spatial considerations consider land cover, noting that similar types of surfaces can have different characteristics (i.e., low intensity impervious, commercial impervious, and industrial impervious). The differences in land use affect hydrologic and pollutant processes in the watershed.

The Howard A. Hanson Dam was completed in 1961, with a primary purpose of providing flood control. It is also used by Tacoma as a water supply.

The spatial extent of the Watershed CM is the Green/Duwamish River watershed, including the area that drains directly to the LDW, and includes all of the streams and lakes in the flow network. Hanson Dam and the Howard Hanson reservoir are located in the upper portion of the Green River watershed. The land area upstream of the dam is almost entirely forested and undeveloped, includes high elevations, and is not anticipated to be a significant source of COCs or subject to source control actions. The dam could be used as a boundary condition to represent inflow into the Green River for the technical approach.

2.1.2 Hydrologic Considerations

Multiple hydrologic components are contained within the CM including air temperature, precipitation, snow melt, interception, evapotranspiration (ET), overland flow, infiltration, interflow, subsurface storage, shallow groundwater flow, and groundwater loss. Precipitation falls on constructed landscapes, vegetation, and soil. Varying soil types allow the water to infiltrate at different rates, while evaporation and plant matter exert a demand on available water. Water flows overland and through the soil matrix. Land areas provide surface flow, interflow, and shallow groundwater (dry weather) flow to the receiving streams and lakes. Figure 2-3 provides an illustration of some of these processes. Within the stream, flow is affected by channel geometry, slope, roughness, flood control features, etc. Flows accumulate through the stream network, eventually exiting the watershed and entering the LDW.

The combined sewer area of the watershed adjacent to the LDW represents an exception to the default CM. Overland flow within a combined sewer area is mostly routed to a treatment plant. When flow exceeds the capacity of the sewers, it overflows from discrete points into the LDW. Land areas in the combined sewer zones do provide groundwater flow into the LDW, and as a result represent the groundwater hydrology from combined sewer service areas.

2.1.3 Pollutant Considerations

The pollutants addressed in the Watershed CM include sediment, and specific COCs or other pollutants that should be considered to support the project objectives. Pollutants from the land surface may be dissolved and/or sediment-associated, and may be associated with surface runoff, interflow, and shallow groundwater. Once pollutants enter the stream, the representation continues with pollutants being represented as dissolved, attached to sediment in the water column, or attached to sediment in the bed, with cycling between the various phases (Figure 2-3). Wet and dry atmospheric deposition may contribute pollutants to both land surface HRUs and directly to waterbodies. Water temperature is represented both for its influence on pollutant processes and as a parameter contributing to impairment in the watershed. The Watershed CM also includes point sources discharging to waterbodies along with associated water temperature and pollutant loads.

Sediment is represented from both land surfaces and within each stream. The Watershed CM represents land surface processes governing the buildup, detachment and transport of sediment to streams. Both the erosion and transport of sediments vary significantly with particle size and possess differing physical properties. In the channel, erosion and deposition of sediment occurs in varying proportions by particle size.

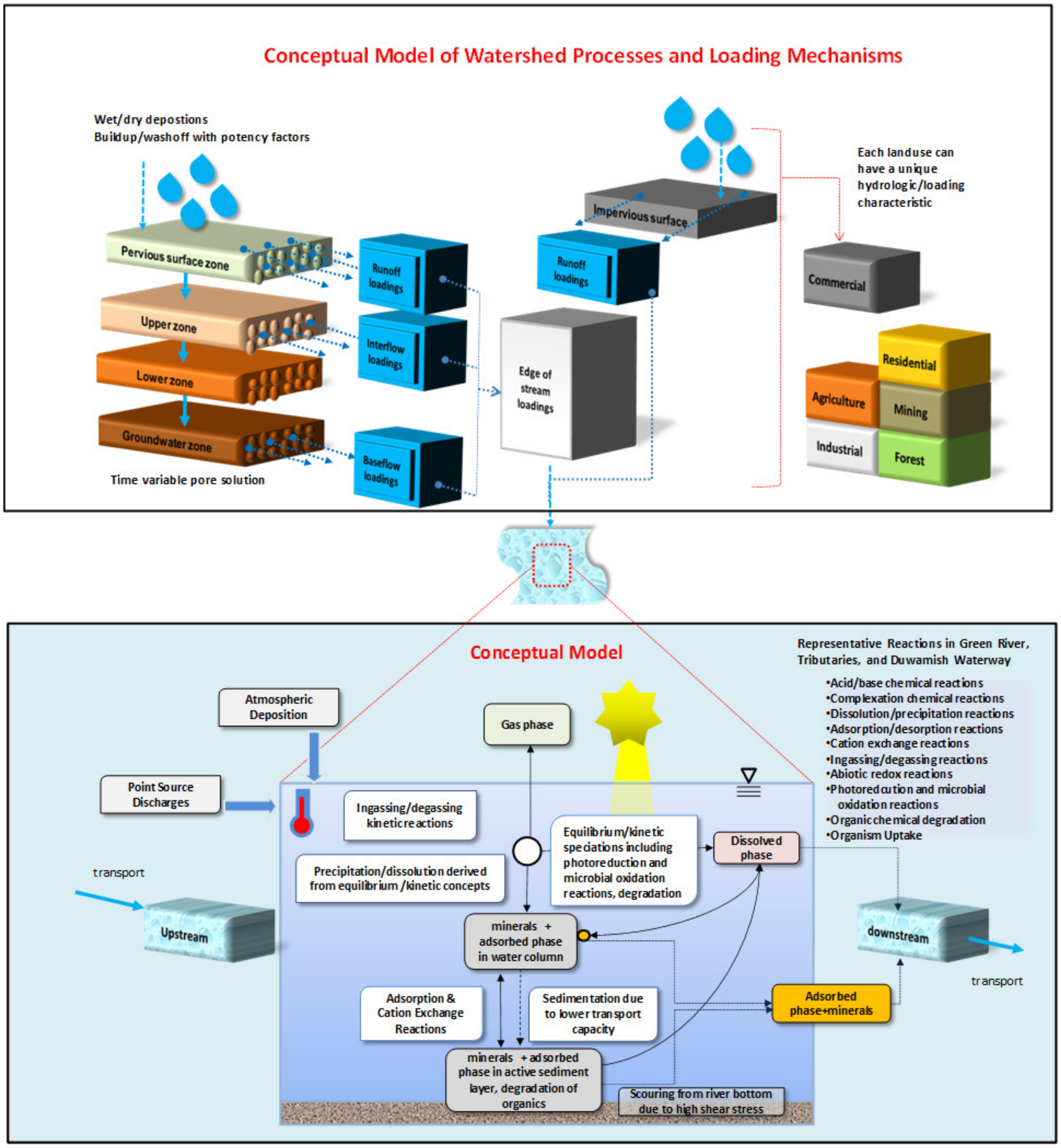

Figure 2-3. Conceptual model for watershed and instream loadings and processes

Pollutants from the land surface may be dissolved and/or sediment-associated, and may be associated with surface runoff, interflow, and shallow groundwater. Once pollutants enter the stream, the dynamic representation continues with pollutants being represented as dissolved, attached to sediment in the water column, or attached to sediment in the bed, with cycling between the various phases. Wet and dry atmospheric deposition may contribute pollutants to both land surface HRUs and directly to waterbodies. Water temperature is represented both for its influence on pollutant processes and as a parameter contributing to impairment in the watershed. The CM also includes point sources discharging to waterbodies along with associated water temperature and pollutant loads.

2.1.4 Sources and Pathways of Pollutants in the Watershed

The flexibility of the Watershed CM allows for the representation of multiple sources and pathways within the Green/Duwamish River watershed and discharging to the LDW. The following sources and pathways can be readily addressed by the CM:

- Urban runoff and associated loads of sediment, COCs and other pollutants (examples of urban areas include Tukwila, Kent, and Auburn),
- Point source discharges (industrial, regulated stormwater outfalls, etc.),
- Spills and/or leaks (contaminated sites and industrial operations areas contributing high contaminant loads),
- Legacy COCs in bed sediments,
- Atmospheric deposition, including spatial variation in deposition rates,
- Agricultural runoff and associated loads of sediment, COCs and other pollutants,
- Other surface runoff,
- Groundwater discharge,
- Advective transport from upstream to downstream locations,
- Deposition of contaminated sediments,
- Transport of resuspended contaminated sediments,
- Bank erosion/leaching, and
- Volatilization.

The net effect on the receiving waters, including both the LDW and upstream waters, is determined by a myriad of chemical and physical reactions, dependent on contaminant, sediment type, major ion chemistry, and other factors.

2.2 Lower Duwamish Waterway Conceptual Model

The Conceptual Site Model (CSM) developed by the LDWG in the RI included the major pathways, source control activity, historical wastes, and source identification and control efforts for the LDW along with sediment transport in three major reaches of the waterway. While the discussion of the CSM in the RI/FS[8] covered the major hydrology, hydrodynamics, and sediment transport issues relevant for an understanding of the behavior of contaminants in the LDW and was considered during interpretative and modeling activities, the modeling based on the CSM assumed that the chemicals were 100% bound to particulates. While sediment binding of dioxin, PCBs, PAHs and metals is often a dominant process regulating the fate and transport of chemicals, the CM concepts presented herein will assure the development of a comprehensive geographic and analytical tool that includes the direct modeling of dissolved and particulate contaminant concentrations in surface water, pore water, and sediments of the

[8] The CSM developed by the LDWG in the RI included the major pathways, source control activity, historical wastes, and source identification and control efforts for the LDW along with sediment transport in three major reaches of the waterway (Reach 1 from RM 0.0 to RM 2.2, Reach 2 from RM 2.2 to RM 4.0, and Reach 3 from RM 4.0 to RM 4.8; Windward Environmental, 2010). The CSM was discussed in the RI with respect to the physical conditions and transport, chemical conditions and transport, and the sediment transport and contamination. Subsequent to the RI report, the FS report summarized and further defined the CSM presented in the RI based on a physical CSM and a chemical CSM for the delineation of sources, pathways to the LDW, and source control strategies (AECOM, 2012a).

LDW[9], watershed-based loading inputs from the Green/Duwamish River watershed, and advective transport of water and sediments into the LDW. Over time, this framework can be used to determine the pollutant loading for all 303(d)-listed impairments to facilitate attainment of designated uses.

For this LDW CM, and because many issues with impairments and toxic effects exist in the LDW, information on contaminant sources, release hydrodynamics, sediment scour, sedimentation and transport, chemical contamination, and toxicity test results were used to identify segments of the LDW that would represent many of the important source types, pathways, sediment dynamics, and contamination areas requiring attention. A review and interpretation of information in the FS (AECOM, 2012a) was used to illustrate this CM in two segments of the LDW (Segment 1: RM 0.3 to RM 1.2 and Segment 2: RM 2.3 to RM 3.1). The illustrations below (Figure 2-4 and Figure 2-5) show the complexity of the LDW and the important processes that influence contaminant concentrations in water, sediment, and biota. It should be noted that atmospheric deposition of PAHs, dioxins/furans, PCBs and historic arsenic are important considerations, and are shown in both CM segments. Segment 1 is a net depositional area for sediments while Segment 2 shows both depositional and high scour areas and underscores the need for a robust sediment transport modeling capability. While these two segments contain similar dominant processes affecting chemical dynamics and sediments, it is important to note that shellfish harvesting and bird watching are additional risk components in Segment 1 compared to Segment 2.

In Segment 1, numerous sources exist for releases of COCs and other pollutants to the LDW, including industrial facilities, storm drain outfalls, CSOs, industrial spills and leaks, atmospheric deposition, and sheet flow stormwater runoff (Figure 2-4). While the majority of the segment from RM 0.3 to RM 1.2 was identified as a net depositional area, periods of high flow or navigation impacts contribute to sediment resuspension and transport of contaminants in dissolved or particulate forms.

[9] Previous modeling did not specifically consider reactive chemical transport of arsenic, PCBs, cPAHs, and dioxin/furan but estimated their sediment concentrations by assuming that all of the contaminant was bound to particulates with no chemical exchange between water-sediments and thus limited the predictive capabilities in the long-term for sediment flushing, burial or recontamination processes. Furthermore, the dissolved concentrations of contaminants, both in the water column and in sediment porewater, are important to explicitly model to provide relevant exposure concentrations to aquatic organisms, both short and long-term. It is noted that sediment PCBs were modeled for the FWM, but did not include reactive transport or transformations due to degradation, dissolved phase transport, or volatilization of lighter molecular weight PCB congeners.

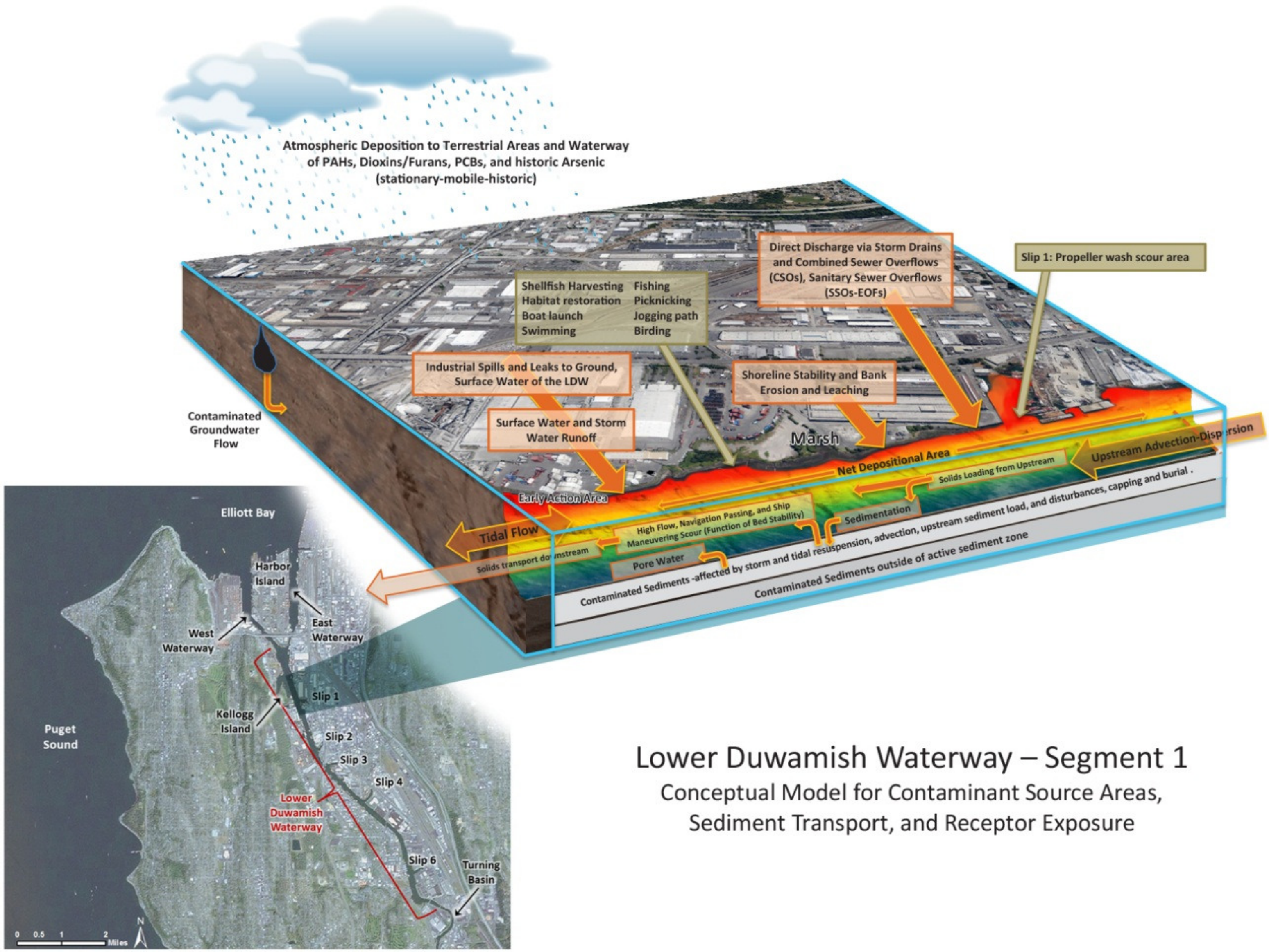

Figure 2-4. Conceptual model for contaminant source areas, sediment transport, and receptor exposure in a portion of Segment 1 (RM 0.3 to RM 1.2)

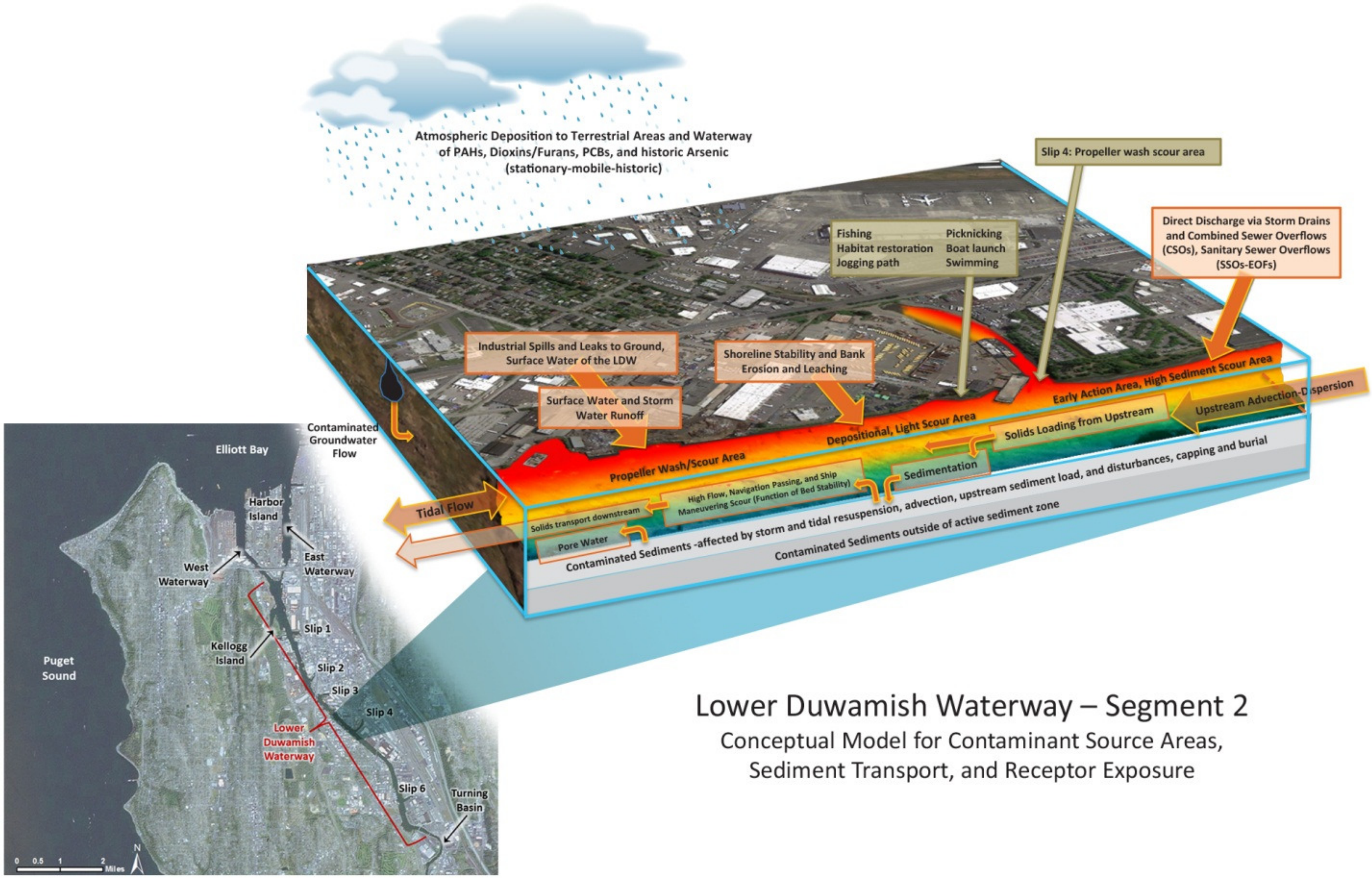

Figure 2-5. Conceptual model for contaminant source areas, sediment transport, and receptor exposure in a portion of Segment 2 (RM 2.3 to RM 3.1)

Figure 2-4 illustrates that the contaminated sediments are affected by storm and tidal resuspension, advection, upstream sediment loading, and disturbances (propeller wash, navigation maneuvering), shoreline stability/erosion/leaching, and capping. The dynamics of the sediment transport are driven by the upstream flow velocity, tidal effects and sediment contributions and are directly affected by the bed stability in the segment. Risk-based activities and use in the segment include shellfish harvesting, fishing, habitat restoration, picnicking, boating, and swimming and were considered for the risk assessments. One of the EAAs (Duwamish/Diagonal CSO) is located at the downstream end of the segment.

In Segment 2, very similar source contributions were evident along with the same processes in the water column and bed region of the segment from RM 2.3 to RM 3.1 (Figure 2-5). Risk-based activities and uses in the segment include fishing, habitat restoration, picnicking, boating, and swimming, which were considered for the risk assessments. EAAs are located in Slip 4 and adjacent to the facility south of Slip 4.

The attenuation of pollutants from these activities is directly influenced by system hydrology and hydrodynamics along with the source loading rates and pathways for important contaminants. Due to the complexity of the LDW, it is reasonable to examine the CM first with respect to physical characteristics of the estuarine environment, followed by the chemical characteristics.

2.2.1 Sediment Dynamics in the LDW

Sediments play an important role in the regulation of dissolved contaminants in the water column and sediment porewater. The sediment composition within the LDW is affected by the flow characteristics from upstream, tidal effects, and sediment transport and deposition/resuspension. In the FS for the LDW, the results of two sequential sediment transport models (STMs) were discussed: Sediment Transport Analysis Report (STAR) (Windward Environmental and QEA, 2008) and the STM (QEA, 2008), as described in Section 4. The STAR evaluated the geomorphology, hydrodynamics, saltwater wedge, and scour potential in various areas and identified the three reaches of the LDW, previously mentioned in the FS. The STM built on the STAR and used upstream river flow data spanning a 21-year period (1960 to 1980) to examine upstream sediment load, hydrograph flow events, net sedimentation, and scour. The three reaches, each with a shallow (intertidal) bench area, a deep (subtidal) bench area, and a navigation channel, were defined as follows:

> "Reach 1 is downstream (north) of RM 2.2 and is occupied by the saltwater wedge during all flow and tidal conditions. Sedimentation rates are variable; although this reach is net depositional in both the navigation channel and the adjacent bench areas. In the navigation channel, sedimentation rates vary from intermediate to high, with a small area near RM 0.8 to RM 0.9 having lower deposition rates. Net sedimentation rates on the benches are also intermediate to high, with two small areas having lower deposition. Empirical data show that the intertidal areas have relatively low net sedimentation rates, on the order of 0.5 centimeters/year (cm/yr). This reach is not likely to be subject to scour during the 100-year, spring-tide, high-flow event except in a few localized areas.
>
> "Reach 2 extends from approximately RM 2.2 to RM 4.0 and includes the toe of the saltwater wedge during high-flow events; the saltwater wedge extends even farther upstream during average-flow conditions. The toe of the saltwater wedge is pushed downstream of this reach (to RM 1.8) only during extreme flow events (100-year, high-flow event and greater). Reach 2 is subject to some scour during high-flow events but is net depositional on annual time scales. Net deposition rates are spatially variable within this reach.
>
> "Reach 3 extends from RM 4.0 upstream to RM 5.0. Flow in portions of this reach is characteristic of a freshwater tidal river during high-flow events. This reach is occupied by the saltwater wedge only during low- and average-flow conditions. This reach is also net depositional on annual time scales. Both the model and empirical data indicate that the navigation channel and Upper Turning Basin located in Reach 3 have higher net sedimentation rates than other areas of the LDW. Greater episodic erosion may occur in this reach than in the other reaches during high-flow events.
>
> "The chemical CM, which is discussed in Section 2.3.2 [of the FS], describes the distribution of COCs, specifically the risk drivers, in sediment. Sediment with the highest concentrations of risk drivers is not distributed uniformly across the LDW, but rather occurs in concentrated areas (e.g., EAAs). In depositional

> areas, higher contaminant concentrations are buried in the subsurface sediment by lower concentration surface sediment originating from the upstream Green/Duwamish River." (AECOM, 2012a)

The STM (QEA, 2008) also evaluated additional physical processes related to (1) bed stability and the scour potential from high-flow events and passing ship traffic and (2) net sedimentation rates that were important during the FS.

2.2.1.1 Resuspension

Resuspension (scour) of sediments in the LDW can be caused by high-flow events from upstream Green/Duwamish River watershed flows and internally by ship-induced scour from passing vessels in the navigational channel and maneuvering vessels. While the magnitude of historical high-flow events has been lessened by the construction of Howard Hanson Dam, the events can still result in significant sediment resuspension. Under tidal influences, higher excess bed shear stresses occur in the main channel rather than in the shallower benches during high-flow events and tidal excursions. The net erosion depth during a 100-year event was determined to be 22 centimeters (cm) at RM 3.1 and on the order of 10 cm in scattered locations above RM 2.9.

Increased sediment shear stress can be produced by both propeller wash and during maneuvering and transit and to a lesser extent by the passage of vessels in the navigation channel. The depth of scour was generally proportional to velocity of the vessel, sediment size, and duration and frequency of the event and, specifically, the propeller wash effects are generally related to the size, draft, and power of vessels. The propeller wash effects tended to be concentrated in slips, berthing areas, and shallow shorelines where scour can be significant although on a very local scale. Navigational passing effects were not determined to be a major transport mechanism relative to other mixing processes and tended to be constrained to the top 10 cm active sediment zone. Sediment bed forms associated with maneuvering vessels have been observed in many areas of the LDW and typically varied from a few cm to over 30 cm. in some locations. Most of the scour marks are less than 10 cm although this value is reflective of the net scour rather than absolute scour, as areas scoured are partially filled after passing.

2.2.1.2 Net Sedimentation Rates

During the RI (Windward Environmental, 2010) and STM (QEA, 2008) empirical evidence and modeling were used to determine that net sedimentation ranged from 0.2 cm/yr to greater than 2.0 cm/yr in the intertidal and subtidal areas, with lowest sedimentation rates in shallower water depths. In the navigation channel, net sedimentation was in excess of 2 cm/yr and as high as 150 cm/yr in the Upper Turning Basin. Upstream sediments are trapped in this area, which has resulted in biennial dredging activity to maintain navigation depth (note: the pollutant concentration associated with these sediments requires further investigation, as presented in this technical approach).

2.2.2 Pollutant Considerations in the LDW

Sources in the LDW contribute contaminants to both the water column and sediments. Pollutant releases from land surfaces may be dissolved and/or sediment-associated, and may be associated with surface runoff, direct discharge, and shallow groundwater. Once pollutants enter the LDW, the dynamic representation continues with pollutants being represented as dissolved, attached to sediment in the water column, or attached to sediment in the bed, with cycling between the various phases, including sediment porewaters. Wet and dry atmospheric deposition may contribute pollutants to both land surface and directly to the LDW. Water temperature is represented both for its influence on pollutant processes and as a parameter contributing to impairment in the watershed. The LDW CM also includes point sources discharging to waterbodies along with associated water temperature and pollutant loads.

> *Existing conditions used to develop the CM are changing as source control and cleanup activities are carried out. Impacts of ongoing and planned activities can be quantified over time through various scenarios.*

Because the LDW receives large sediment influx from the Green River, significant partitioning of contaminants to the sediments occurs. While the RI/FS presented a focus on contaminated sediments and associated risks, elevated (above water quality criteria [WQC]) concentrations of contaminants were observed in pore water and seeps along the LDW. Concentrations of contaminants in the surface water did not typically exceed WQC but, nevertheless, would contribute to elevated sediment concentrations and associated pore water. The observed extent and magnitude of sediment contamination is illustrated in a series of diagrams presented in Section 2 of the FS (AECOM, 2012a). From these figures, it is apparent that sediment contamination can be very high locally with areas of lower concentrations in between these "hot spots," dependent on the risk driver.

The following sections present various sources, pathways, and activities that affect the LDW CM . The existing conditions used to develop the LDW CM are changing over time as source control and cleanup activities are carried out. The results of these ongoing and planned activities can be estimated over time using a comprehensive PLA tool.

2.2.2.1 Sources and Pathways of Pollutants in the LDW

Two components of the LDW CM are the sources and their pathways for contaminants entering the LDW. The same source categories and pathways described in Section 2.1.4 for the Watershed CM are relevant in the LDW CM, although the magnitudes may differ. For example, volatilization of contaminants from sources or areas can contribute contaminants to the LDW through air deposition and during precipitation events (due to build up/wash off processes) and can reduce surface water concentrations via loss to the atmosphere. Volatilization processes, while potentially present throughout the watershed, may play a more significant role in the LDW.

The major sources and pathways by which pollutants find their way into the LDW and affect water, sediments and biota, include:

- Urban runoff and associated loads of contaminants, COCs and other pollutants (nonpoint stormwater discharges),
- Point source discharges (e.g., CSOs, regulated stormwater outfalls, etc.),
- Spills and/or leaks to the ground, surface water, or directly into the LDW,
- Legacy COCs in bed sediments,
- Atmospheric deposition, including spatial variation in deposition rates,
- Vessel discharges,
- Other surface runoff,
- Groundwater migration/discharge,
- Advective transport from upstream areas to the LDW,
- Deposition of sediments,
- Transport of resuspended contaminated sediments,
- Release of contaminated sediment porewater, and
- Volatilization.

Pathways include stormwater, combined sewer overflows, other surface water inputs, groundwater, spills, and atmospheric deposition. These pathways provide the method of transport for contaminants and/or contaminated media to waterbodies. Contaminants, media, and pathways define a pollutant source.

2.2.2.2 Historical and Ongoing Sources of Contaminants

There is a long history of industrial activity along the LDW and there have been many direct discharges, spills, leaks and storm runoff events that have contributed to the sediment contamination and other impairments in the LDW. There are over 100 permitted facilities in the LDW Source Area.. According to the PP, there are 208 pipes, creeks, and streams directly discharging to the LDW (EPA, 2013), which make up many of the pathways to the LDW. Some of the sources for PCBs, arsenic, PAHs, and dioxins/furans have been reduced or eliminated, but sources still exist and continue to contribute to the observed concentrations. Potential sources of PCBs, arsenic, polycyclic aromatic hydrocarbons (PAHs), and dioxins/furans are summarized below, as these are the primary human health risk-driver pollutants presented in the PP (EPA, 2013).

Although the manufacture of PCB was generally banned in 1979, it is still produced as byproducts of some industrial processes (referred to as *inadvertent manufacture of PCBs*; e.g., burning of some wastes in municipal and industrial incinerators) (ATSDR, 2000; EPA, 2004), historical PCB use continues to affect the LDW today in a number of ways, including flaking and volatilization of paints, caulking, and other building materials that contain PCBs and as well as from PCB-contaminated soils and groundwater due to past waste management practices. Historical sources of PCBs include dielectric fluids, waste oils, hydraulic oils, paints, and sealants. PCBs were also historically released with cement kiln emissions, along with dioxins/furans. PCBs also come from industrial, commercial, and residential properties (e.g., building materials such as paint and caulk).

Arsenic was historically and is still currently used in lumber treatment and is released with other metals during watercraft repair. Arsenic was also released historically in air emissions from smelters, wood-treating facilities, and distillate oil combustion. Atmospheric releases of arsenic have been significantly minimized by the closure of smelters. Releases of arsenic and other metals to the LDW have been reduced by housekeeping practices and controls on wastewater discharge at facilities that practice activities such as ship maintenance.

PAHs are generated from the burning of organic matter, fossil fuels, and charcoal (pyrogenic) and are present in refined petroleum products (petrogenic). Therefore, PAHs are continually generated and released to the study area and airshed through petroleum use and combustion. In addition, PAHs were historically released from brick manufacturing operations, hydraulic equipment manufacturing, machine shops, and from repair and fueling of vehicles, airplanes, trains, and watercraft. They can continue to be released by most of these sources; but best management practices (BMPs) controlling spills and leaks have reduced input from these sources. Finally, timber piles and dolphins (groups of closely driven piles used as a fender for a dock, a mooring, or a guide for boats) in the LDW and utility poles and railroad ties in the watershed were treated with creosote, which can deposit PAHs directly into the LDW as these structures degrade, or deposit them onto impervious surfaces.

Dioxins/furans are not used in manufacturing operations but are unintentionally formed as byproducts of incineration when chlorine and organic material are present. They were historically (and are currently) released from the burning of waste and from paper mills, cement kilns, and drum recycling. Historically, dioxins/furans were byproducts of pentachlorophenol used in wood treating and pesticide production; neither activity is present in the area today; however, there may be facilities that that currently store products that contain dioxins/furans.

Many of the sources described above are also associated with other pollutants on the 303(d) list and addressed to some extent by the Superfund cleanup by the PP. However, addressing the full suite of pollutants (Section 1.3) will require evaluation of many additional sources, especially those causing impairment from conventional parameters and bacteria. These other sources include more land use-based sources associated with the Green/Duwamish River watershed and are discussed in Section 5.

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3 Data Assessment

Existing data were collected from regional databases to assess suitability for source assessment and model development. Information was primarily evaluated for spatial and temporal completeness in representing the LDW and the Green/Duwamish River watershed. This chapter presents discussion and visual representation associated with each data type, focusing on relevance, to characterize the Duwamish Estuary, Lower Green River, Middle Green River, and Upper Green River subwatershed systems, while considering the sources and pathways identified for the CMs (Section 2).

3.1 Existing Data

Technical approach designed to address all 303(d)-listed impairments; however, the following are presented as examples throughout this section:

- *Primary human health pollutants from PP (arsenic, dioxins/furans, cPAHs, and PCBs)*
- *General conventional pollutants*

Existing data were predominantly gathered from regional monitoring databases or agencies including, but not limited to, Ecology's Environmental Information Management System (EIM) and the Toxic Cleanup Program's LDW Sherlock database (December 2013), EPA's STOrage and RETrieval (STORET), the LDW FS and RI studies, and United States Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program. Environmental quality data are presented by matrix (sediment, water, tissue, and air) while other data types, such as streamflow, meteorology, and hydrodynamics data, are described in separate sections. EIM contains data collected from groundwater, surface water, and stormwater investigations and studies performed by others throughout the watershed (sediment and transport, water quality, biological data). The Sherlock database stores updated LDW sediment and water quality data from government, private, and educational institutions. STORET contains physical, biological, and water quality data. The FS and RI studies describe sediment data, water quality, tissue, and bioassay data. NAWQA supplied similar data with additional available groundwater data. These data sources are further described in the *Lower Duwamish Waterway Water Quality Assessment Data Inventory and Sources* files (Tetra Tech, 2013). Various data types and their application to broad technical approach categories are presented in Table 3-1 (see Section 5.3 for descriptions of these technical approach categories). The technical approach is designed to address all known 303(d)-listed impairments; however, the primary human health pollutants (identified in the Superfund PP as the human health risk drivers (arsenic, dioxins/furans, cPAHs, and PCBs) (EPA, 2013) and general conventional pollutants are presented as examples of the data available to support selection and presentation of the recommended technical approach (Table 3-2).

Table 3-1. Data type and associated use

Data Type	Source Assessment	Watershed Model		Receiving Water Model[1]		Food Web Model	
		Configuration	Calibration/ Validation	Configuration	Calibration/ Validation	Configuration	Calibration/ Validation
Ambient Surface Water Quality	•		•	•	•		
Point Source Water Quality[2]	•	•	•	•			
Groundwater Quality	•	•		•	•		
Ambient Surface Sediment Quality	•		•	•	•		
Point Source Solids/Sediment Quality[2]	•	•	•	•			
Ambient Subsurface Sediment Quality	•			•	•		
Tissue Quality	•	•		•	•	•	•
Air Quality	•	•		•	•		
Physical	•	•		•			
Streamflow			•	•	•		
Meteorological		•		•			
Hydrodynamic				•	•		
Sediment Distribution	•	•		•	•		
Bank Samples			•		•		

[1] Near field modeling of discharges would be included as part of the receiving water analyses.

[2] Includes, but is not limited to, Discharge Monitoring Report (DMR) data.

Table 3-2. EPA Superfund human health and ecological chemicals of concern (LDW) and Washington State impairment parameters (Green/Duwamish watershed)

Parameter Group	Parameter	EPA Superfund COCs		303(d) Impairments			Category 4 Impairments	
		Human Health	Ecological	Sediment	Tissue	Water	Sediment	Water
Bacteria	Bacteria					X		X
Bioassay	Sediment Bioassay			X			X	
Conventional	Dissolved Oxygen					X		
Conventional	pH					X		
Conventional	Temperature					X		X
Dioxin/Furan	2,3,7,8-TCDD				X			
Other SVOCs	Dibenzofuran		X	X			X	
Dioxin/Furan	Dioxins/Furans	X						
Metals	Arsenic	X	X	X			X	
Metals	Arsenic, Inorganic				X			
Metals	Cadmium		X	X			X	
Metals	Chromium		X	X			X	
Metals	Copper		X	X		X	X	
Metals	Lead		X	X			X	
Metals	Mercury		X	X			X	
Metals	Silver		X	X			X	
Metals	Zinc		X	X			X	
Nutrients	Total Phosphorus					X		X
Nutrients	Ammonia-N							X
Other SVOCs	1,2,4-Trichlorobenzene		X				X	
Other SVOCs	1,2-Dichlorobenzene		X				X	
Other SVOCs	1,4-Dichlorobenzene		X				X	
Other SVOCs	2,4-Dimethylphenol		X				X	
Other SVOCs	2-Methylphenol						X	
Other SVOCs	4-Methylphenol		X	X			X	
Other SVOCs	Benzoic Acid		X	X				
Other SVOCs	Benzyl Alcohol		X					
Other SVOCs	Hexachlorobenzene		X		X		X	
Other SVOCs	Hexachlorobutadiene						X	
Other SVOCs	n-Nitrosodiphenylamine		X				X	
Other SVOCs	Pentachlorophenol		X				X	
Other SVOCs	Phenol		X	X			X	
PAHs	2-Methylnaphthalene		X	X			X	
PAHs	Acenaphthene		X	X			X	
PAHs	Acenaphthylene						X	
PAHs	Anthracene		X	X			X	

Parameter Group	Parameter	EPA Superfund COCs		303(d) Impairments			Category 4 Impairments	
		Human Health	Ecological	Sediment	Tissue	Water	Sediment	Water
PAHs	Benzo[a]anthracene	X	X	X	X		X	
PAHs	Benzo[a]pyrene	X	X	X	X		X	
PAHs	Benzo[b]fluoranthene	X			X			
PAHs	Benzo[ghi]perylene		X	X			X	
PAHs	Benzo[k]fluoranthene	X			X			
PAHs	Benzofluoranthenes, Total (b+k+j)		X	X			X	
PAHs	Chrysene	X	X	X	X		X	
PAHs	Dibenzo[a,h]anthracene	X	X	X	X		X	
PAHs	Fluoranthene		X	X			X	
PAHs	Fluorene		X	X			X	
PAHs	HPAHs		X	X	X		X	
PAHs	Indeno(1,2,3-cd)pyrene	X	X	X	X		X	
PAHs	LPAHs		X	X			X	
PAHs	Naphthalene	X	X	X			X	
PAHs	Phenanthrene		X	X			X	
PAHs	Pyrene		X	X			X	
PCBs	PCB	X	X	X	X		X	
Pesticides	4,4'-DDD				X			
Pesticides	4,4'-DDE				X			
Pesticides	4,4'-DDT				X			
Pesticides	Alpha-BHC				X			
Pesticides	Dieldrin				X			
Pesticides	Total Chlordane				X			
Pesticides	Toxaphene				X			
Phthalates	Bis(2-Ethylhexyl) Phthalate		X	X	X			
Phthalates	Butyl benzyl phthalate		X	X			X	
Phthalates	Dibutyl phthalate			X			X	
Phthalates	Diethyl phthalate						X	
Phthalates	Dimethyl phthalate		X	X			X	
Phthalates	Di-N-Octyl Phthalate			X			X	

3.1.1 Water Quality Data

3.1.1.1 Ambient Surface Water Quality Data

Ambient surface water quality data provide information on the quality of the receiving water and are used to assess attainment of designated uses. Ambient data measured in receiving waters represent the cumulative conditions from a combination of sources, including various upstream watershed sources, lateral loads from point sources directly discharging into the receiving water, and in-stream conditions (Section 2).

Ambient surface water quality data are available throughout the LDW, Elliott Bay, Duwamish River, and farther upstream in the Green/Duwamish River watershed from EIM, RI/FS, NAWQA, and STORET, among others. All ambient surface water quality data from within the Duwamish Estuary (LDW), Lower Green River, Middle Green River, and Upper Green River subwatersheds, and Elliott Bay are summarized in Table A-1 of Appendix A including study names, number of stations, and number of sampling events, and range from 1959 to 2012, with most of the data occurring in the past decade. Data retrieved from the EIM, Sherlock, STORET, FS, RI, and NAWQA databases were not always clear on identifying a sample as ambient or discharge related, in those unclear cases assumptions were made about classification of a sample based on location, sample type, and grab type information included in the raw databases. Table 3-3 presents a summary of the total number of assumed ambient surface water quality sampling events and stations for the pollutants that are primary human health risk-drivers (shaded in the table below and detailed in Table 3-2 above) as well as other pollutant groups associated with 303(d)-listed impairments. The percentages show the percent of the total number of sampling events (or stations) that collected data for each parameter group. Overall, conventional pollutants had the highest percentage of stations and sampling events. Of the primary pollutants associated with human health risks, arsenic had more ambient surface water quality sampling events than PAHs, dioxins, furans, and PCBs.

Table 3-3. Summary of ambient surface water quality data (1959-2012)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Total Sampling Events
Arsenic	31	11%	644	1%
Bacteria	87	32%	1,999	4%
Conventionals	121	44%	14,076	28%
Dioxin/Furan	0	0%	0	0%
Metals	32	12%	1,213	2%
Other SVOCs	14	5%	127	0%
PAHs	19	7%	312	1%
PCBs	18	7%	97	0%
Pesticides	8	3%	105	0%
Petroleum	3	1%	27	0%
Phthalates	8	3%	94	0%
VOCs	3	1%	28	0%

Note: Shading represents pollutants that are primary human health risk drivers.

Maps of monitoring locations show the spatial resolution of these data for primary human health and general conventional pollutants (Figure 3-1 below as an example, as well as Figure A-1 through Figure A-5 of Appendix A). The figure below is presented as an example for the various water, sediment, and tissue data presented throughout this section, while all maps are presented in Appendix A. Each map presents a spatial summary of the number of sampling events within a 5-acre cell (left panel) and locations of all recent (collected within the past 10 years) and older (data are older than 10 years) sampling locations (lower right panel). The purpose of the map in the larger panel, which is generally scaled to recent samples, is to show both the spatial resolution and the number of sampling events, highlighting the amount of data by parameter in a spatial context. The temporal resolution represented by the lower right panel distinguishes the data collected in the past ten years (recent) from older data; this time cutoff was selected to maintain some consistency with the general date ranges used for 305(b) assessments (Section 1.3).

With the exception of conventional parameters, ambient surface water quality data are limited in the LDW and the Green/Duwamish River watershed. Table 3-4 summarizes potential data gaps for ambient surface water quality data parameters. For the primary human health pollutants, spatial coverage in the LDW and the Green/Duwamish River watershed and the quantity of data varies by parameter, with better spatial representation for arsenic, PAHs, and PCBs (Figure A-1 and Figure A-3 of Appendix A, respectively). Dioxin/furans and PAHs do not have recent ambient surface water quality sampling locations (Figure A-2 and Figure A-4, respectively), which will limit the accuracy of any data-driven watershed loading estimates. Overall, more recent (within the past ten years) ambient surface water quality data are limited in quantity and geographic scale with the majority of recent data located in the Duwamish Estuary subwatershed (LDW). These data were evaluated along with other data types (ambient surface sediment, and point source-related water and solids data) to identify potential data gaps and inform selection of an applicable technical approach. Further and more detailed data gap analysis will occur in the next tasks of the project to identify any additional needs for modeling. All potential dataset gaps are discussed further in Section 5.3.5.

Table 3-4. Detailed summary of ambient surface water quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	10	413	10	144	11	87	0	0	17	245	31	644
Bacteria	20	603	20	534	45	852	2	10	54	1,288	87	1,999
Conventional	64	2,676	32	3,207	72	9,813	8	3,738	121	14,076	121	14,076
Dioxin/Furan	0	0	0	0	0	0	0	0	0	0	0	0
Metals	9	486	9	344	12	355	2	28	12	486	32	1,213
Organometals	0	0	0	0	0	0	0	0	0	0	0	0
Other SVOCs	10	120	2	4	2	3	0	0	2	4	14	127
PAHs	11	245	4	37	4	30	0	0	9	98	19	312
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	0	0	0	0	0	0	0	0	0	0	0	0
PCBs	12	43	3	26	3	28	0	0	18	97	18	97
Pesticides	2	89	2	5	4	11	0	0	3	93	8	105
Petroleum	1	23	1	2	1	2	0	0	1	2	3	27
Phthalates	8	94	0	0	0	0	0	0	0	0	8	94
VOCs	1	24	1	2	1	2	0	0	1	2	3	28

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

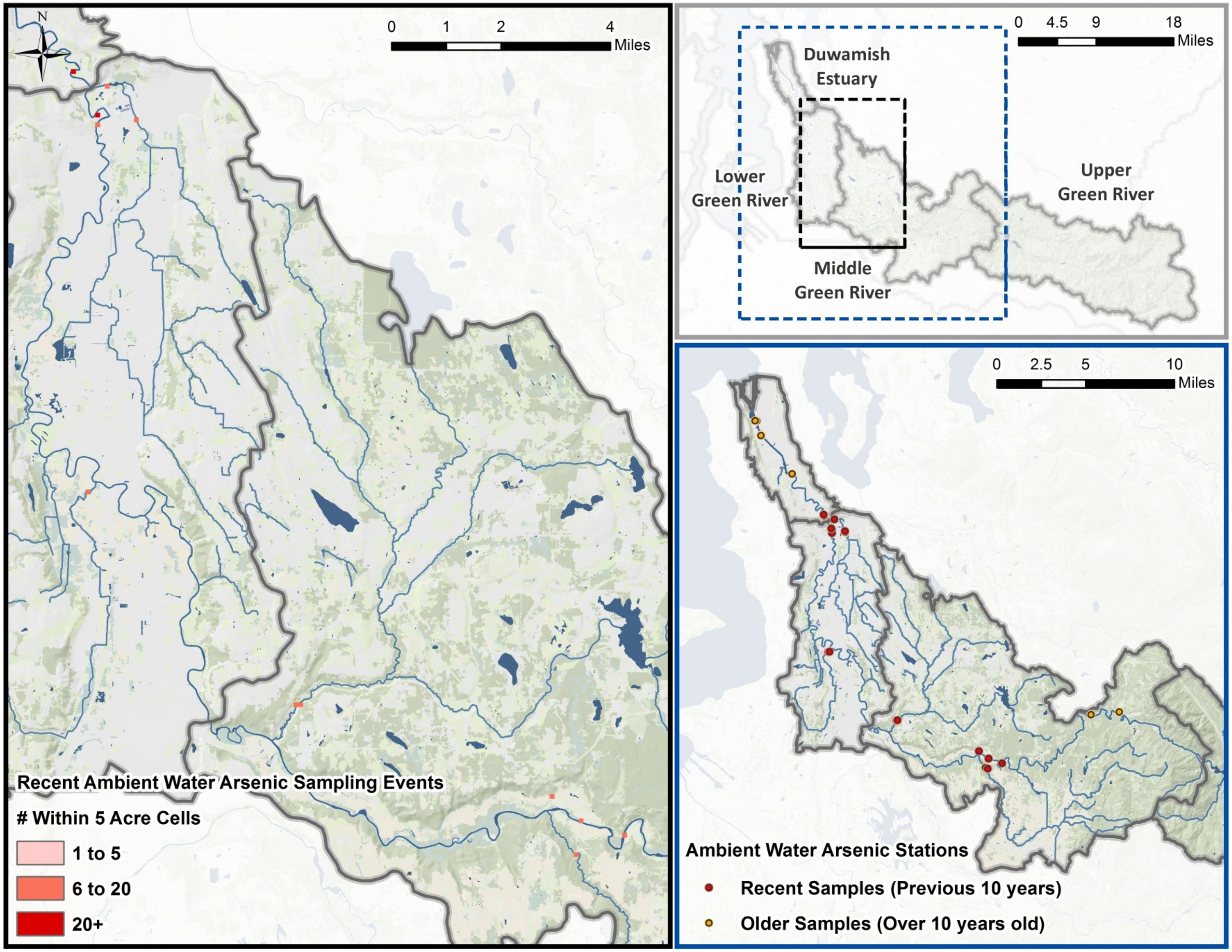

Figure 3-1. Ambient water quality sample locations for arsenic

3.1.1.2 Point Source Water Quality Data

The surface water quality data described previously represent ambient water quality conditions within a waterbody. Alternatively, point source discharge data characterize specific sources or inputs to those receiving waterbodies. These sources or inputs are often, but not exclusively, associated with permitted facilities, such as stormwater (municipal or industrial), CSOs, and wastewater (Section 2).

At this time Ecology has identified 288 outfalls to the LDW including inactive outfalls, NPDES-permitted outfalls, and outfalls without permits. There are over 100 NPDES-permitted facilities and/or discharges in the LDW Source Area and over 300 permitted facilities and/or discharges throughout the Green/Duwamish River watershed, which are illustrated in Figure 3-2 (note: locational information was unavailable for several discharge points; however, the vast majority are illustrated in the map). The permitted dischargers were identified through consultation with Ecology and Ecology's Water Quality Permitting and Reporting Information System (PARIS) database[10]. Permit types include municipal stormwater permits (for municipal separate storm sewer systems [MS4]), Industrial Stormwater General Permit, and municipal (sanitary) wastewater and CSO permits. Sand and gravel general permits, construction stormwater general permits, and boatyard general permits were not included in this summary. Note that MS4 outfalls are not identified and mapped in PARIS.

Data associated with point source discharges are available from multiple sources. These include water chemistry data from discharge-related samples taken in special studies and available through the data sources described above (Appendix A Table A-2). In addition, discharge monitoring report (DMR) data are available for some facilities through the PARIS database. These DMR data include parameters such as flow, turbidity, pH, metals, ammonia, antimony, arsenic, diesel, biochemical oxygen demand (BOD), oil and grease, nitrate and nitrite, phosphorus, total suspended solids (TSS), bacteria, mercury, and PAHs (Appendix A Table A-3). Table 3-5 summarizes the number of outfalls and/or facilities that report DMR data to PARIS. DMR data in general are limited. Appendix A presents more details on specific sampling event data (generally not linked to a specific permit) as well as a summary of available data from permit-specific DMR information. These data can be incorporated into the technical approach to characterize direct discharges and lateral loads to the LDW and the Green/Duwamish River watershed.

Table 3-5. Summary of point source DMR reporting

Parameter Group	Number of Reporting Outfalls/Facilities	Percent of Outfalls/Facilities
Arsenic	0	0%
Bacteria	6	2%
Conventional	4 - 190	1 – 55%
Dioxin/Furan	0	0%
Metals	1 - 164	0 – 48%
Other SVOCs	0	0%
PAHs	1	0%
PBDE	0	0%
PCBs	0	0%
Pesticides	0	0%

[10] http://www.ecy.wa.gov/programs/wq/permits/paris/index.html

Parameter Group	Number of Reporting Outfalls/Facilities	Percent of Outfalls/Facilities
Petroleum	7 - 27	2 – 7%
Phthalates	0	0%
VOCs	0	0%

Note: Shading represents pollutants that are primary human health risk drivers.

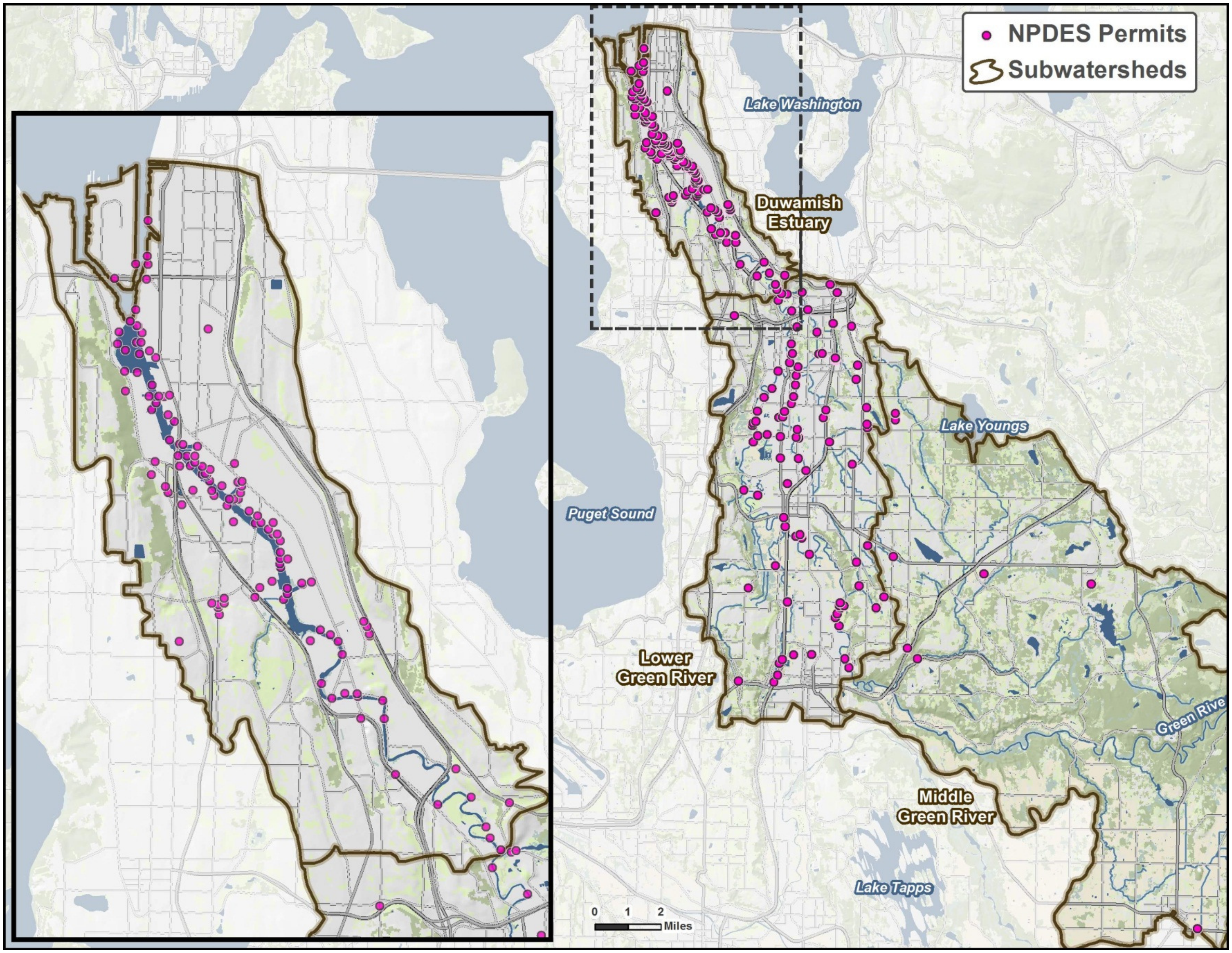

Figure 3-2. Permitted discharges near the LDW and the Green/Duwamish River watershed

For the purposes of this technical approach, point source water quality data refers to data that is either representative of discharge quality or of what is or was present on site at the time of sample collection (and which may be discharged). These data have been compiled from the same databases as the ambient surface water quality data, but have been queried for samples associated with stormwater outfalls, CSO overflows, and other point sources.

Discharge-related data are available from 1989-2012 and the majority of these stations have recent data (i.e., data collected within the past ten years) (see Appendix A Figure A-6 through Figure A-10 for maps of the primary human health and general conventional pollutants). These include ongoing data from Boeing's long-term stormwater treatment system (LTST) performance monitoring, which contains monthly and post-storm stormwater events and King County CSO monitoring data (Appendix A, Table A-2). Arsenic and metals are the most widely analyzed parameters of the various pollutant groups, with around 300 sampling events each analyzed from over 40 stations. Available source monitoring for water is illustrated in Appendix A, Figure A-6 through Figure A-10. For all example parameters, most of the discharges are located near and adjacent to the LDW in the Duwamish Estuary subwatershed. Water discharge data are not generally available for the primary human health pollutants (Appendix A Figure A-6 and Figure A-7). Table 3-7 details the potential data gaps in the discharge-related data set. Overall, the spatial and temporal resolution is better in the LDW compared to the Green/Duwamish River watershed.

Table 3-6. Summary of point source water quality data (1989-2012)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Arsenic	40	80%	272	40%
Bacteria	4	8%	21	3%
Conventional	40	80%	217	32%
Dioxin/Furan	0	0%	0	0%
Metals	42	84%	300	44%
Other SVOCs	32	64%	257	38%
PAHs	32	64%	256	38%
PBDE	12	24%	15	2%
PCBs	35	70%	174	26%
Pesticides	19	38%	78	11%
Petroleum	6	12%	21	3%
Phthalates	32	64%	181	27%
VOCs	15	30%	60	9%

Note: Shading represents pollutants that are primary human health risk drivers.

Table 3-7. Detailed summary of point source discharge water quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 yrs)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	40	272	0	0	0	0	0	0	40	272	40	272
Bacteria	3	19	0	0	1	2	0	0	3	19	4	21
Conventional	39	196	0	0	1	21	0	0	39	196	40	217
Dioxin/Furan	0	0	0	0	0	0	0	0	0	0	0	0
Metals	42	300	0	0	0	0	0	0	42	300	42	300
Organometals	0	0	0	0	0	0	0	0	0	0	0	0
Other SVOCs	32	257	0	0	0	0	0	0	32	257	32	257
PAHs	32	256	0	0	0	0	0	0	32	256	32	256
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	12	15	0	0	0	0	0	0	12	15	12	15
PCBs	35	174	0	0	0	0	0	0	35	174	35	174
Pesticides	19	78	0	0	0	0	0	0	19	78	19	78
Petroleum	6	21	0	0	0	0	0	0	6	21	6	21
Phthalates	32	181	0	0	0	0	0	0	32	181	32	181
VOCs	15	60	0	0	0	0	0	0	15	60	15	60

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.1.3 Groundwater

Groundwater quality data provide information on the composition of groundwater and are used to characterize potential inputs to surface waters. Groundwater quality data are available throughout the LDW (but very few samples are available farther up into the Green/Duwamish River watershed) from EIM, RI/FS, NAWQA, and STORET, among others. Available groundwater quality data are summarized in Table A-4 of Appendix A. This table includes study names, number of stations, and number of sampling events, and range from 1988 to 2011. Table 3-8 below presents a summary of the total number of groundwater quality sampling events and stations for the pollutants that are primary human health risk drivers (shaded in the table below) as well as other pollutant groups associated with 303(d)-listed impairments. Also shown are the percent of all sampling events (or stations) that collected data for each pollutant group. Overall, volatile organic compounds (VOCs) and petroleum had the highest percentage of stations and sampling events. Of the priority pollutants associated with human health risks, PAHs had more groundwater quality sampling events than dioxins/furans and PCBs.

Table 3-8. Summary of groundwater quality data (1990-2011)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Dioxin/Furan	6	1%	8	0%
Metals	568	55%	3,396	49%
Other SVOCs	483	47%	2,489	36%
PAHs	484	47%	2,699	39%
PBDE	0	0%	0	0%
PCBs	132	13%	485	7%
Pesticides	140	14%	291	4%
Petroleum	708	68%	3,994	58%
Phthalates	233	22%	1,000	14%
VOCS	957	92%	5,956	86%

Note: Shading represents pollutants that are primary human health risk drivers.

Maps of groundwater monitoring locations and the distribution of sampling events show more abundant data than for ambient surface water or point source discharge water quality monitoring (Figure A-11 through Figure A-15 of Appendix A). Table 3-9 summarizes the potential data gaps in groundwater quality data. Groundwater data are abundant for most of the primary human health pollutants throughout the LDW, but limited to nonexistent in the Green/Duwamish River watershed. Groundwater data for dioxins/furans are limited. Groundwater data for conventional pollutants are primarily in the Duwamish Estuary subwatershed; however, the Lower and Middle Green River subwatersheds also have some recent conventional groundwater data. Most of these data were also collected within the past 10 years.

Table 3-9. Detailed summary of groundwater water quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	272	1,630	46	406	0	0	0	0	316	2,034	318	2,036
Bacteria	3	6	0	0	0	0	0	0	3	6	3	6
Conventional	169	940	78	484	9	41	0	0	248	1,378	256	1,465
Dioxin/Furan	6	8	0	0	0	0	0	0	6	8	6	8
Metals	343	2,016	198	1,099	27	281	0	0	548	3,330	568	3,396
Organometals	0	0	0	0	0	0	0	0	0	0	0	0
Other SVOCs	416	2,082	65	403	2	4	0	0	483	2,489	483	2,489
PAHs	360	2,105	115	528	9	66	0	0	484	2,699	484	2,699
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	0	0	0	0	0	0	0	0	0	0	0	0
PCBs	126	477	6	8	0	0	0	0	132	485	132	485
Pesticides	130	258	10	33	0	0	0	0	140	291	140	291
Petroleum	355	1,834	321	1,895	32	265	0	0	677	3,800	708	3,994
Phthalates	206	705	27	295	0	0	0	0	233	1,000	233	1,000
VOCs	596	3,656	328	2,038	33	262	0	0	918	5,751	57	5,956

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.2 Sediment Quality Data

3.1.2.1 Ambient Surface Sediment Quality Data

Ambient surface sediment quality data reflect concentrations of pollutants within the top layer of sediments in receiving waters.

The ambient surface sediment data from EIM, RI/FS, NAWQA, and STORET, among others, were collected from 1984 to 2011. Table A-5 in Appendix A presents a summary of the compiled data for all ambient surface sediment data. Table 3-10 summarizes the number and percent of stations and sampling events for the primary human health risk-drivers (shaded in the table below) and other pollutant group samples. Conventional pollutants had the highest number of stations and sampling events, followed by PCBs.

Ambient data represent existing surface sediment quality with loads from various sources or pathways, including stormwater, industrial point sources, illegal discharges, aerial deposition, past smelter activity, and in-sediment and in-stream processes.

Table 3-10. Summary of ambient surface sediment quality data (1980-2012)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Alkylated PAHs	63	1%	67	0%
Arsenic	2,294	35%	3,090	9%
Conventional	3,228	49%	5,020	15%
Dioxin/Furan	370	6%	737	2%
Metals	2,379	36%	3,272	10%
Organometals	661	10%	899	3%
Other SVOCs	2,402	36%	3,313	10%
PAHs	2,304	35%	3,062	9%
PBBs	14	0%	15	0%
PBDE	21	0%	21	0%
PCBs	2,892	44%	4,271	12%
Pesticides	1,185	18%	1,637	5%
Petroleum	230	3%	321	1%
Phthalates	2,123	32%	2,770	8%
VOCs	600	9%	843	2%

Note: Shading represents pollutants that are primary human health risk drivers.

Monitoring locations have been mapped to illustrate the spatial resolution of the ambient surface sediment quality data for primary human health and general conventional pollutants (Figure A-16 through Figure A-20 of Appendix A). As expected, the vast majority of stations are located within the LDW, providing considerable data to support identification of a PLA technical approach for the parameters of interest. These more recent data represent the existing conditions and will not represent surface sediment quality post-cleanup in remediated areas. However, as described in Section 5, the technical approach can include scenarios that change input concentrations at specific locations within the LDW, allowing for quantification of receiving water conditions over time while considering varying input sediment concentrations. This can be used as a tool to evaluate sediment remedy effectiveness.

Table 3-11 summarizes the data gaps for ambient surface sediment quality. While the LDW itself is well represented by surface sediment quality data, spatial coverage in the Green/Duwamish River watershed is more limited for all parameters mapped.

Table 3-11. Detailed summary of ambient surface sediment quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	59	63	1	1	2	2	1	1	41	44	63	67
Arsenic	2,205	2,998	47	48	41	43	1	1	950	1,265	2,294	3,090
Bacteria	0	0	5	5	0	0	0	0	5	5	5	5
Conventional	3,125	4,870	54	71	48	78	1	1	1,411	2,514	3,228	5,020
Dioxin/Furan	363	729	4	5	3	3	0	0	302	641	370	737
Metals	2,284	3,150	49	56	45	65	1	1	989	1,365	2,379	3,272
Organometals	661	899	0	0	0	0	0	0	257	370	661	899
Other SVOCs	2,317	3,227	47	48	37	37	1	1	1,041	1,573	2,402	3,313
PAHs	2,217	2,974	49	50	37	37	1	1	985	1,354	2,304	3,062
PBBs	14	15	0	0	0	0	0	0	0	0	14	15
PBDE	0	0	0	0	21	21	0	0	21	21	21	21
PCBs	2,806	4,180	48	53	37	37	1	1	1,312	1,978	2,892	4,271
Pesticides	1,099	1,549	48	49	37	38	1	1	428	566	1,185	1,637
Petroleum	200	273	7	12	23	36	0	0	42	62	230	321
Phthalates	2,039	2,685	46	47	37	37	1	1	840	1,136	2,123	2,770
VOCs	576	818	23	24	1	1	0	0	72	140	600	843

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.2.2 Point Source Solids or Sediment Data

Point source or discharge-specific sediment or solids data were gathered from the EIM database and RI/FS data, among other sources. Data include solids measurements from oil/water separators, storm drains, sediment traps, stormwater filters, and surface debris and are analyzed for many parameters, including the primary human health and conventional pollutants. Devices where solids collect may be routinely cleaned. These data are best used for source tracing and BMP effectiveness evaluation purposes unless they were specifically collected and studied to represent sediment discharge quality loadings.

Available point source discharge solids data are available for 1998-2012 (Appendix A Table A-6), with over 2,000 total sampling events. For the primary human health and conventional pollutants, Arsenic, PAHs, and PCBs had the most stations and many parameters had over 1,000 sampling events (Table 3-12). Similar to the water point source discharge data, these inputs are focused around the LDW (Figure A-21 through Figure A-25 of Appendix A). All of the primary human health pollutants had similar spatial distributions of available sediment point source discharge data limited to the Duwamish estuary subwatershed (Table 3-13 and Appendix A Figure A-21 through Figure A-25). Most of these data are representative of storm drain system data rather than point source DMR data or CSO outfall data. These data would provide a strong foundation to estimate sediment concentrations and potentially loadings from the known point sources as part of the technical approach.

Table 3-12. Summary of point source solids or sediment quality data (1998-2012)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Arsenic	1,170	68%	1,590	58%
Conventional	896	52%	1,232	45%
Dioxin/Furan	78	5%	102	4%
Metals	1,177	68%	1,603	58%
Other SVOCs	909	53%	1,350	49%
PAHs	954	55%	1,384	50%
PBDE	11	1%	15	1%
PCBs	1,228	71%	1,925	70%
Pesticides	38	2%	38	1%
Petroleum	719	42%	978	36%
Phthalates	830	48%	1,163	42%
VOCs	35	2%	35	1%

Note: Shading represents pollutants that are primary human health risk drivers.

Table 3-13. Detailed summary of point source solids or sediment quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	1,170	1,590	0	0	0	0	0	0	1,155	1,574	1,170	1,590
Bacteria	0	0	0	0	0	0	0	0	0	0	0	0
Conventional	896	1,232	0	0	0	0	0	0	888	1,224	896	1,232
Dioxin/Furan	78	102	0	0	0	0	0	0	78	102	78	102
Metals	1,177	1,603	0	0	0	0	0	0	1,162	1,587	1,177	1,603
Organometals	0	0	0	0	0	0	0	0	0	0	0	0
Other SVOCs	909	1,350	0	0	0	0	0	0	901	1,342	909	1,350
PAHs	954	1,384	0	0	0	0	0	0	946	1,376	954	1,384
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	11	15	0	0	0	0	0	0	11	15	11	15
PCBs	1,228	1,925	0	0	0	0	0	0	1,169	1,865	1,228	1,925
Pesticides	38	38	0	0	0	0	0	0	38	38	38	38
Petroleum	719	978	0	0	0	0	0	0	704	962	719	978
Phthalates	830	1,163	0	0	0	0	0	0	821	1,154	830	1,163
VOCs	35	35	0	0	0	0	0	0	35	35	35	35

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.2.3 Subsurface Sediment Data

Subsurface sediment quality data represent the sediment concentrations below the surface layer of sediment. They often represent conditions after many years of sediment deposition, with older sediments located below surface sediments. Chemistry data are available for subsurface sediment samples (1990-2012) with most sampling events occurring in the past 10 years (Table A-7 of Appendix A) from various sources including Ecology's EIM database, FS data, Ecology's LDW Sherlock database, and the USACE LDW, East Waterway, and West Waterway Subsurface Sediment Characterization report (USACE, 2013). These samples were generally analyzed for the same suite of parameters as the ambient surface sediment and point source solids/sediment data and can be used to characterize conditions in subsurface conditions in the contaminant fate and transport simulations. These data can be used for model calibration of sediment deposition pollutants. The data can also be used to estimate the initial conditions of sediment and pollutants in the channel bottom during model configuration. In addition to subsurface sediment sampling data, soil sampling and bank sediment sampling data are available and summarized in Appendix A, these data can be used for reference in the EFDC modeling, but are not as extensive as the subsurface sampling data available.

Table 3-14 presents the number of stations and sampling events associated with various pollutant groups, including the primary human health (shaded in the table below) and conventional pollutants. Many pollutant groups had over 500 sampling events. These data are also illustrated for a subset of example pollutants in Figure A-26 through Figure A-30 of Appendix A. Table 3-15 summarizes the potential subsurface sediment data gaps, all of the subsurface data were collected in the LDW (Duwamish Estuary subwatershed) and are well distributed throughout the waterbody. PCBs had more sample events than the other primary human health pollutants; however, the spatial distribution of these events are similar throughout.

Subsurface data will not necessarily represent subsurface sediment quality post-cleanup in remediated areas; they represent existing conditions at the time of sample collection.

As noted above for the surface sediment data, it is important to recognize that these subsurface data will not represent subsurface sediment quality post-cleanup in remediated areas and they only represent existing conditions at the time of sample collection. The technical approach allows an evaluation of scenarios that change input subsurface concentrations at specific locations within the LDW. This can be used as a tool to evaluate the effectiveness of the LDW sediment remedy (Section 5).

Table 3-14. Summary of subsurface sediment quality data (1990-2012)

Parameter	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Arsenic	341	56%	585	34%
Conventional	554	91%	1,584	93%
Dioxin/Furan	86	14%	120	7%
Metals	402	66%	789	46%
Organometals	91	15%	147	9%
Other SVOCs	333	55%	618	36%
PAHs	331	55%	609	36%
PCBs	558	92%	1,541	91%
Pesticides	223	37%	312	18%

Parameter	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Petroleum	28	5%	61	4%
Phthalates	331	55%	588	35%
VOCS	151	25%	203	12%

Note: Shading represents pollutants that are primary human health risk drivers.

Table 3-15. Detailed summary of subsurface sediment quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	341	585	0	0	0	0	0	0	209	388	341	585
Bacteria	0	0	0	0	0	0	0	0	0	0	0	0
Conventional	554	1,584	0	0	0	0	0	0	368	1,213	554	1,584
Dioxin/Furan	86	120	0	0	0	0	0	0	86	120	86	120
Metals	402	789	0	0	0	0	0	0	261	564	402	789
Organometals	91	147	0	0	0	0	0	0	73	117	91	147
Other SVOCs	333	618	0	0	0	0	0	0	207	440	333	618
PAHs	331	609	0	0	0	0	0	0	205	431	331	609
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	0	0	0	0	0	0	0	0	0	0	0	0
PCBs	558	1,541	0	0	0	0	0	0	371	1,182	558	1,541
Pesticides	223	312	0	0	0	0	0	0	128	187	223	312
Petroleum	28	61	0	0	0	0	0	0	15	33	28	61
Phthalates	331	588	0	0	0	0	0	0	204	409	331	588
VOCs	151	203	0	0	0	0	0	0	59	104	151	203

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

Chemistry data are also available for sediment porewater (1998, 2004, and 2005) samples (Table A-16 of Appendix A). These samples were generally analyzed for the same suite of parameters as the ambient surface water and point source data and can be used to characterize conditions at the sediment-water interface in contaminant fate and transport simulations.

3.1.3 Tissue Data

Tissue data quantifies the bioaccumulation of toxic chemicals in living organisms, especially bottom dwellers and shellfish. While tissue concentrations are difficult to represent in a physical model, they can be correlated with sediment and water quality data that more directly quantify loadings in and to a waterbody. The RI and other existing studies were used to compile tissue data and cover a period of 1984 to 2008 (Table A-8 in Appendix A). PCBs had the largest dataset for tissue quality (Table 3-16). In addition, as shown in Table 3-17 and Appendix A Figure A-31 through Figure A-35, most of the tissue data were collected from the LDW (Duwamish Estuary subwatershed) and the locations are generally consistent among parameters. Some tissue samples were also collected in Elliott Bay, Puget Sound, and farther upstream in the Duwamish River. These data will be useful for calibration of the food chain model (FCM) bioaccumulation model. In addition, they are useful to characterize bioaccumulation and to compare with numeric targets for determination of designated use attainment.

Table 3-16. Summary of tissue quality data (1984-2007)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Alkylated PAHs	41	8%	41	3%
Arsenic	321	61%	464	37%
Conventionals	414	78%	710	56%
Dioxin/Furan	7	1%	21	2%
Metals	346	65%	518	41%
Organometals	355	67%	645	51%
Other SVOCs	317	60%	507	40%
PAHs	305	58%	453	36%
PCBs	462	87%	974	77%
Pesticides	321	61%	650	52%
Phthalates	308	58%	422	33%

Note: Shading represents pollutants that are primary human health risk drivers.

Table 3-17. Detailed summary of tissue quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	41	41	0	0	0	0	0	0	41	41	41	41
Arsenic	321	464	0	0	2	2	1	1	301	328	324	467
Bacteria	0	0	0	0	0	0	0	0	0	0	0	0
Conventional	397	684	5	12	12	14	0	0	398	480	414	710
Dioxin/Furan	5	17	0	0	2	4	0	0	6	17	7	21
Metals	340	492	0	0	5	25	1	1	290	325	346	518
Organometals	352	634	2	10	1	1	0	0	289	333	355	645
Other SVOCs	310	477	0	0	6	29	1	1	287	307	317	507
PAHs	305	453	0	0	0	0	0	0	285	296	305	453
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	0	0	0	0	0	0	0	0	0	0	0	0
PCBs	452	934	2	9	7	30	1	1	384	483	462	974
Pesticides	311	610	2	9	7	30	1	1	293	329	321	650
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0
Phthalates	308	422	0	0	0	0	0	0	292	304	308	422
VOCs	0	0	0	0	0	0	0	0	0	0	0	0

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.4 Air Quality Studies

Air pollution can be a source of contamination through wet deposition (rain or snow), dry deposition (falling particles), or gas absorption. Deposition can be direct (onto the water surface directly) or indirect (onto the land and then transported to receiving waters through stormwater) (Section 2). Air quality data have been compiled from past reports and will be updated with several very pertinent and ongoing studies in future phases of this project.

King County conducted a year-long bulk atmospheric deposition study in the LDW, Lower Green and Middle Green River portions of the Green/Duwamish River watershed to assess select metals, mercury, PAHs, PCB congeners, seven polychlorinated dibenzo-dioxins (PCDDs), and ten polychlorinated dibenzo-furans (PCDFs) (King County, 2013b). The study analyzed chemical fluxes at six locations, five of which were in the Green/Duwamish River watershed. A microscale level study was performed at the Kent Station which demonstrated that substantial differences can occur between two stations as close as 0.3 miles away from each other. The study tied metal and organic fluxes closely to the degree of urbanization at the stations. Stations near industrial land use had substantially higher metal and PCB fluxes than areas sampled by other studies along the Puget Sound shoreline using the same sampling methods. The King County and other existing studies were used to compile air data and cover a period of 2007 to 2012 (Table A-9 in Appendix A). Conventional parameters had the largest dataset for air quality (Table 3-18).

The results of the King County LDW bulk atmospheric deposition study complement that of the Lake Washington bulk air deposition study by EPA and King County (King County, 2011b) and the study of atmospheric deposition of air toxics to Puget Sound by Ecology (Brandenberger et al., 2010). The Lake Washington study measured PCB and polybrominated diphenylethers (PBDE) concentrations in ambient water (lake, rivers, creeks and ship canal) and relevant transport pathways (municipal stormwater, CSOs, bridge runoff, and bulk air deposition in two locations). The Puget Sound study measured trace metals, PBDES, and PAHs at seven sampling stations to provide updated annual loading estimates from atmospheric deposition to the Puget Sound from Padilla Bay south to Nisqually River. While not hydrologically connected to the Green/Duwamish River watershed, air quality data in the Lake Washington study (King County, 2011b) and Puget Sound study (Brandenberger et al., 2010) should be evaluated for applicability in the Green/Duwamish River watershed. Note that watershed and airshed boundaries do not coincide; airsheds are typically much larger than watersheds.

These studies should provide significant and thorough insight for these contaminants in the general vicinity of this study area and should be further considered. Data from these studies are expected to appear in the EIM or LDW Sherlock databases and should be incorporated during implementation of the PLA technical approach.

Additionally, Ecology completed an air deposition scoping study in December 2013 (Ecology, 2013b). The study compiled and identified research efforts associated with stationary and mobile sources and performed a literature review of other regional and national studies. Ecology used this information to create a conceptual input model of major loading pathways to the LDW. The results of this study demonstrated that atmospheric emissions are a major source of COCs to the LDW. While local deposition to the LDW water surface is minimal compared to upstream lateral loads, estimates of indirect deposition range from 6 to 100 percent of lateral loads. Local atmospheric deposition sources of arsenic, cPAHs, and PCBs should be targeted for control efforts, while regional sources are the significant contributor to dioxins/furans and mercury loads.

Table 3-19 summarizes potential data gaps in air deposition data which are many. Existing national data are available for use if necessary or to fill in potential data gaps in the local studies described above. Specifically, several national databases collect atmospheric deposition data. The Air Quality System Data Mart available from EPA (http://www.epa.gov/ttn/airs/aqsdatamart/index.htm) contains data for hazardous air pollutants (HAP), which include many of the contaminants of concern in the LDW, including arsenic and PAHs. There are three stations within King County with data for these pollutants (over 30,000 records for HAP parameters from 2008-2012) that can be used to supplement any other local sources of data.

Table 3-18. Summary of air quality data (2001-2012)

Parameter Group	Number of Stations	Percent of Stations	Number of Sampling Events	Percent of Sampling Events
Arsenic	5	23%	104	4%
Conventionals	15	68%	2,571	96%
Dioxin/Furan	5	23%	43	2%
Metals	5	23%	104	4%
PAHs	5	23%	106	4%
PCBs	5	23%	42	2%
VOCs	1	5%	1	0%

Note: Shading represents pollutants that are primary human health risk drivers.

Table 3-19. Detailed summary of air quality data

Parameter Group	Count by Subwatershed								Recent Data (within last 10 years)		All Data	
	Duwamish Estuary		Lower Green River		Middle Green River		Upper Green River					
	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events	Station	Sampling Events
Alkylated PAHs	0	0	0	0	0	0	0	0	0	0	0	0
Arsenic	3	72	2	32	0	0	0	0	5	104	5	104
Bacteria	0	0	0	0	0	0	0	0	0	0	0	0
Conventional	0	0	5	345	8	1,021	2	1,205	14	2,515	15	2,571
Dioxin/Furan	3	26	2	17	0	0	0	0	5	43	5	43
Metals	3	72	2	32	0	0	0	0	5	104	5	104
Organometals	0	0	0	0	0	0	0	0	0	0	0	0
Other SVOCs	0	0	0	0	0	0	0	0	0	0	0	0
PAHs	3	73	2	33	0	0	0	0	5	106	5	106
PBBs	0	0	0	0	0	0	0	0	0	0	0	0
PBDE	0	0	0	0	0	0	0	0	0	0	0	0
PCBs	3	25	2	17	0	0	0	0	5	42	5	42
Pesticides	0	0	0	0	0	0	0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0	0	0	0	0
Phthalates	0	0	0	0	0	0	0	0	0	0	0	0
VOCs	0	0	1	1	0	0	0	0	1	1	1	1

Notes: Gray shaded parameter cells represent primary human health risk drivers. Orange shaded cells have no data. Cream/yellow shaded cells have limited data.

3.1.5 Physical Data

GIS data were compiled to accurately represent the physical environment of the study area. Data were gathered from the USGS, Ecology, Washington State Geospatial Portal, the United States Department of Agriculture (USDA), and Horizon Systems Corporation (note: locational information for various monitoring stations were also obtained as part of the environmental data compilation). Geospatial data include digital elevation data, stream coverage, WRIA boundaries, land use, soil coverage, dam location, topography, NPDES discharge locations, MS4 storm drain network, USGS national hydrography dataset (NHD), transportation, and flow monitoring stations (Table A-9 in Appendix A).

Digital elevation data from the USGS are presented in Figure 3-3, illustrating the topography of the land in the watershed. The Cascade Mountains are shown by the higher elevation areas in the eastern headwaters, draining to Howard Hanson Reservoir. Downstream of the dam, the watershed flattens out with much less topographic variability in the Middle and Lower Green River and Duwamish Estuary subwatersheds.

Figure 3-4 and Figure 3-5 illustrate the land use of the entire Green/Duwamish River watershed and the Duwamish Estuary subwatershed, respectively, using a 2010 coverage obtained from Ecology. The upstream drainage is dominated by forest areas, while manufacturing, trade, and transportation activities are located directly adjacent to the LDW, with a significant concentration of residential and commercial areas interspersed within. It should be noted that the transportation representation in this GIS layer includes only major transportation and utility properties and does not include the actual streets and highways, which are a widespread land use. These land use data would be useful for overall source assessment discussions, while information from special studies and available data would be used to supplement more detailed source assessment information.

Topography: Cascade Mountains in the eastern headwaters, draining to Howard Hanson Reservoir. Downstream of the dam, the watershed flattens out with much less topographic variability in the Middle and Lower Green River and Duwamish Estuary subwatersheds.

Land Use: Upstream drainage dominated by forest areas, while manufacturing, trade, and transportation activities are located directly adjacent to the LDW, with a significant concentration of residential and commercial areas interspersed within.

In addition, bathymetry data for the LDW and adjacent marine waters are critical for receiving water modeling efforts to support model configuration. While model grids have already been developed to support previous modeling efforts, if raw bathymetry data are considered useful for review and/or refinement of model grids, several sources are available. These sources are presented in Appendix A (Figure A-10).

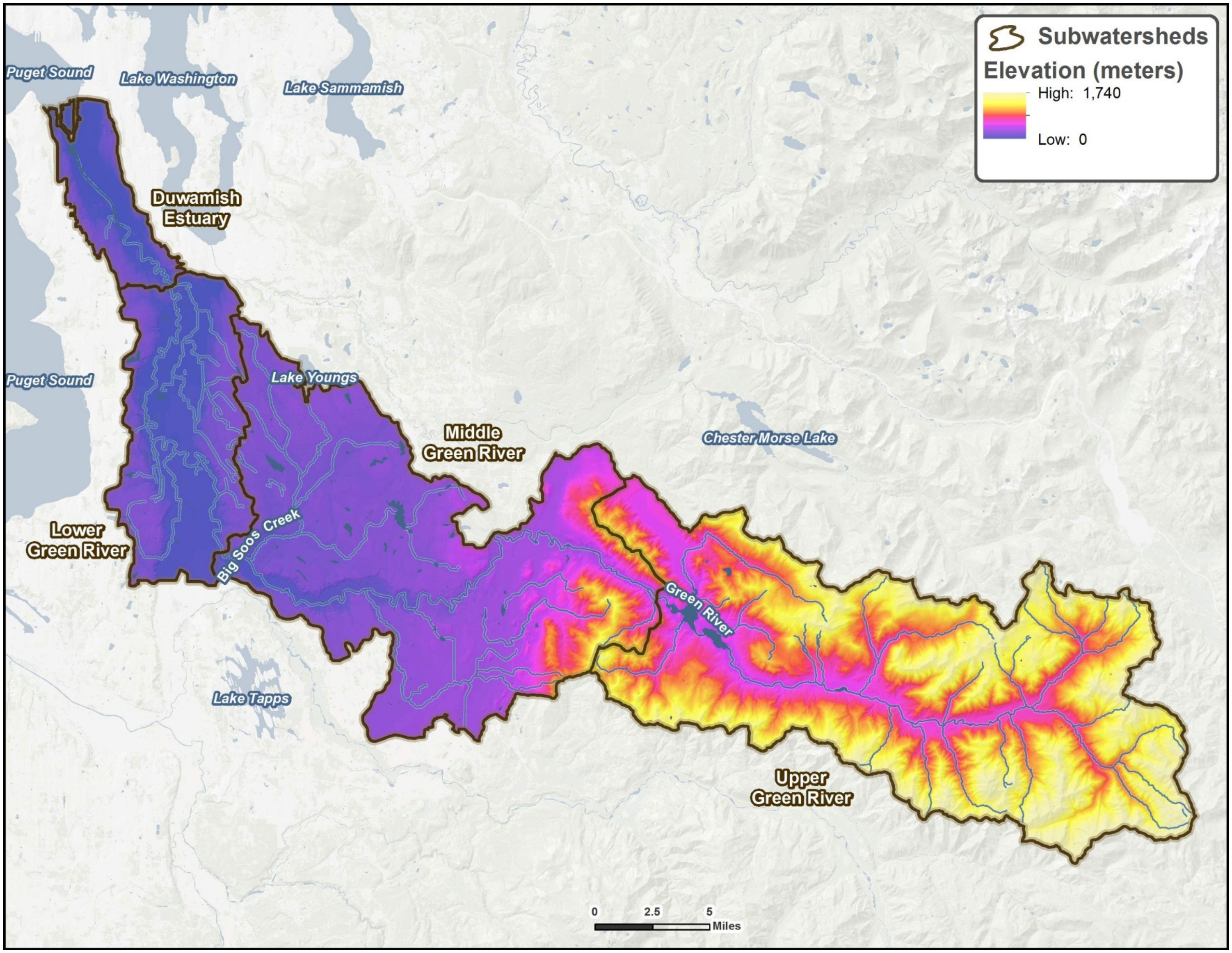

Figure 3-3. Elevation in the Green/Duwamish River watershed

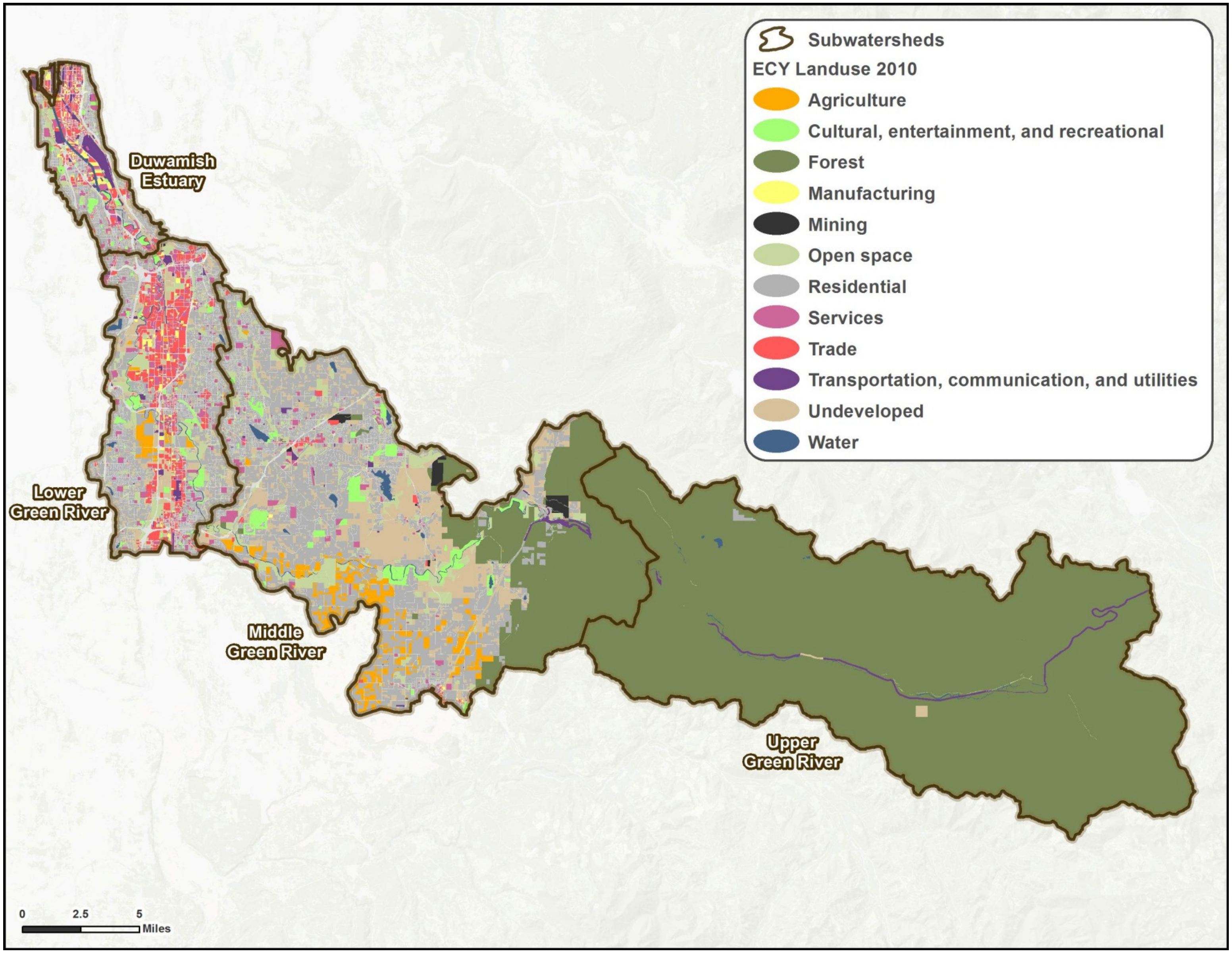

Figure 3-4. Land use of the Green/Duwamish River watershed

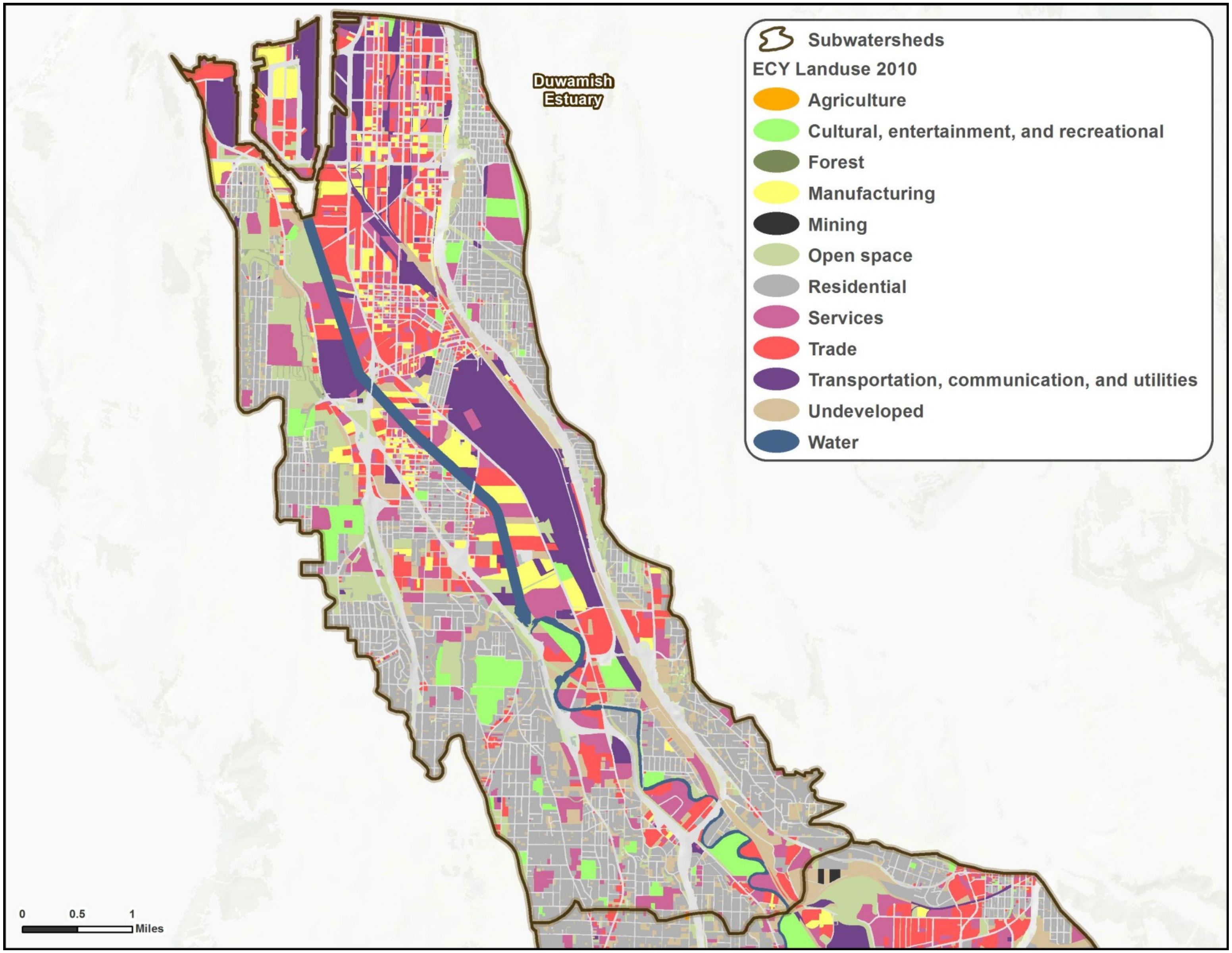

Figure 3-5. Land use of the Duwamish Estuary subwatershed

3.1.6 Streamflow Data

King County Flood Control District (KCFCD) addresses all flood-associated issues since 2007, when it was established, to protect citizens and property from damage (www.kingcountyfloodcontrol.org). To address regional flooding, the District's goals are to improve levee function, flood water conveyance and capacity, reduction of hazards and facilitate solutions from recent developments and transportation concerns. The King County Flood Hazard Management Plan describes numerous methods to address regional flooding. From the 2011 Annual Report, the District has been active in enacting flood damage repairs, home elevation, and numerous capital improvement programs. Furthermore, new flood boundary maps have been developed for the Green River upstream of the LDW to Geyser State Park (King County, 2011a).

In the Upper Green River subwatershed, the Howard Hanson Dam serves as a major flood control element as do the levees lining the Lower Green River into the Duwamish River. Dam and reservoir state-storage-discharge data are available, but necessitates personal communication for release and would be acquired prior to any technical work to ensure accurate representation of inflows to the LDW and the lower portion of the Green/Duwamish River watershed.

Additional gauges are available to represent tributaries and the main stem throughout the study area. Specifically, streamflow data were gathered from gauges maintained by the USGS, King County, and Ecology and can be used for model development and calibration. USGS stations (Appendix A Table A-11) have full extent of data from the late 1990s to present, or at least five years of continuous daily records. Two new USGS stations are being added in the LDW that will measure continuous turbidity in addition to flow and other conventional parameters. In addition, King County has over 20 active continuous flow gauges in the study area, some of which also collect precipitation, water temperature, air temperature, and turbidity data (Figure 3-6). Most of these active stations began collecting data in the late 1980s or early 1990s. In addition, there are inactive stations in the watershed, which may provide useful flow data at critical locations in the watershed, if no recent data are available. Similarly, EIM stations are instantaneous and generally old, but may be useful for model calibration if they are located on smaller streams that may not be otherwise monitored. Overall, the gauges are well-distributed in the areas downstream of the Howard Hanson Reservoir (Figure 3-6) and cover the past decade or two of time well (Table A-11 of Appendix A).

3.1.7 Meteorological Data

Meteorological data were predominantly collected from the National Oceanic and Atmospheric Administration (NOAA) National Climatic Data Center (NCDC) surface airway stations and can be used to support hydrodynamic and watershed modeling. Atmospheric forcing data include precipitation, air temperature, wind speed, dew point, cloud cover, ET, and solar radiation. Precipitation varies greatly in the greater Seattle region, and the large watershed is subject to a spectrum of precipitation patterns. For example, annual precipitation records from 1971-2000 in the central part of the study area at Landsburg, show an annual average precipitation of 56 inches, while data in the upstream portion of the watershed recorded at Cougar Mountain indicate almost double that value, at over 100 inches. These spatially-variable precipitation patterns dictate flow to the LDW, with additional influence from tidal components. Finer-scale meteorological data are available for the Green/Duwamish River watershed.

Meteorological data regionally relevant are available from 1991 to present. King County's Hydrologic Information Center also contains rainfall, stream gages, precipitation, air and water temperature, turbidity and other meteorological data for some stations (Appendix A Table A-12). The available meteorological stations are illustrated in Figure 3-7. In the meteorological station map (Figure 3-7), there are several NOAA-NCDC meteorological stations with full suites of atmospheric forcing data. In addition, King County's precipitation gauges provide good spatial and temporal coverage throughout most of the watershed.

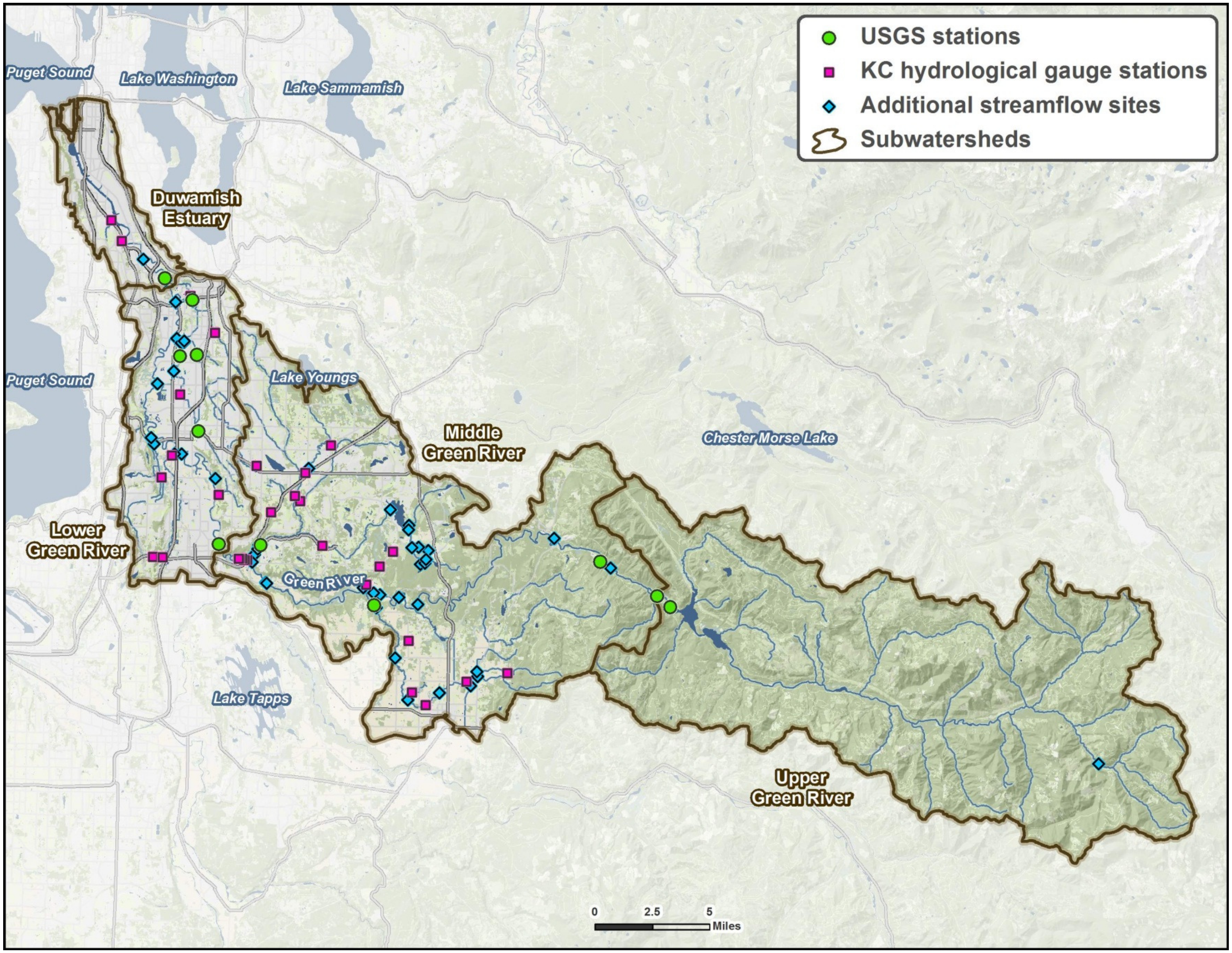

Figure 3-6. Streamflow gauge locations

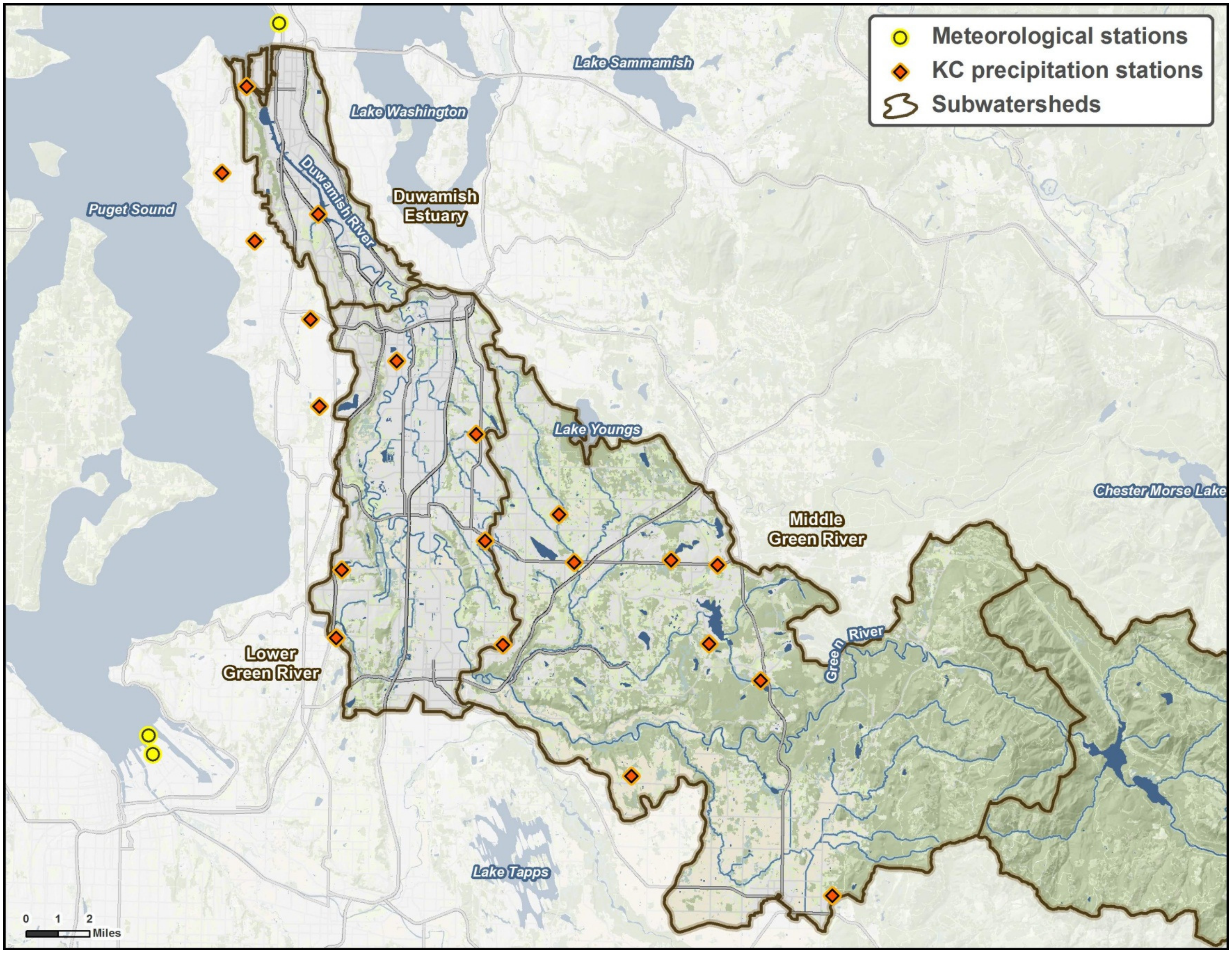

Figure 3-7. Meteorological stations

3.1.8 Hydrodynamic Data

Data to support hydrodynamic modeling of the LDW receiving water were obtained from a variety of sources including USGS, Ecology, EPA, NOAA, King County and associated studies. LDW and surrounding waterbodies that would represent boundary conditions are well represented as water temperature, salinity, density, dissolved oxygen, nitrogen, phosphorous, Secchi depth, chlorophyll *a*, turbidity, wind speed and direction, pH, conductivity, tide, and current datasets were all compiled to assist in implementation of the technical approach (see tables in Appendix A).

Important for hydrodynamic receiving water modeling, tidal data are available for 1991-present and are collected at 6 minute, hourly, and monthly intervals at several active stations (see Figure 3-8 and Table A-13 of Appendix A). Data can also be used from inactive tide stations for calibration purposes (Table A-13), which are also available, if necessary, based on important spatial locations and or time periods. In addition, a single current monitoring station is located in Puget Sound to the north of the study area (Figure 3-8) for 2009-present, which would likely dictate time periods used in the technical approach.

Additional water quality data are useful for transport calibration. These data are available long-term, continuous (i.e., mooring stations), and instantaneous monitoring stations throughout the waterbodies that could be used as external boundary conditions (Appendix A Table A-13 and Figure 3-8). The temporal (1989 to present) and spatial resolutions (Figure 3-8) of the continuous and long-term data provide a strong basis for modeling the LDW and representing its boundary conditions. The instantaneous measurements are less pertinent, but could be used to fill in spatial gaps (Tables A-14 and A-15 of Appendix A).

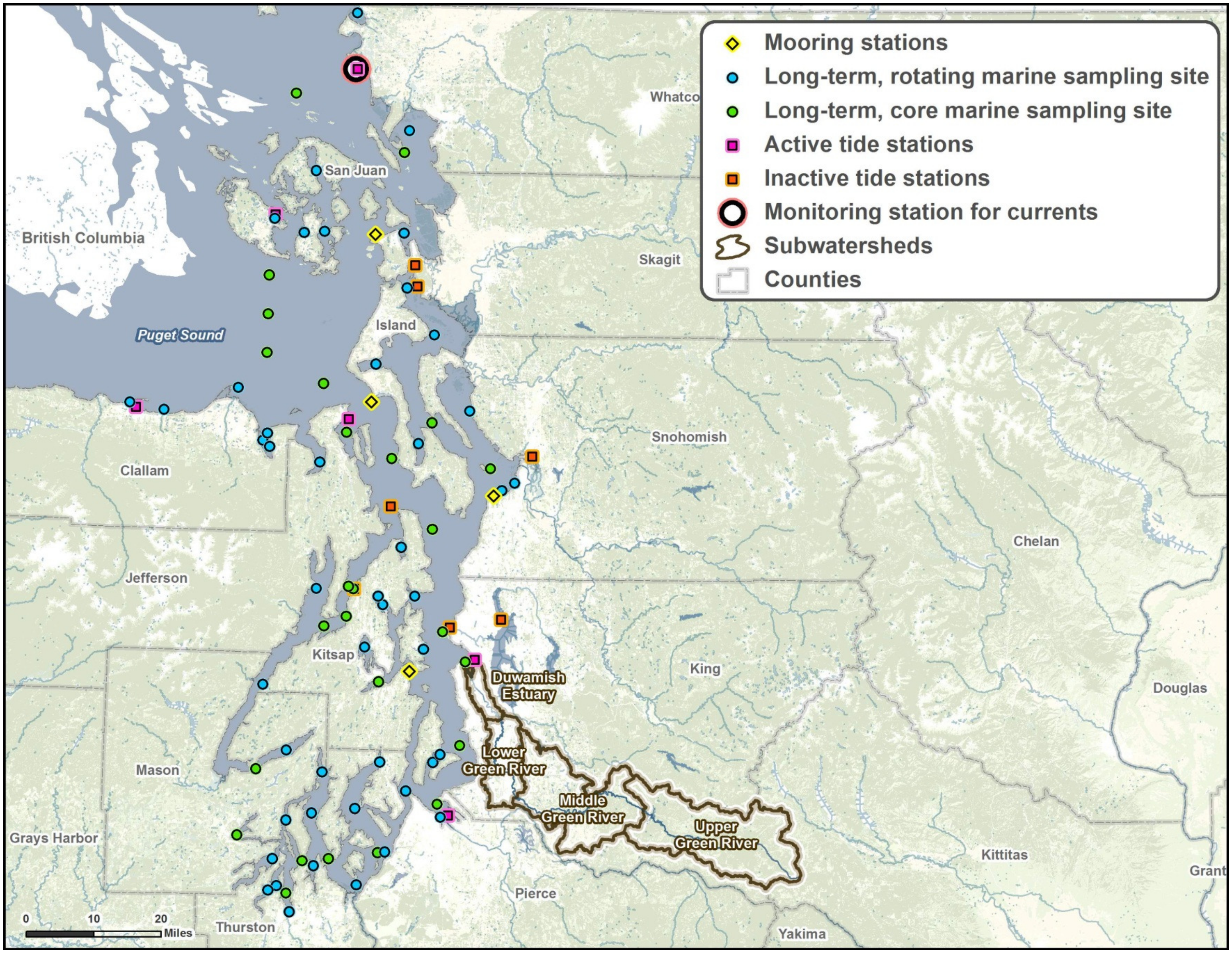

Figure 3-8. Tide and current stations in the assessment region

3.1.9 Sediment Distribution and Transport Data

Sediment size data are critical to understand the transport and deposition of sediment in a receiving waterbody. Sediment distribution is described by a variety of characteristics. Specifically, they are defined either by particle class as bedrock, clay, silt, etc. or by particle size from -3 to greater than 10 on the Krumbein phi scale, which describes particle class when a class is not provided. Sources of sediment size data are presented in Table A-17 of Appendix A and stations are illustrated in Figure 3-9. More recent data are present (within the past ten years) throughout the LDW and older data are available in specific LDW locations, including around Harbor Island (overall ambient data are available for the 1990s through 2010, while discharge sediment size data are for 2002-2010). Porosity, bulk density (wet and dry) data were also compiled and are useful for sediment transport modeling efforts.

A sediment transport characterization study has been completed in the LDW. Specifically, the Sediment Transport Characterization describes results of the geochronology and erosion sediment samples collected as part of the RI. The study was designed to:

- Collect and analyze sedimentation data from bench areas,
- Understand the depositional environment within the LDW through the combination of bench-area data with navigations channel data/info and bathymetric analyses,
- Collect and analyze data regarding potential sediment bed erosion,
- Quantify the effects of hydrodynamics on spatial distribution of bottom shear stress in LDW under different flow conditions,
- Determine potential bed scour areas, and
- Quantify anthropogenic forces on sediment bed erosion.

From the sediments collected during the erosion study, the composition is predominantly sandy silts with relatively uniform bulk sediment properties, both vertically throughout the sediment column and spatially throughout the LDW (Windward Environmental and QEA, 2005). Additional result data tables are available in the report and these findings were useful to inform technical approach selection.

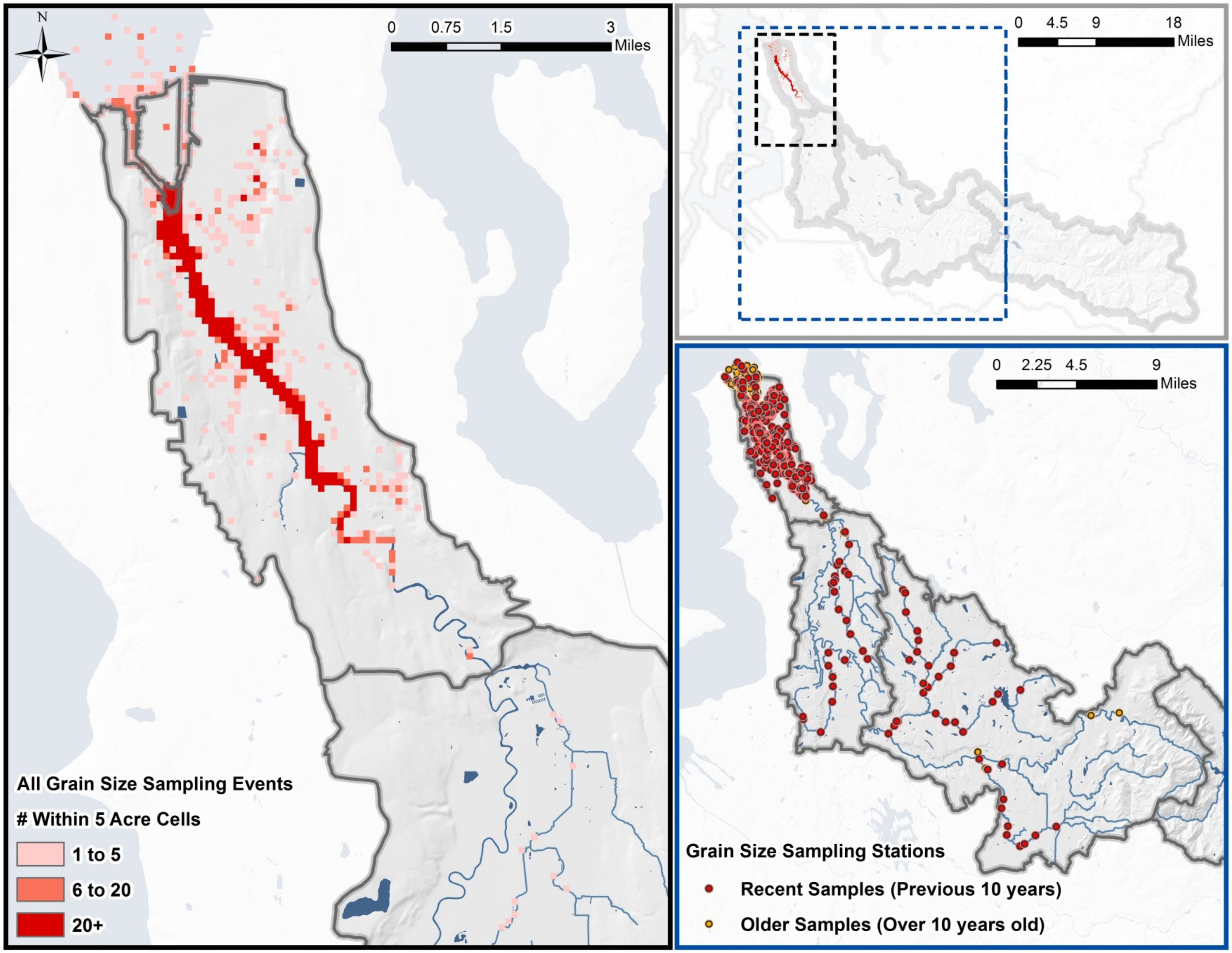

Figure 3-9. Grain size sampling sites near the LDW

3.2 Ongoing Data Collection Efforts

The LDW has been extensively studied and monitored for several decades. Local agencies and organizations have collected significant and pertinent data presented in various regional reports prior and subsequent to the National Priorities Listing (Superfund) in 2001. Several primary databases were queried to characterize the study area and support development of the technical approach. These databases are periodically updated and will likely contain data for currently ongoing studies that are pertinent to the PLA tool. Therefore, these databases should be re-queried prior to implementation of any technical work on the PLA tool to ensure currently ongoing studies are incorporated into the technical approach.

Several databases are periodically updated; these data sources will be re-queried prior to implementation of technical work on the water quality assessment tool to ensure ongoing studies are incorporated into the technical approach.

- ***Environmental Information Management System (EIM)***: Ecology maintains a database of continuously updated environmental data. This includes studies done specifically for or by Ecology within the State. Studies performed by permittees and other entities, such as environmental assessments (sediment and transport, water quality, biological data [fish tissue]), are also generally included in EIM. Data can be downloaded based on WRIA 9 and are expected to ultimately include new data from upcoming and ongoing studies of interest to the LDW and the Green/Duwamish River watershed.
- ***EPA's STORET***: This EPA database contains physical, biological, and water quality data, which can be readily retrieved based on Hydrologic Unit Code (HUC)/ county/state (or study name, if known). The warehouse is comprised of continuously updated data from various contributors including government, private, and educational institutions.
- ***LDW Sherlock Database***: Ecology posted a copy of the LDW Sherlock database (dated December 2013) on the LDW project SharePoint site. This is tool created by SAIC to manage data for specific studies and evaluations requested by Ecology source control staff. This database includes sediment and water quality data for the LDW and is periodically updated.
- ***USGS NAWQA***: Data in the NAWQA database can be retrieved based on a user specified HUC and parameter(s) of interest. These data include animal tissue, biological community, surface water, ground water, sediment, and site description data and are associated with USGS studies.
- ***Ecology's Permit and Reporting Information System (PARIS):*** Data in PARIS includes DMRs as well as stand-alone reports representing the quality of permitted discharges and/or potential pollutants present on-site.

Additionally, data from the following studies should be obtained prior to initiation of any technical work to build the comprehensive PLA assessment tool. Ecology is performing a Green River loading study (RM 11) to quantify sediment and toxic chemical loads associated with upstream sources in the Green River to the LDW. King County is performing a Green River suspended solids study to evaluate relative concentrations of select contaminants suspended in the Green and Duwamish Rivers. The study will collect suspended solids from two locations on Green River and three major tributaries that discharge to the river. Both studies should provide significant insight of contaminants of concern and their loading contribution to the LDW. Data from these studies are expected to appear in the EIM or LDW Sherlock databases.

4 Existing Receiving Water and Watershed Models

The Duwamish River and its watershed, including the Green River, have been modeled as part of a number of efforts over the last two decades. Hydrodynamic, sediment transport, and contaminant transport fate modeling studies of the LDW began with the King County CSO water quality assessment of the Duwamish River and Elliott Bay in the late 1990's (King County, 1999). Follow on work was conducted by EPA (Hayter, 2006; Arega and Hayter, 2004) and as part of the LDW Superfund RI/FS process (including food web modeling) (Windward Environmental and QEA, 2008; QEA, 2008; Windward Environmental, 2010; AECOM, 2012b). In addition, the watershed has been studied through a combination of watershed modeling (Aqua Terra and King County, 2003) and receiving water modeling of the Green River (Kraft et al., 2004). The watershed modeling efforts have been led by King County and refinement of the watershed models continues (King County, 2013a). King County (2011d) has also conducted some modeling analysis, including nearfield modeling, of CSO flow and sediment loads.

To help guide the selection of a technical approach for the PLA, the previous modeling efforts have been summarized in Table 4-1, and the model domains, or area covered by the simulations, are shown in Figure 4-1. These modeling efforts are described in further detail in the three subsections that follow. The reviews were conducted with the following questions in mind:

1. What type of assessment tool or model was used?
2. What monitoring data were available and how were they used?
3. Which contaminants were addressed? How do they overlap with the 303(d)-listed pollutants?
4. What sources, pathways, and transport processes are represented? Are any missing?
5. Are legacy pollutant loads and/or ongoing sources considered?
6. How reliable are the results? How strong is the model calibration?

4.1 LDW Hydrodynamic, Sediment, and Contaminant Transport and Fate Modeling

Recent hydrodynamic, sediment transport, and contaminant transport fate modeling studies of the LDW trace back to the King County CSO water quality assessment of the Duwamish River and Elliott Bay in the late 1990's (King County, 1999). King County developed an EFDC-based hydrodynamic, sediment transport, and contaminant transport model. The model domain extended into Elliott Bay and upstream into the river beyond the turning basin using approximately 500 horizontal grid cells and 10 vertical layers. In addition to upstream river flow and loads, the model include over 50 CSO discharges with a number of the large CSO discharges represented by an embedded buoyant jet model. Areas adjacent to the LDW were modeled for stormwater (flow only) using a Storm Water Management Model (SWMM) model originally developed by King County engineers.

Although the EFDC has an internally coupled sediment transport module allowing an arbitrary number of cohesive and noncohesive sediment size classes, data limitations resulted in use of two cohesive classes and a single noncohesive class. EFDC's internally coupled contaminant transport and fate model can simulate an arbitrary number of contaminants. Simulated contaminants included six metals and twelve non-metals: 1,4 dichlorobenzene, 4-methylphenol, arsenic, benzo(a)anthracene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k) bis(2-ethyl hexyl)phthalate fluoranthene, cadmium, chrysene, copper, dibenzo(a,h)anthracene, fecal coliform, fluoranthene, indeno[1,2,3-cd]pyrene, lead, mercury, nickel, phenanthrene, pyrene, total PCBs, tributyltin, and zinc.

Table 4-1. Previous modeling studies of the LDW and Green/Duwamish River watershed

Study	Modeling Tool	Sources Represented	Pathways Addressed for LDW	Parameter																																	Comments
				Flow	Temperature	Suspended Sediments	Bed Sediments	Total PBCs	Arsenic	Cadmium	Copper	Mercury	Nickel	Zinc	tributyltin	Dioxins/Furans	1,4 dichlorobenzene	4-methylphenol	cPAHs as a group	benzo(a)anthracene	benzo(b)fluoranthene	benzo(k)fluoranthene	bis(2-ethyl hexyl)phthalate	chrysene	dibenzo(a,h)anthracene	fluoranthene	indeno[1,2,3-cd]pyrene	phenanthrene	pyrene	fecal coliforms	nutrients	dissolved Oxygen	organic matter	chlorophyll *a*/algae	pH-Alkalinity	conductivity	
King County (1999)	EFDC	upstream river flow and loads, CSOs to LDW	hydrodynamic, sediment transport, and contaminant transport; upstream and internal loading	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X							Served as foundation for subsequent work in the 2000's.
Arega and Hayter (2004); Hayter (2006)	EFDC	primary source documentation is limited	built upon the earlier King County (1999) work																																		Primary source documentation for this work is limited.
Windward Environmental and QEA (2008); QEA (2008)	EFDC, SEDZLJ	Same as King County (1999)	Re-calibrated hydrodynamics based on earlier work	X	X	X	X																														Refinements made to King County (1999); STM benefited from extensive field data.
AECOM (2012b)	EFDC, BCM	BCM included bed and accounted for external loads from upstream and CSOs	See above; included new representation of pollutants; BCM for arsenic and PCBs, cPAHs and dioxin/furan also considered (only PCBs for FWM)	X	X	X	X	X	X							X			X																		See King County (1999); BCM not predictive, dynamic model; unclear if groundwater was included.
King County (2011d)	CORMIX, EFDC, Scaling Analysis	CSO flow and sediment loads	Near-field sedimentation	X		X	X																														EFDC and scaling analysis for near-field sedimentation. Currently limited to one CSO site.
Kraft et al. (2004)	CE-QUAL-W2	Loads from seven tributaries plus upstream/ downstream boundaries	Upstream inputs to LDW: flow and pollutants identified	X	X	X																									X	X	X	X	X	X	Simulated flow and elevations compared well with measured data; some lack of water quality fit in lower river; no validation; report recommends refinements such as missing flow sources.

Study	Modeling Tool	Sources Represented	Pathways Addressed for LDW	Parameter																																	Comments
				Flow	Temperature	Suspended Sediments	Bed Sediments	Total PBCs	Arsenic	Cadmium	Copper	Mercury	Nickel	Zinc	tributyltin	Dioxins/Furans	1,4 dichlorobenzene	4-methylphenol	cPAHs as a group	benzo(a)anthracene	benzo(b)fluoranthene	benzo(k)fluoranthene	bis(2-ethyl hexyl)phthalate	chrysene	dibenzo(a,h)anthracene	fluoranthene	indeno[1,2,3-cd]pyrene	phenanthrene	pyrene	fecal coliforms	nutrients	dissolved Oxygen	organic matter	chlorophyll *a*/algae	pH-Alkalinity	conductivity	
Aqua Terra and King County (2003)	HSPF	Upland sources (point sources uncertain); instream sources	Upstream inputs to LDW: flow and identified pollutants	X	X	X																									X	X	X	X	X		Some water quality parameters compared well and some did not; absence of point sources; no validation; refinement needed on transfer of groundwater between subwatersheds.
Windward Environmental (2010)	Arnot and Gobas FWM, EFDC	Uses EFDC for PCB inputs	Sediment PCBs and tissue PCBs			X	X	X																													Spatial variation in tissue contamination was not well predicted.

Note: Blank cells indicate parameter was not simulated in that study.

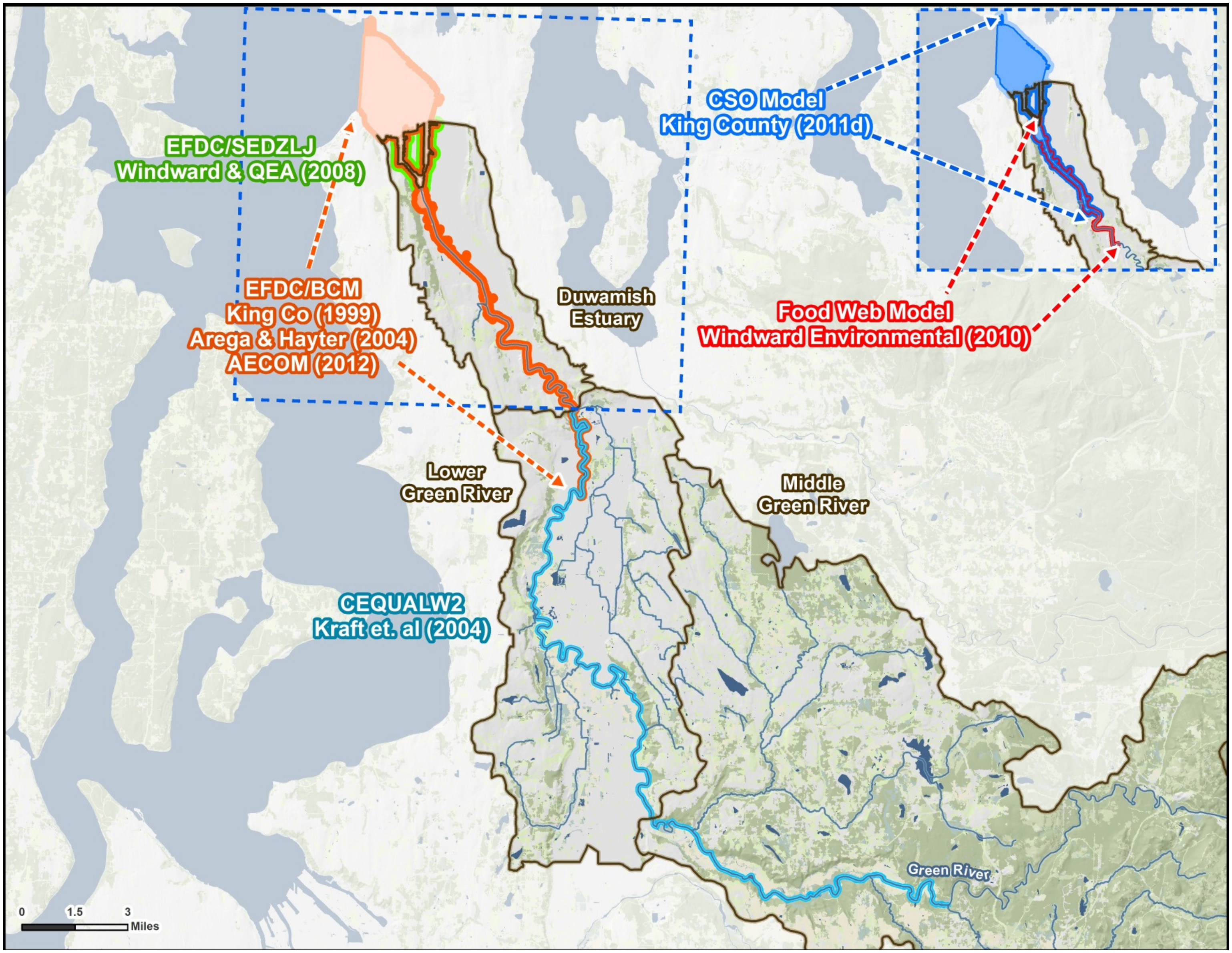

Figure 4-1. Model domains associated with previous modeling efforts

Model calibration and validation included comparison of hydrodynamic predictions with tidal gauge, current meter and salinity observations. Observed water column sediment concentrations and concentrations of a number of pollutants were also compared with model predictions. The calibrations were further refined in subsequent studies. The model was used for multi-year simulations to evaluate various CSO control strategies.

The LDW RI/FS process resulted in a wide range of investigations including additional modeling studies and the collection and analysis of observational data to support modeling. Hydrodynamic and sediment transport studies built upon the earlier King County (1999) work. As part of an EPA evaluation of contaminated sediment transport and fate models (Hayter, 2006), Arega and Hayter (2004) refined the earlier King County EFDC hydrodynamic model with increased horizontal resolution from 500 to 2,000, with the purpose of testing the capability of a public domain, three-dimensional, hydrodynamic and transport and fate model in simulating the highly stratified flow conditions in the LDW. Unfortunately, primary source documentation for this work is limited to a conference abstract. However, the refined EFDC hydrodynamic model was adopted and modified for use in the RI/FS modeling and its recalibration is documented in Windward Environmental and QEA (2008), Appendix B of the STAR.

The EFDC hydrodynamic model documented in the STAR report subsequently became the basis of the hydrodynamic model used as part of the STM developed by QEA (2008) for the LDWG. The STM estimated surface sediment bed composition for the model domain illustrated in Figure 4-1. The bed composition can be considered an aggregate of sources in the watershed, considering both erosional and depositional processes. The primary purposes of the STM study were to develop a tool to evaluate short and long-term sediment processes in the LDW including identifying the impacts of low recurrence events and areas of net deposition and erosion and the fate of eroded material, refine the CSM, and to support FS analyses including estimates for the transport and fate of contaminants (PCBs modeled and arsenic/PCBs calculated with a spreadsheet approach). The STM version of EFDC was modified to reduce the 2,000 horizontal cell grid to approximately 1,000 cells to facilitate multi-decade simulation. Recalibration of this version of the EFDC hydrodynamic model is also documented by QEA (2008). Development of the STM benefited from extensive field data collected during the RI/FS processes. Of particular importance was the collection of bed cores for Sedflume analysis which provided a robust basis for quantifying bed erosion potential. The STM was based on modifying the EFDC sediment transport module to include the SEDZLJ formulation and decoupling from the hydrodynamic model so that multiple long-term sediment transport simulation scenarios could be efficiently conducted using saved hydrodynamics. Upstream and lateral sediment loads are included as boundary conditions.

The approach adopted for evaluation of contaminant transport and fate process in the FS was a GIS and spreadsheet-based approach referred to as the Bed Composition Model (BCM) documented by AECOM (2012b), although it is not a model, but instead calculates the concentrations of contaminants in sediment external to the EFDC/STM model. The approach relies on sediment dynamics predicted by the STM and EFDC and assumes all contaminants are bound to particulates and routed with the sediment, an assumption that will lead to significant uncertainty in the predicted sediment concentrations over time. Long-term simulation results are likely to be unreliable for the prediction of future conditions. The calculations are based on initial particulate contaminant concentrations in Green River boundary inflows, lateral flows along the LDW, and bed sediments while assuming that there is no presence/interactions with dissolved phases and no calculation of porewater chemistry, dissolution, adsorption, or other transformation reactions. This is a simpler non-modeled approach compared to one that might use a process-driven, adsorptive contaminant transport and fate model or model component (Hayter, 2006), such as the one in the EFDC model that was used for the earlier King County (1999) study.

The approach allowed the calculation of a spatial (horizontal and depth in bed) inventory of pollutants in the LDW, which also was driven by external loads from upstream and lateral CSO loads. Extensive information from the STM was then used to evaluate potential for contaminant mobilization and/or burial and the used in the evaluation of remedial measures. Application of the approach primarily focused on arsenic and PCBs although cPAHs and dioxin/furan were considered.

Subsequent to the EFDC/STM modeling, the Arnot and Gobas FWM for the LDW utilized a recalibrated EFDC model to predict dissolved and particulate PCBs based on a partition coefficient to support the FWM.[11] This technical approach will include a more rigorous modeling of PCBs, metals, and other contaminants to predict sediment-associated contaminants in multiple classes, porewater concentrations, and water column concentrations in the LDW. This will provide a direct model linkage of sediment and water quality attributes and enable the dynamic simulation of long-term water, porewater, and sediment concentrations to reduce assumptions and simplifications used in the application of the FWM to the LDW. These changes will improve ERAs for future conditions.[12]

A significant amount of model development and modeling experience has been accumulated in the LDW over the past 15 years. The EFDC-based hydrodynamic, sediment transport, and contaminant transport and fate framework was used throughout, with the note that only PCBs were modeled and that other contaminants were calculated externally, applying assumptions that lead to large potential uncertainty in the long-term predictions. This hydrodynamic and sediment work provides a strong basis for using an EFDC framework for future studies while replacing the BCM approach and PCB modeling approach (for the FWM) with the more physically- and chemically-realistic contaminant transport and fate module in EFDC (with modifications, as needed, to best represent transformations of specific contaminants) allowing direct interaction with hydrodynamic and sediment processes.

4.1.1 Hydrologic and Hydraulic Modeling for CSO Control Plan

To support the 2012 King County long-term CSO control plan (King County, 2012), several hydrologic and hydraulic models were developed or recalibrated building upon a long history of modeling for CSOs in the area (King County, 2011c). This included recalibration of selected CSO area basins and pipe systems using DHI MOUSE/Mike Urban. Trunks and interceptor flow are represented by the hydraulic model, UNSTDY. Seattle Public Utilities conducted work using EPA SWMM (moving away from Infoworks). A detailed review of these modeling efforts was not conducted for this technical approach document; however, some of the information (e.g., flow time series; CSO constituent data) may be useful in supporting an updated receiving water model of the LDW.

4.1.2 Near-Field Sediment Contamination Modeling from CSOs

CSOs in the LDW are known to discharge COCs, which are typically associated with sediments present in CSO outflow. King County is assessing management options for cleanup of contaminated sediment at several CSO sites in the Duwamish River and Elliott Bay, and has supported investigations into predictive modeling of sediment contamination from near-field discharges. The modeling efforts have focused on simulating conditions in sediments around CSO outfalls. Work to date is discussed in King County (2011d). Modeling objectives include predicting concentration contours of COCs around CSO outfalls, and evaluating source-control and cleanup scenarios.

A CM was first developed to characterize processes affecting sediment contamination from an outfall. Major components included near-field initial dilution, water column hydrodynamics and transport, and sediment processes. Next, available data were obtained to characterize all aspects of CSO outfall structures, CSO effluent, sediments and contaminants in the vicinity of outfalls, and receiving water quality. The effort was restricted to eight CSO sites identified in previous planning work.

[11] Windward Environmental, 2010. Appendix D: Food Web Model for the LDW-Attachment 3 EFDC Calibration Process for Predicting PCB Water Concentrations in LDW.
[12] Windward Environmental, 2010. Appendix D: Food Web Model for the LDW.

Initial modeling efforts have largely focused on a single site, the Brandon CSO. Models of varying complexity were employed to assess suitable approaches for the final modeling framework:

1. Scaling analyses, using governing equations from EFDC
2. CORMIX model
3. EFDC model with fine grid at CSO outfall

Rather than focusing on long-term simulations, a series of models were developed representing various tidal conditions to place bounds around the expected ranges of transport, and to assist in identifying the most important processes affecting outcomes. The CORMIX simulations used EFDC estimates of velocities. Results indicated that the EFDC model with an appropriate grid scaled for plume dispersion was likely superior to the CORMIX model for representing dispersion and settling; evaluation of performance was hampered by the coarse spatial scale of sediment monitoring data. However, the report suggested that scaling analysis had utility for predicting the most critical processes and results.

4.2 King County CE-QUAL-W2 Modeling for Green River

The previous section focused on receiving water modeling for the LDW. Additional instream modeling has been conducted for the Green River upstream of the LDW. For King County, Portland State University prepared a CE-QUAL-W2 model of the Green River (Kraft et al., 2004). The two dimensional, laterally averaged hydrodynamic and water quality model was developed for the Middle and Lower Green River from RM 45 to RM 11.2. The Middle Green River begins east of Tacoma below a diversion dam for the City of Tacoma and downstream of Howard Hanson Reservoir, and continues to Auburn where the Lower Green River picks up and continues to the confluence of the Duwamish River at Tukwila.

The Middle Green River and Lower Green River have been modeled previously using Hydrologic Engineering Centers (HEC) tools by King County and the Army Corps of Engineers (HEC-2 and HEC-RAS in the mid and late 1990's). These were one-dimensional models of river hydraulics aimed at flooding and floodplain management. Much of this information was incorporated into the CE-QUAL-W2 model.

The river was modeled with 217 longitudinal segments (approximately 250 meters long) with a vertical thickness of 1 meter. The model inputs included river bathymetry, flow, temperature and water quality characteristics for boundary conditions and major tributaries, stage data and meteorological conditions. Stream cross-sections were developed based on HEC models provided by King County combined with USGS digital elevation models, and verified using aerial imagery.

The upstream flow boundary to the model was specified by combining the measured flow at USGS Gauge 12106700 and simulated flows from Hydrologic Simulation Program – Fortran (HSPF) models. Measured temperature and water quality data were also specified at the upstream boundaries. The downstream boundary was specified by measured stage, water quality and temperature data. Instream loadings into the river from major tributaries were also characterized by flow from HSPF, temperature and water quality data. Meteorological data included air temperature, dew point temperature, cloud cover and solar irradiance, measured at the Seattle-Tacoma International Airport.

The model was calibrated for flow, water surface elevation, temperature, dissolved oxygen, ammonia nitrogen, nitrate-nitrite, dissolved and particulate organic matter, orthophosphorus, chlorophyll *a*, temperature, pH, alkalinity, conductivity, fecal coliform, inorganic suspended solids, and algae. The model was calibrated separately for two different period of May 1995 - November 1996 and April 2001 - July 2002. These periods were chosen based on the availability of data for upstream boundaries and larger tributaries.

Sources and pathways represented in the model included tributary inputs and instream sources. Groundwater and point sources were not modeled explicitly. Legacy sources of pollutants, if any, were also not modeled in this previous effort.

The simulated flow and water surface elevations compared well with measured data at the USGS station used for comparison for both calibration periods. The simulated water quality at a station located in the Middle Green River compares well with the measured data. However, the water quality fit was not as good for two stations in the Lower Green River. As discussed in the report, this lack of fit suggested a major source of flow input and high concentrations were not accounted for in the model for the Lower Green River. A sensitivity analysis confirmed this hypothesis.

The model has not been validated (i.e., two calibration periods were simulated). Additional flow and stage gauging data are required to ascertain the missing inflows into the model. More data collection especially in the Lower Green River was recommended in the report to improve the model. It was also suggested to move the upstream boundary of the model further upstream toward Howard Hanson Reservoir to provide a more accurate boundary condition as well as to help better characterize the groundwater inflows to the river.

4.3 King County Watershed Modeling (HSPF)

Aqua Terra in conjunction with King County prepared a series of HSPF models for sub-watersheds draining to Greater Lake Washington including Lake Union and the Green/Duwamish River (Aqua Terra and King County, 2003). The report reviewed is entitled, *King County Watershed Modeling Services – Green River Water Quality Assessment* (Green WQA)*, and Sammamish-Washington, Analysis and Modeling Program, Watershed Modeling (SWAMP) Report*. This report was available on the King County website along with individual subwatershed sections for Little Bear Creek (July 2003), Swamp Creek (July 2003), North Creek (July 2003), Black River and Springbrook Creek (July 2003), Newaukum Creek (July 2003), Soos Creek (date unknown; obtained by Tetra Tech separately through its work on the Soos Creek temperature TMDL) were also reviewed in this assessment.

The HSPF models were developed to support the SWAMP, and Green WQA studies. These studies were being performed to provide hydrologic and water quality information for use by King County to evaluate existing conditions and plan for the future. Little Bear Creek, Swamp Creek and North Creek are in the SWAMP and therefore are not directly associated with the LDW. The models for Black River and Springbrook Creek, Newaukum Creek, and Soos Creek drain into the Green River upstream of the LDW.

The watershed models in all of the reviewed documentation were setup and configured similarly. Model segmentation involved delineating watershed area into drainage basins and then into further based on 1) pervious/impervious land units and receiving reaches and 2) physical parameters (e.g., pervious land use composition, pervious geology and soils composition, elevation, slopes, channel length, etc.). GIS datasets for setup and configuration were obtained from King County, USGS and created by Aqua Terra. In addition, a number of historical and ongoing data sets collected by King and Snohomish counties, the University of Washington, federal agencies (e.g., NOAA, National Weather Service [NWS]), and various local jurisdictions were incorporated into the watershed models and used for calibration.

The models were calibrated to examine the following constituents: flow, water temperature, sediment, dissolved oxygen, ammonia as nitrogen, nitrate as nitrogen, orthophosphate, BOD, refractory organic nitrogen, phosphorous and carbon, benthic algae, alkalinity, total inorganic carbon (TIC), pH, E. coli, silica, total dissolved solids (TDS), metals, and organic toxicants (*but with a caveat that TDS, metals, and organic toxicant are not included in the model because of limitations on the total number of constituents in HSPF*). The simulated constituents compare well with the 303(d)-listed constituents for the water column (bacteria, dissolved oxygen, pH, nutrients, and temperature), but compare poorly with the 303(d)-listed constituents in sediments (PCBs, cPAHs, dioxins/furans, metals, and phthalates). This suggests that the sediment-water relationship may not be characterized sufficiently in this modeling system, and could be refined.

The upland sources of modeled constituents were simulated via the PQUAL (Pervious Quality Constituent) and IQUAL (Impervious Quality Constituent) routines of the model. These routines are "general" constituent routines that can simultaneously produce loadings of multiple user-defined constituents based on sediment erosion and water runoff from the land. These loads are then transferred to the stream segments, which are modeled with the RCHRES (ReaCHes/REServoirs) module.

The models were setup to simulate upland loadings in these watersheds. Point sources are briefly mentioned but it appears that they were not explicitly included in the model setup. Additionally, atmospheric deposition has not been included in the SWAMP models but appears to be included in the Green WQA models, though the reasoning is not clear. All relevant pathways and transport mechanisms appear to be included. Additionally, it is unclear if the SNOW module of the HSPF model was included for the hydrology calibration. Lastly, legacy pollutants are not explicitly simulated as contaminant sources.

Initial model parameterization was generally obtained from work performed to generate nonpoint target loading rates. These rates, by land use and constituent were developed by reviewing literature values for the region and a study of the Puget Sound Basin by the USGS.

Generally, the calibration results suggested a good fit for the constituents that had monitoring data. One potential limitation is that calibration of organics was indirectly based on the apparent organic nitrogen and phosphorous values inferred from measured total nitrogen, total phosphorous, and the inorganic nutrient forms (i.e., nitrate, ammonia, and orthophosphate) because no direct monitoring data existed. Additionally, it appears as though all monitoring data were used for calibration therefore the models have not been validated. Each section of the report provides a section pertaining to unresolved calibration issues. Generally, these issues observed by the modeler pertain to the in-stream water quality biochemical transformations and potential of over estimation of nonpoint source load to make up for the load not represented by leaving out NPDES facilities. In addition, groundwater transfers between basins appear to be a significant issue to address in future refinement efforts.

Based on information obtained from King County's website (King County, 2013a), it appears additional work on these models and others, including the System for Urban Stormwater Treatment and Analysis IntegratioN (SUSTAIN) and HSPF models, has been conducted beginning in 2012 and continues in 2014 as part of a stormwater retrofit planning project for the Green River watershed. The primary focus is on flow and TSS. While this work is in progress, the domain of the watershed models cover most of the subwatersheds of the Duwamish and Green rivers with exception of portions of the LDW served by CSOs, and Green River upstream of Howard Hanson Dam. In addition, an HSPF model of the Soos Creek watershed was used by Tetra Tech in development of TMDLs for temperature and dissolved oxygen. Water quality simulations for nutrients, DO, and algae were added to the model. HSPF was also used to provide flow for habitat assessment.

4.4 Food Web Model of the LDW

A FWM was developed in support of the RI to estimate PCB concentrations in tissues and sediment, with a goal of using the model to estimate risk-based threshold concentrations (RBTC) in sediment for the RI (Windward Environmental, 2010). The model may also have utility for assessments of remaining risk associated with contaminated sediment cleanup scenarios. The FWM uses the Arnot and Gobas model (Arnot and Gobas, 2004), a steady-state model originally developed for the Great Lakes region. It estimates PCB concentrations in the tissues of aquatic organisms, including plankton, invertebrates, and fish, with bioaccumulation from three modeled media (sediment, porewater, and the water column).

The domain of the FWM is the LDW from RM 0.0 to 5.25 (Figure 4-1). The model includes six target species based on their importance in the ecosystem or due to human consumption – three fish, two crabs, and one clam. Plankton, benthic macroinvertebrates, and juvenile fish are also included. Input parameters and their probability distributions were based on monitoring data or taken from literature. The updated King County EFDC model was used to develop area-averaged input concentrations of PCBs. A Monte-Carlo analysis was performed using the probability distributions, and the best overall set of parameters was identified for predicting PCB concentrations in tissue. The best-fit parameter set estimated PCB concentrations within a factor of 1.2 on average compared to tissue monitoring. A sensitivity analysis was conducted, which found that the parameters that most affected model sensitivity were derived from literature and had large associated ranges.

The FWM was calibrated for the entire LDW and then tested at smaller spatial scales reflecting uncertainty in the species home ranges. The conclusion of the assessment was that the model may be inappropriate for most species at the scale of the entire LDW. However, it did perform well for clams at locations with sediment total PCB concentrations of ≤3,300 micrograms per kilogram (µg/kg) dry weight (dw). The model was then used to develop RBTC ranges corresponding to seafood ingestion scenarios.

5 Technical Approach

As a result of historical and ongoing discharges and other activities within the watershed, sediments in the LDW are contaminated with a number of pollutants and many waterbodies throughout the watershed are impaired. There are over 250 waterbody segment-pollutant combinations on the 2012 303(d) list in the study area, and the impairments occur in sediment, tissue, and water for over 50 pollutants. The waterbody segments are impacted by loadings of pollutants from various non-point sources and point sources. A watershed model is needed to quantify the loading and runoff from the drainage basin and land-based sources. For tidally impacted areas and large waterbodies, a receiving water model that can simulate complex three dimensional circulation and pollutant fate is needed. In addition to a watershed model and a coupled hydrodynamic and water quality model of the LDW, one or more FWMs are needed to link the contaminant levels in water and sediment to biotic tissues. Simple empirical approaches using data or biota-sediment accumulation factors (BSAF) may not provide sufficient reliability for predicting how contaminants in fish and aquatic life tissue will respond to potential management practices. Therefore, to establish a link from pollutant sources and pathways (both on land and direct discharges to the water column, sediment, and tissue quality, an integrated modeling system that can simulate all the important processes is required.

The development of the integrated modeling system will focus on the representation of sources, fate, transport, and bioaccumulation of these contaminants from the land to the water and sediment, and to tissue. The objective is to develop an integrated modeling system that accurately represents the following key processes: hydrology and source loading processes from the drainage basin; routings of water and pollutants through the stream network; hydrodynamics, thermodynamics, and sediment and contaminant fate and transport in the LDW; and bioaccumulation of contaminants in the LDW ecosystem. In addition to the contamination and impairment in the LDW and Elliott Bay, a number of stream/river segments and lakes in the Green/Duwamish River watershed are on the 303(d) list for a variety of parameters. The modeling system should be designed to simulate these waterbodies as well.

As discussed earlier in this report, the nature and extent of the contamination, aquatic and human health risks,

***__Objective__**: Predict both short- and long-term improvements in water, sediment, and tissue quality as source control and sediment cleanup efforts are implemented, while quantifying loads from various sources throughout the watershed and comparing ambient conditions to numeric targets.*

***__Model Scenarios__**: "A model that's calibrated to existing conditions and is modified to represent new conditions, or a "scenario." These model scenarios can be used to quantify management scenarios (source control, sediment cleanup, etc.). Make adjustments to input data (i.e., initial concentrations, hydraulic changes, reduced watershed loads, removal/modification of point sources, etc.) and run model to observe changes over time and/or through space.*

***__Key Questions and Considerations__**:*

- ***How does the approach consider existing and future cleanup and source control?***

  Proposed approach will be calibrated to existing conditions (i.e., existing at the time of data collection). 'Existing' conditions are changing over time as source control and cleanup activities are carried out. Management activities will be incorporated into the approach using modeling scenarios. For example, to simulate sediment cleanup, the initial concentrations associated with certain model grid cells can be reduced to post-remedy values; simulations will evaluate spatial and temporal changes in conditions throughout the LDW. For source control efforts, watershed load reductions can be applied and similarly evaluated. Various combinations of scenarios can be performed. Nearfield analysis of individual discharges can also be conducted with an added analysis.

- ***How does the approach benefit existing management efforts?***

  The approach can quantify load and concentration reductions associated with management efforts through model scenarios (see above). It can show benefits both near the managed area as well as potential benefits elsewhere in the system. Can also identify geographic areas where management efforts are needed and would have the most impact.

- ***How will the approach be applied over time to meet numeric targets?***

  Model simulations can be performed over many years to show the length of time before numeric targets are met (both with and without specific management scenarios, as described above).

and Superfund remediation strategies have been investigated through the LDW's Superfund RI, risk assessment, and FS efforts. Hydrodynamic, sediment transport, and limited contaminant transport and fate modeling efforts and food web bioaccumulation modeling (of variable complexity) have played a significant role in these studies. The general focus of these modeling efforts was the development of calibrated, predictive forecast models to assess the long-term consequences of remedial action alternatives associated with the sediment, including natural recovery. Some of the studies focused on CSO control. In addition, a number of watershed modeling efforts have been conducted for portions of the Green River watershed. These studies and models provided important insights for pollutant source and concentration relationships in the watershed. However, these models were developed as separate efforts addressing individual issues and covering differing simulation periods. A more integrated and comprehensive PLA strategy is identified and described below.

The recommended approach builds upon previous assessments and modeling by expanding on available modeling data and information to include additional sources, pollutants, or pathways. It also investigates the relative contributions from multiple sources and can connect these to the spatial distribution of contamination over time through the use of modeling scenarios. Modeling scenarios are "copies" of the calibrated, existing model where input data have been modified to represent new conditions. For example, scenarios can represent reduced loading due to source control or remediation activities, hydraulic changes to the system, or tidal and other meteorological changes.

The model and assessment, if developed correctly, will not only be valid for the modeled time period which will cover the past 5 to 10 years, depending on data availability, but also be valid for evaluating future conditions with different meteorological, tidal, and pollutant control conditions. Specifically, the recommended approach focuses on existing conditions and can use modeling scenarios to simulate changes in conditions associated with sediment cleanup, source control actions and regional toxics reduction activities. The main objective of the modeling is to predict both short- and long-term improvements in water, sediment, and tissue quality as source control and sediment cleanup efforts within the basin are implemented through the use of modeling scenarios that change various input parameters (i.e., initial conditions or concentrations, reduced watershed loads, reduction of point sources, etc.). Modeling will also quantify loads from various sources and pathways throughout the watershed and compare the ambient conditions to numeric targets to determine attainment of designated uses or required reductions through time as well as to identify specific geographic areas where management efforts would have the greatest impact.

This section presents the selection and description of a comprehensive framework to address impairments throughout the LDW and the Green/Duwamish River watershed, which can be used as a long-term water quality management tool. This framework utilizes a watershed loading, hydrodynamic, sediment and contaminant transport and fate, and food web bioaccumulation modeling approach. In addition to this framework, which covers the entire watershed, near-field analyses can be developed by building off of the hydrodynamic model to address specific discharge control issues with high spatial resolution. The decision process and support for the recommended framework are also described below.

5.1 Selection Criteria

In selecting an appropriate technical approach for a comprehensive PLA, technical, regulatory, and user criteria were considered. Technical criteria include the physical system in question, including watershed or receiving water characteristics and processes and the constituent(s) of interest (considering the details presented in the CMs [Section 2]). Regulatory criteria include water quality standards or procedural protocols. User criteria are the operational constraints imposed by the end-user and include factors such as hardware/software compatibility and financial resources. The following discussion details the considerations for each of these categories. Based on these considerations, a recommended framework is presented below to represent watershed and receiving water conditions and their subsequent impact on tissue quality.

5.1.1 Technical Criteria

The watershed and receiving waters of the Green/Duwamish and LDW system present a challenging system for representing hydrology and water, sediment, and tissue quality conditions. This section outlines key functions and processes considered in the selection of an appropriate technical approach. These technical criteria are divided into four main topics: physical domain, time periods, source contributions, and constituents.

5.1.1.1 Physical Domain

Representation of the physical domain is perhaps the most important consideration in selection of a technical approach. The physical domain is the focus of the technical effort – typically described by either the receiving water itself or by a combination of the contributing watershed and the receiving water. Selection of the appropriate modeling domain depends on the constituents of interest and the conditions under which the receiving water exhibits impairment. For a receiving water dominated by point source inputs that exhibits impairments under only low-flow conditions, a steady-state approach is typically used. This type of modeling approach focuses on only in-stream (receiving water) processes during a user-specified condition. For receiving waters affected additionally or solely by rainfall-driven flow and pollutant contributions, a dynamic approach is recommended. A dynamic approach will consider all the time-variable external forces and internal processes.

Upper extent of the watershed modeling domain will begin after the Howard Hanson Dam; ambient data will be used to represent flow and loading from the Upper Green River subwatershed.

Water and sediment quality in the LDW and the Green/Duwamish River watershed are affected by point sources and rainfall-driven flow and pollutant contributions that deposit in tributaries and the receiving waters; therefore, a dynamic approach is recommended for the sediment and contaminant fate and transport modeling. For food web/bioaccumulation analysis, tissue responses to contaminant levels in the water column and sediment are slower compared to the responses of contaminant levels in the water column and sediment. Therefore, the food web/bioaccumulation simulation can use the steady-state assumptions for a certain time period. Dynamic models consider time-variable point and nonpoint source contributions from a watershed surface or subsurface, or throughout the water column of a receiving waterbody. Some models consider monthly or seasonal variability, while others enable assessment of conditions immediately before, during, and after individual rainfall events. The set-up and calibration of dynamic models requires a substantial amount of data . In addition, several dynamic modeling studies have already been completed for the LDW and the Green/Duwamish River watershed (Section 4), and provide a strong foundation for future efforts.

Boundary locations are another component of the physical domain. The Green/Duwamish River watershed is divided into four main subwatersheds (Figure 1-4 through Figure 1-6). The Upper Green River subwatershed is upstream of the Howard Hanson Reservoir and is mostly forested. Discharge data from the dam can be used to represent a flow and loading boundary condition from this subwatershed; therefore, the upper extent of the modeling domain is expected to begin immediately after the Howard Hanson Dam (i.e., in the Middle Green River subwatershed; Figure 1-5), unless inclusion of the Upper Green River subwatershed is necessary to characterize specific sources, pathways, or other technical considerations. The contributing watershed area continues downstream through the Lower Green River and Duwamish Estuary subwatersheds (Figure 1-4). Collectively, these subwatersheds contribute loading to the LDW, which is also impacted by conditions in Elliott Bay and Puget Sound through tidal processes. The open water boundary condition is expected to extend into Elliott Bay, and possibly into Puget Sound, to take advantage of available data to represent this boundary. Previous modeling efforts (King County, 1999; Arega and Hayter, 2004; AECOM, 2012b) also extended the modeling domain into Elliott Bay for this reason.

5.1.1.2 Time Periods

It is expected that the watershed model will be setup to simulate 10 to 20 years and the LDW receiving water model will be set up to simulate 5 to 10 years. Available data and information often drive the time periods selected in a technical approach. In addition, computational "cost" should be considered for the receiving water model describing hydrodynamic, sediment, and contaminant fate and transport simulation. The hydrology, source loading, hydrodynamic and sediment and contaminant fate and transport, and food web/bioaccumulation may have differing simulation periods depending on the availability of data and computational cost of different models.

5.1.1.3 Source Contributions

Primary sources of pollution to a waterbody must be considered in the technical approach selection process. Accurately representing contributions from permitted point sources and nonpoint sources is critical for a proper representation of the system and the ultimate evaluation of potential load reduction scenarios. There are many known point sources in the LDW study area, including sources that have been extensively studied as part of the Superfund process. It is important to consider their historic contributions as well as how their loadings have changed upon implementation of source control and cleanup activities.

Limited data are available for many of the sources through both special studies and DMR data (see Appendix A). For the nonpoint sources, a watershed model will be used to generate the loadings of sediment and selected contaminants. Water quality and sediment monitoring data from ambient receiving water samples and discharges were compiled and evaluated for their spatial and temporal resolution (Section 3). Limited data are available to represent the discharge conditions of some point sources in and near the LDW (including the Duwamish Estuary subwatershed), while discharge data are less complete in the Lower and Middle Green River subwatersheds. For many parameters, these data are likely not sufficient to fully characterize all sources of toxics and sediment in the watersheds draining to impaired waterbodies. For the watershed nonpoint source loadings, quantification of the sources will be addressed through the model calibration and simulation.

The watershed model can simulate a comprehensive set of sources including those that can be controlled and those that may not be technically or economically controllable. The watershed model can also extrapolate loadings from a data rich area to less monitored segments of the study area. However, ambient water quality data that represent the overall conditions in rivers or receiving waters are lacking for many of the primary human health pollutants and other chemicals of concern (dioxin/furan, organometals, other SVOCs, pesticides, petroleum, phthalates, and VOCs), but are adequate for conventional parameters. These data are important to support model calibration.

An additional detailed review of the available data will be performed during the next phase of the project where any new data needed for modeling efforts will be identified. Some targeted data collection may be needed to fill certain data gaps. During model development, sensitivity runs can be conducted to evaluate the contributions of different point and non-point sources.

5.1.1.4 Constituents

Identifying the constituent(s) or "state variables" to be assessed is another important consideration during technical approach selection. "State variables" are components of the hydrology or pollutant transport, such as sediment transport simulation. If key state variables are omitted from the simulation, the model might not simulate all necessary aspects of the system and might produce unrealistic results. A delicate balance must be met between minimal constituent simulation and maximum applicability.

The focus of this technical approach is the primary human health risk driver pollutants identified in the Superfund cleanup (arsenic, cPAHs, PCBs, and dioxins/furans) (EPA, 2013) as well as other 303(d)-listed pollutants including other toxic compounds, metals, and various conventional parameters (Section 1.3). Quantification of adsorption/desorption of organic contaminants and metals requires simultaneous representation of sediment transport processes including water column advection, deposition and resuspension. Organic contaminants and metals tend to absorb to fine inorganic sediment and particulate organic material in the water column and sediment bed. Since the sediment bed is a major reservoir of organic contaminants and metals, and can act as both a source and sink with respect to the water column, the sediment bed and contaminant levels in the bed must be simulated. The use of dynamic simulations will consider changes in sediment load over time and additional scenarios can be performed to evaluate changes to both sediment and contaminant loading.

Because of the different behaviors of coarse and fine sediments, and the differences of adsorption and desorption of contaminants to coarse and fine sediment, multiple classes of sediments will be simulated. The adsorption and desorption of PCBs, PAHs, and pesticides are generally related to the organic carbon (OC) that are attached to the sediment particles. The sediment OC can be simulated with modeled OC or observed OC. If data are available, the partition coefficient can be calibrated directly. Otherwise, the adsorption and desorption of OC to inorganic sediment particles will be indirectly calibrated by evaluating the adsorption and desorption of contaminants to sediment particles.

Previous modeling studies have focused on sediment transport simulations (Section 4) and provide a strong foundation for subsequent analyses for individual constituents, including the following:

- Water temperature affects hydrodynamics and governs the reaction rates of contaminants and other conventional water quality constituents.
- Conventional water quality constituents associated with 303(d) impairments may also need to be included in the modeling framework.
- The simulation of food web/bioaccumulation will include constituents associated with tissue impairments and applicable COCs.

5.1.2 Regulatory Criteria

As discussed in Section 6 of this report, numerous targets exist for several different media in the LDW and contributing watershed. Ongoing and future cleanup and source control efforts to address water column, sediment, and tissue contamination can be supported by the technical approach described later in this section. A properly designed and applied technical approach provides a source-response linkage and enables estimation of existing and potential future loadings that will attain designated uses and distribution of loads among sources and pathways. The technical approach must enable direct comparison of model results to in-stream water, sediment, and tissue concentrations. Load reduction scenarios to simulate reductions associated with sediment cleanup, source control and regional toxics reduction efforts can be run, evaluated through time, and compared to the various water and sediment targets by changing input values for different model parameters. Food web bioaccumulation modeling will be performed to evaluate the relationship between water and sediment targets with tissue concentrations in aquatic life. For the watershed and receiving water loading analyses and for future implementation activities, it is also important that the framework enables examination of point-source and land use loadings as well as in-stream concentrations.

> *A properly designed and applied technical approach provides source-response linkage and enables estimation of existing and allowable loadings to attain designated uses and distribution of loads among sources.*
>
> *Load reduction scenarios to simulate cleanup and source control efforts can be run, evaluated over time, and compared to associated targets.*

5.1.3 User Criteria

User criteria are determined by needs, expectations, and resources. Modeling software must be compatible with existing personal-computer-based hardware platforms and be free, public domain programs. In addition, due to potential future use for planning and permitting decisions, software should be well-documented, tested, and accepted. From a resource perspective, the level of effort required to develop, calibrate, and apply the model must be commensurate with available funding, without compromising the ability to meet technical criteria. In addition to these primary criteria, the required time-frame for model development, application, and completion is important.

5.2 Evaluation of Technical Approaches

Establishing the relationship between the numeric targets and source loading is a critical component of a PLA and load reduction analysis (Section 2). It allows for the evaluation of management options that will achieve various load reduction scenarios, including sediment remedial actions and attainment of water quality standards and designated uses. The link can be established through a number of techniques, ranging from qualitative assumptions based on sound scientific principles to sophisticated modeling techniques. Ideally, the linkage will be supported by monitoring data that associate certain waterbody responses to flow and loading conditions. In addition, selection of a recommended technical approach also involves consideration of the technical, regulatory, and user criteria described above (Section 5.1).

To support the objectives for this project (Section 1.1), the development of a comprehensive linked watershed/receiving water/food web bioaccumulation modeling system is needed to represent the LDW and the Green/Duwamish River watershed. Potential modeling systems are described below.

A watershed model is essentially a series of algorithms applied to watershed characteristics and meteorological data to simulate land-based processes over an extended period, including rainfall-runoff, interflow, groundwater flow, flow routing, water temperature, and pollutant loadings. Watershed models often use build-up and wash-off representations of pollutants on the surfaces and can accommodate air deposition of pollutants. Many watershed models are also capable of simulating in-stream processes using land-based contributions as input.

Development of a comprehensive linked watershed/receiving water/food web modeling system is needed to represent the LDW and the Green/Duwamish River watershed.

Receiving water models are composed of a series of algorithms to simulate water circulation, water temperature, sediment transport, fate and transport of contaminants, and kinetics and transport of conventional water quality constituents of the waterbody. External forces are applied including meteorological data, flow and pollutant loadings from point and nonpoint sources, and other boundary conditions. The models are used to represent physical, chemical, and biological aspects of a lake, river, or estuary. These models vary from simple 1-dimensional box models to complex 3-dimensional models capable of simulating water movement, salinity, temperature, sediment transport, pollutant transport, and bio-chemical interactions occurring in the water column.

Watershed models can provide flow and pollutant loading to a receiving water model and can also simulate water quality processes within streams and lakes with relatively simple algorithms. Receiving water models can simulate detailed processes in rivers, lakes, and estuaries. The receiving water model results, including water temperature and contaminant levels in the water column and sediment, can be used as inputs to a food web/bioaccumulation model to estimate contaminant levels in tissue. With a food web/bioaccumulation model integrated with a watershed model and a receiving water model, the sources of contaminants and the fate and transport of these contaminants are completely described and management scenarios can be evaluated. Representation of these three model domains are discussed below.

5.2.1 Watershed Representation

The following characteristics were considered priority needs during the watershed model evaluation process and are linked to the CM described in Section 2. The selected watershed modeling system should ultimately be able to:

- address a variety of pollutants.
- address a watershed with mixed land uses and not oversimplify stormwater flow patterns nor stormwater's regulatory construct.
- accurately represent rainfall events and resulting peak runoff by providing adequate time-step estimation of flow, and by not oversimplify storm events.
- represent reservoir features (e.g., lakes or retention/detention ponds).
- simulate various pollutant transport mechanisms (e.g., groundwater contributions, sheet flow, pollutant build-up and wash-off from the land surface, atmospheric deposition, and point sources).

The primary methods considered to represent the Green/Duwamish River watershed included complex approaches that acknowledge the variety of pollutants and pathways in the system. A data-driven approach was also considered; however, for many parameters, there are some data in the watershed, but all sources or pathways are not represented. A calibrated watershed model can be used to characterize loadings from the Green/Duwamish River watershed beginning at the Howard Hanson Dam, ensuring that all watershed sources are represented, including catchments adjacent to the LDW.

For the watershed component of the modeling, the HSPF and Loading Simulation Program- C++ (LSPC) models were the primary approaches considered given the historical use of this framework by King County (e.g., Aqua Terra and King County, 2003; see summary in Section 4). LSPC is built from the same underlying code and algorithms in HSPF, and HSPF parameters can be readily transferred to an LSPC input format. LSPC offers added flexibility in watershed and pollutant representation: one example is there is no limit to the array size compared to HSPF. Given the large number of pollutants and the complexity of the watershed, HSPF has limitations such that it may be necessary to use multiple HSPF models feeding into the LDW. LSPC also makes it easier to apply multiple precipitation files.

LSPC offers a number of key advantages over other modeling platforms, including:

- LSPC is able to simulate a wide range of pollutants.
- Both rural and urban land uses can be represented.
- Both stream and lake processes can be represented.
- LSPC represents both surface and subsurface impacts to flow and water quality.
- The time-variable nature of the modeling enables a straightforward evaluation of the cause and effect relationship between source contributions and waterbody response, as well as direct comparison to relevant WQC.
- The proposed modeling tools are free and publicly available. This is advantageous for distributing the model to interested parties and government agencies.
- LSPC provides storage of all modeling and point source permit data in a Microsoft Access database and text file formats to allow efficient manipulation of data.
- LSPC presents no inherent limitations regarding the size and number of watersheds and streams that can be modeled.
- LSPC provides post-processing and analytical tools designed specifically to support document development and reporting requirements.
- A comprehensive modeling framework using the proposed LSPC approach facilitates development of loading assessments and other potential future projects to address water quality impairments.

Both LSPC and HSPF require considerable data for configuration and calibration, providing the ability to represent complex pollutant interactions in detail. These models are able to provide a variety of hydrologic and pollutant loading outputs, which facilitate linkages to a receiving water model. To simulate these complex loading processes and to model chemical constituents effectively on a watershed scale, a watershed model must be coupled to an advanced chemical loadings/reactive transport model. The selected model should possess the following capabilities to be a scientifically sound representation of the watershed loading and transport system and to be an advantageous management tool:

- Simulate hydrologic variations due to time variable weather patterns and the related transient saturation or unsaturated condition of the surface/subsurface.
- Simulate time variable chemical loadings from various sources in the watershed.
- Simulate geochemical interactions within a stream channel.
- Provide model results with a broad range of spatial and temporal scales.
- Evaluate source loading abatement scenarios for water quality control/management design with different spatial scales (e.g., lateral sources to LDW and loads from the Green River).
- Evaluate source loading abatement scenarios for water quality control/management design.

To meet these criteria, the LSPC model is proposed (EPA, 2009b). The model is a comprehensive watershed hydrology/loading model and uses a one-dimensional channel (Figure 5-1 shows the hydrologic representation of LSPC model). The model includes hydrological and chemical/sediment loading simulation to predict chemical fate and transport on a basin scale. The model can generate either hourly results or daily average results to predict and compare the modeled outcome with the existing observed data and/or to further utilize the results for advanced management decision support.

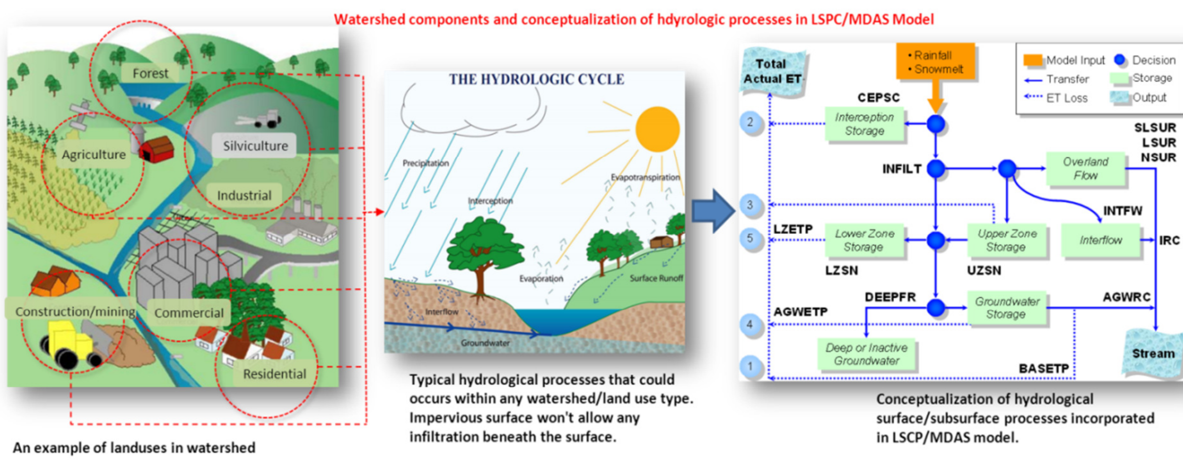

Figure 5-1. Hydrologic component of the LSPC model

5.2.2 Receiving Water Representation

Receiving water models were also considered as a part of the evaluation given the complex flow dynamics in the LDW, coupled with the variable hydrologic inputs from the Green/Duwamish River watershed. Several receiving water studies have been completed in the LDW over the past 15 years (Section 4). As noted earlier, the EFDC-based hydrodynamic, sediment transport, and contaminant transport and fate framework was used throughout these previous efforts, with the exception of the more recent BCM component. The previous efforts provide a strong basis for using an EFDC framework for future studies, especially since it is assumed that these previous models will be made available as a starting point. Therefore, details on the model selection are not discussed in this technical approach;

rather focus is placed on application of this model in the next section. Essentially, use of other receiving water models would be more simplistic and prove inadequate to answer the project questions regarding source loading and required reductions, considering the need for dynamic representation of water-sediment interactions. In addition, the EFDC model has been applied worldwide for both hydrodynamic and water quality applications and can be easily linked to the watershed models that have been evaluated for representation of watershed source loadings.

5.2.3 Food Web/Bioaccumulation Representation

Food web/bioaccumulation models are needed to link contaminant levels in the water column and sediment to contaminant levels in aquatic life. Various food web/bioaccumulation models have been developed by EPA and other agencies including AQUATOX, BASS, Biotic Ligand Model, Ecofate, E-MCM, QEAFDCHN, RAMAS, and TRIM.FaTE. Different models cover different contaminants, and most of the food web/bioaccumulation models simulate the bioaccumulations of PCBs and PAHs. For example, the Arnot and Gobas (2004) FWM has been applied to LDW for bioaccumulations of PCBs and PBDEs. The FWM model assumes that the bioaccumulation processes reach steady-state for a given time period. In addition to organic toxicants, arsenic in tissue is also on the 303(d) list for the LDW. The USGS Biodynamic Model of Bioaccumulation (DYMBAM) can simulate the bioaccumulation of metal contaminants in affected organisms.

For all these food web/bioaccumulation models, environmental conditions including toxicant concentration in various media are needed. In an integrated modeling system, a receiving water model will provide such information. For example, the previous FWM developed for LDW used the model results from EFDC as the inputs.

5.3 Recommended Framework

> *The recommended framework is a comprehensive linked watershed/receiving water/food web modeling system. Including processes essential for modeling hydrology, hydrodynamics, and water, sediment, and tissue quality, utilizing existing information, and building from and incorporating lessons learned in previous studies to address impairments.*

An important distinction between the recommended approach and the previous approaches is the inclusion of contaminant transport and transformations processes directly in the model framework. The previous modeling was focused on the hydrodynamics and sediment transport in the LDW and did not attempt to model and predict water quality. Contaminant concentration estimates were developed by using estimates of the contaminant concentration in the three major sediment sources (upstream, lateral, and bed) and the output of the STM for these three sediment sources in a spreadsheet calculation of the future concentration in what was referred to as the BCM. The BCM assumed that the contaminants were only associated with sediments and that there was no dissolved phase, adsorption/desorption, or degradation. In addition to only considering arsenic, cPAHs, dioxin/furans, and PCBs, there are severe limitations in the BCM approach for predicting the long-term conditions for water and sediments in the LDW as follows:

1. The contaminants calculated were assumed to all be bound to sediment particles.
2. No loss/gain of contaminants via physical, chemical, or biological degradation mechanisms (desorption, adsorption, diffusion, biotransformation, degradation, dechlorination, volatilization).
3. No calculation of dissolved and pore water concentrations (except in the recalibrated EFDC model for PCBs as used in the FWM, and others).

The recommended approach would replace the contaminant calculation preformed for arsenic and PCBs (in the BCM) with a fully process-driven model capable of simulating the important processes regulating the transport and fate of dissolved and particulate contaminants, including arsenic, PCBs, dioxins, other metals and specific cPAHs relevant for the assessment of future conditions and effectiveness of the management strategies implemented in the LDW.

The results of the previous assumptions led to conservative estimates and could lead to higher predicted concentrations for various alternatives presented in the FS. While the assumptions lead to "conservativeness" with respect to ecological or human health risk calculations, it also leads to longer time predictions for attainment of long-term concentration targets.

The recommended framework for this PLA is a comprehensive linked watershed/receiving water/food web modeling system representative of the processes essential for accurately modeling hydrology, hydrodynamics, and water and sediment quality (Figure 5-2).

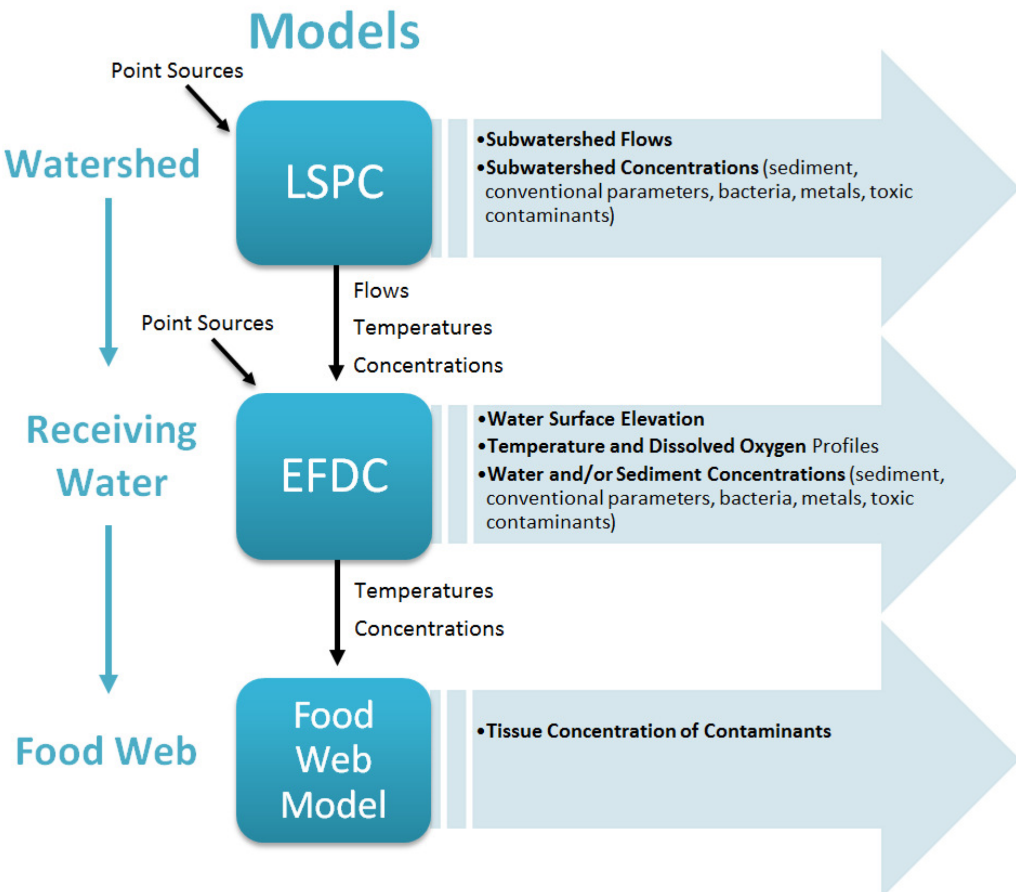

Figure 5-2. Linked watershed-receiving water-bioaccumulation modeling framework

This framework involves the configuration, calibration, and validation of a new modeling system utilizing existing information, and building from and incorporating lessons learned in previous modeling studies to address the 303(d) impairments (Section 1.3).

5.3.1 Background on Selected Models

The first component of the modeling system is a watershed model that predicts runoff and external pollutant loading as a result of rainfall events. The second component is a hydrodynamic and contaminant fate and transport model that simulates complex water circulation and pollutant transport patterns. The third component is a food web/bioaccumulation model to simulate the bioaccumulation of organic toxicants and arsenic. LSPC is proposed as the basis for the watershed model; EFDC is proposed as the basis for the receiving water model; and Arnot and Gobas's FWM is proposed as the basis for the bioaccumulation model. The EFDC model would be linked to and driven in part by the LSPC model of the Green/Duwamish River watershed. These models are components of USEPA's TMDL Modeling Toolbox (Toolbox) (EPA, 2003a). The Toolbox is a collection of models, modeling tools, and databases that have been utilized over the past decade to simulate pollutant loadings to and within impaired waters. LSPC is the primary watershed hydrology and pollutant loading model and EFDC is the receiving water hydrodynamic and water quality model in the Toolbox modeling package. These models, as well as the food web/bioaccumulation model, are generally described below and the subsequent sections provide details of the recommended model application. The modeling effort will build on previous modeling. Long-term simulations, fine-scale model configuration, and more complex contaminant transformations will permit a rigorous evaluation of source control and water and sediment quality improvements on a site-specific basis.

Previous efforts provide a strong basis for using an EFDC framework for the receiving water model of the LDW. Use of other models would be more simplistic and prove inadequate to address source loading and reduction questions. Link to a food web/bioaccumulation model to simulate tissue concentrations.

LSPC model of Green/Duwamish River watershed would provide inputs to EFDC. LSPC provides advantages in model size and complexity and chemical transformations.

5.3.1.1 LSPC Watershed Model

LSPC was selected as the watershed model because it provides added flexibility in addressing the needs of the Green/Duwamish River watershed (e.g., in response to array size limitations associated with HSPF, flexibility with assignment of meteorological stations, and representation of more complex sediment processes within the stream segments). Nonetheless, HSPF has similar modeling capabilities and, assuming the previous HSPF efforts would be available, the HSPF parameters would provide a useful starting point for watershed hydrology calibration and validation. Specifically, the LSPC model would be informed by the previous efforts with additions and enhancements, as needed, to address all contaminants of concern (many of which are not included in the previous work) and accomplish the objectives. Further, representation of sources must be designed to facilitate the pollutant allocation process. For example, runoff and pollutant loading is typically based on natural watershed boundaries, which usually do not coincide with constructed drainage system boundaries. If pollutant allocations are needed based on the boundaries of constructed drainage systems (e.g., municipal separate storm sewer systems), GIS layers for land uses and soils can be overlaid with drainage system maps to form HRUs that consider the actual drainage patterns. HRU is the fundamental unit of the watershed model and is typically developed based on land use and soil properties.

An LSPC watershed model would characterize pollutant loadings and their sources to the Green and Duwamish Rivers, simulate the contaminants of concern, and provide a tool to aid in allocation to sources. LSPC simulates watershed processes, including hydrology and pollutant accumulation and wash-off, and represents flow and water quality in the streams that drain to the LDW including the Green River and major tributaries (Shen et al., 2004; EPA, 2003b). LSPC integrates a GIS, comprehensive data storage and management capabilities, a dynamic watershed model (a recoded version of EPA's HSPF), and a data analysis/post-processing system into a convenient PC-based windows interface that dictates no software requirements (EPA, 2009b).

The LSPC model is capable of predicting water quantity and quality from complex watersheds with variable land covers, elevations, and soils. Because it is largely physically based, the model requires specific input data, such as weather, soils, land cover, and topography. This offers the ability to apply the model in areas where observation data are sparse. The model can simulate sediment, metals, and toxic compounds from specific source areas (e.g., subwatershed or land cover areas). This ability to simulate pollutants from specific source areas is needed in order to determine the river's capacity to absorb pollutants, and to estimate the impact of pollutants reductions. Details regarding the theoretical structure of the LSPC model and its modules can be found in the HSPF User's Manual (Bicknell, et al., 2001). Other important components of the LSPC model are described above in Section 5.2.1, specifically the additional capabilities associated with pollutant transformations and representation achieved through the combined LSPC model.

The MDAS (Mining Data Analysis System) module can also be associated with LSPC. It can provide reactive chemical transport capability in a one-dimensional channel with an equilibrium computational code for ionic speciation of cationic/anionic components and adsorption in aqueous systems. The use of MDAS with LSPC for the watershed modeling is not currently anticipated, but is an option if needed.

5.3.1.2 EFDC Receiving Water Model

Replacement of BCM with the more physically realistic pollutant transport and fate module in EFDC is recommended, allowing direct interaction with hydrodynamic and sediment processes.

Pollutant loads from the mainstem of the Green and Duwamish Rivers and catchments adjacent to the LDW described using the LSPC model would feed an EFDC model of the tidally-influenced LDW. The contaminant fate and transport in non-tidal reaches can be simulated in LSPC. If LSPC's relatively simple representation is not sufficient to describe the fate and transport of certain contaminants in some reaches, the EFDC model domain can be extended to cover these reaches. Direct point sources into the LDW including CSOs would also be incorporated into the EFDC model. The EFDC model would provide a single system for integrated hydrodynamics and sediment and contaminant transport. EFDC has been used for pollutant transport and fate in the LDW (as described above, largely using the BCM) to support CSO management and studies of sediment contamination (Arega and Hayter, 2004; Hayter, 2006; King County, 1999; QEA, 2008; Windward Environmental and QEA, 2008; AECOM, 2012b). The model has a wide range of sediment deposition and erosion processes options and its modular sediment processes library formulation allows for timely incorporation of new options including site specific parameterizations such as the SEDZLJ formulation (Jones and Lick, 2001; James et al., 2005). Replacement of the previous BCM approach with the more physically realistic pollutant transport and fate module in EFDC is recommended, allowing direct interaction with hydrodynamic and sediment processes. The EFDC model accepts an arbitrary number of sediment and adsorptive contaminants allowing source tagging of both solids and PCB and also allow simulation of the transport and fate of a range of geochemical tracers.

EFDC is a general purpose modeling package for simulating one- or multi-dimensional flow, transport, and bio-geochemical processes in surface water systems including rivers, lakes, estuaries, reservoirs, wetlands, and coastal regions. The EFDC model was originally developed by Hamrick (1992) at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software. This model is now EPA-supported and has been used extensively to support receiving water modeling studies throughout the country. In addition to hydrodynamic, salinity, and temperature transport simulation capabilities, EFDC is capable of simulating cohesive and non-cohesive sediment transport, near field and far field discharge dilution from multiple sources, eutrophication processes, the transport and fate of toxic contaminants in the water and sediment phases, and the transport and fate of various life stages of finfish and shellfish. The structure of the EFDC model includes four major modules: (1) a hydrodynamic model, (2) a water quality model, (3) a STM, and (4) a toxics model.

Depending on contaminants selected for the modeling, it may be necessary to include more realistic simulation routines for complex organics, arsenic, and other metals. Some of the transformation processes of contaminants could alter a contaminant transport pathway and fate; for example, arsenic speciation under certain ambient conditions and redox excursions could lead to changes in its solubility, toxicity, and bioavailability, which result in different fate and transport regime. New algorithms may need to be developed to accommodate the transformation processes that are not in the current version of the EFDC model. Adding a metal-speciation based routine to EFDC to permit a more detailed simulation of metal transformations, pore water chemistry, and water column dissolved metal chemistry would depend on PLA needs, but the model run time may be a limiting factor in the application.

5.3.1.3 Arnot and Gobas Food Web Model and DYMBAM

The Arnot and Gobas FWM was selected to model the bioaccumulation of PCBs, PAHs, and pesticide in the LDW. The Arnot and Gobas FWM has been applied to various waterbodies for modeling the bioaccumulations of organic toxicants. Compared to AQUATOX, it can more easily facilitate the needed simulation especially for steady-state simulations. A bioaccumulation model has been developed using the Arnot and Gobas FWM framework for the LDW for PCBs. The knowledge and lessons learned during the previous model development will help improve the FWM under this PLA. The FWM will be updated to include other organic toxicants. Depending on the analysis for the available tissue data, FWM can also be developed to evaluate the time variable change of organic toxicants in tissue if needed. The environmental conditions including water temperature and contaminant levels in water and sediment will be provided by EFDC.

> *Tissue Predictions:*
>
> *FCM can be calibrated through comparisons with available tissue data; model scenarios performed to forecast effects of cleanup and source control.*
>
> *Alternative is to develop BSAF values that consider effect of sediment concentrations on fish tissue.*

The Arnot and Gobas FWM can only handle organic toxicants. However, arsenic is also on the 303(d) list. The USGS DYMBAM model was selected to model the bioaccumulation of arsenic because it includes algorithms for bioaccumulation of metals through the aquatic food web. DYMBAM has been successfully used to model the bioaccumulation of selenium in the San Francisco - Bay Delta area. EFDC will provide environmental conditions to DYMBAM.

5.3.2 Components of the Framework

The recommended framework requires data evaluation, which informs subsequent model configuration, calibration, and validation for the watershed, receiving water, and food web bioaccumulation models. Each of these steps is described in this section.

5.3.2.1 Data Assembly, Evaluation and Analysis

An initial step in modeling analyses is the assembly, evaluation, and analysis of available data. In addition to the recent data collected and available for the FS, it is anticipated that ongoing remediation data will also be available. Data groups that have already been compiled and would be further considered include bathymetry, inflows, Elliott Bay elevations, sediment, pollutant, and tracer loading, and sediment bed physical and chemical properties (Section 3). Data would be organized into both time series and spatial snapshot forms using appropriate database and GIS formats, as well as LSPC and EFDC compatible input file formats. Data would also be subjected to a variety of analyses to gain insight into important process dynamics necessary for selection of appropriate model options and to establish procedures and metrics for model-data comparison. Data gaps will be filled with different approaches such as using average values, linear or non-liner interpolations, to configure boundary conditions for driving the watershed and receiving water models.

5.3.2.2 Watershed Model Configuration and Testing

A LSPC model would be configured for the areas contributing to impaired segments in the LDW and the Green/Duwamish River watershed downstream of the Howard Hanson Dam (Figure 1-1) as a series of hydrologically connected subwatersheds with associated stream reaches. Configuring the model involves subdividing the watersheds into modeling units, followed by continuous simulation of flow and water quality for each of these units using meteorological, land use, soils, stream, and monitoring data. Development and application of a watershed model to address the project objectives involves the following major steps:

- Watershed delineation
- Configuration of key model components
- Hydrology calibration and validation
- Water quality calibration and validation

5.3.2.2.1 Watershed Delineation

Watershed delineation refers to subdividing the entire watershed into smaller, discrete subwatersheds for modeling and analysis. LSPC calculates watershed processes using user-defined, hydrologically connected subwatersheds. To facilitate model calibration, this subdivision is primarily based on stream networks and topographic variability and secondarily on the locations of flow and water quality monitoring stations. Using this method, subwatersheds would be defined for the Green/Duwamish River watershed, including subwatersheds adjacent to the LDW, which could be informed by the existing hydraulic and watershed models (Section 4), assuming those models are available. Other information can also support refining the watershed delineation such as manmade basin boundaries based on infrastructure maps.

5.3.2.2.2 Configuration of Key Model Components

Configuration of the watershed model involves considering the following five major components:

A. Waterbody representation
B. Land use representation
C. Meteorological data
D. Hydrologic representation
E. Pollutant representation (concentration and flow)

These components provide the basis for LSPC's ability to estimate flow and pollutant loadings, and to translate those inputs into in-stream pollutant levels. For example, the conceptual handling of sediment erosion and transport in LSPC illustrates representation of important watershed processes (Figure 5-3). Detailed discussions about developing each component above are provided in the following subsections.

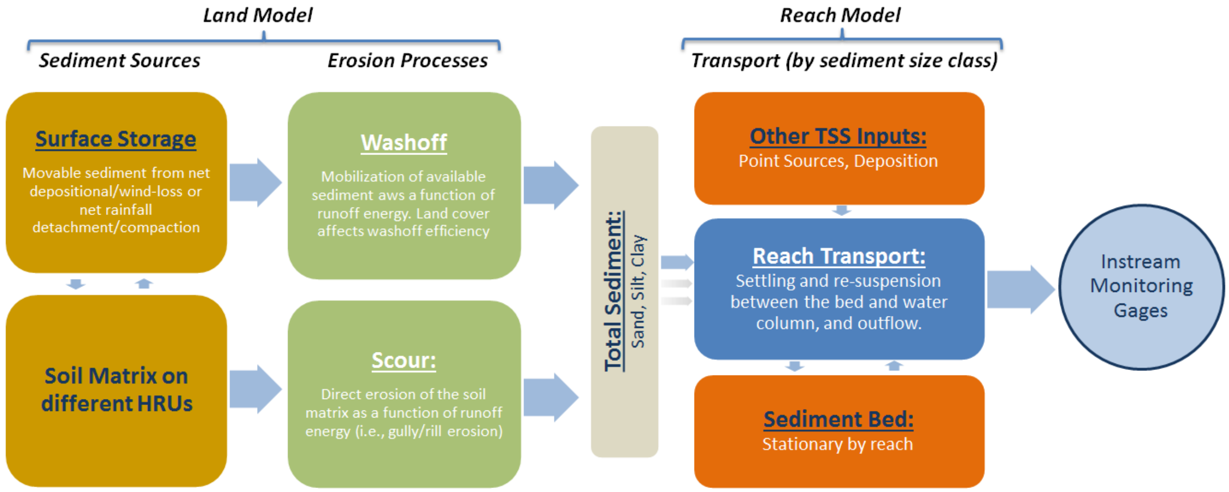

Figure 5-3. Conceptual schematic of LSPC sediment erosion and transport model

A. Waterbody Representation

Waterbody representation refers to the modules, or algorithms, in LSPC used to simulate flow and pollutant transport through streams, rivers, and lakes. Each delineated subwatershed would be represented with a single stream or lake feature. Streams are assumed to be completely mixed, one-dimensional segments with a constant trapezoidal cross section. To route flow and pollutants, LSPC can use automatically generate curves for each stream using Manning's equation and representative physical data. LSPC can also use externally generated rating curves if available. Required stream data include slope, Manning's roughness coefficient, and stream dimensions, including mean depths and channel widths. The NHD stream reach network and a local coverage from King County would be used to determine the representative stream length for each subwatershed. The stream lengths would be used along with the National Elevation Datasets to calculate reach slope. The National Elevation Dataset is a GIS grid coverage of land surface elevation developed by the USGS (see Appendix A for a list of available GIS layers). An estimated Manning's roughness coefficient would be applied to each representative stream reach. Assuming representative trapezoidal geometry for all streams, mean stream depth and channel width would be estimated using regression curves that related upstream drainage area to stream dimensions (Rosgen, 1996). This can be supplemented by HEC-based cross-section information, where available.

B. Land Representation

The LSPC watershed model requires a basis for distributing hydrologic and pollutant loading parameters. Hydrologic variability in a watershed is influenced by land surface and subsurface characteristics. Variability in pollutant loading is highly correlated to land use practices. In addition to land use, infiltration is highly related to soil properties. The combination of land use and soil type generally determines the hydrological characteristics of the land. Drainage patterns can be considered together with land use and soil properties so that loading from these areas can be directly calculated by the model.

To explicitly model the runoff and pollutant loadings in the watershed, the existing Washington State (supplemented by National Land Cover Database [NLCD], where necessary) land use categories would be consolidated to create model land use groupings (Section 3.1.5). The land use coverage provides the basis for estimating and distributing pollutants associated with land-based, precipitation-driven sources. Additional information related to age of development and densities can be incorporated with the land uses. Land uses, soil types, municipal boundaries, and drainage patterns will be combined together to create unique HRUs. LSPC algorithms require that HRUs be divided into separate pervious and impervious land units for modeling. This division would be made for the appropriate land uses (urban) to represent impervious and pervious areas separately, based on typical impervious percentages (Figure 5-4).

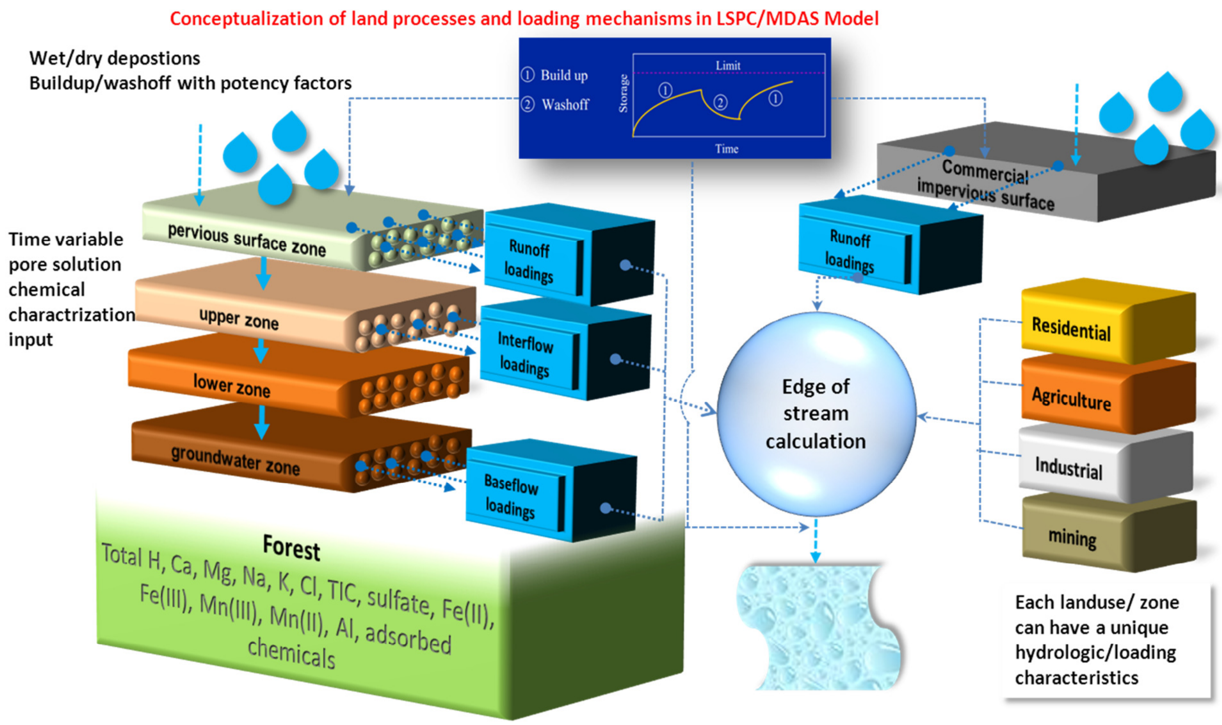

Figure 5-4. Land components of LSPC model

C. Meteorological Representation

Hydrologic processes depend on changes in environmental conditions, particularly weather. As a result, meteorological data are a critical component of the watershed model. These data drive the model and LSPC algorithms that simulate watershed hydrology and water quality; therefore, accurately representing climatic conditions is required to develop a valid modeling system.

The climate data requirements of the model vary depending on whether processes related to snowfall are represented. If snowfall is omitted from the simulation, precipitation (rainfall) and ET are the only data needed. When snow is included, dry bulb air temperature, wind speed and direction, solar radiation, dew point temperature, and cloud cover data are also required. Snowfall may be included in the model setup if it is a significant component of the precipitation totals in the study area downstream of the Howard Hanson Dam. Seasonal snowfall, snow accumulation, and snowmelt affect the timing and magnitude of watershed stream flows.

Precipitation data would be accessed from NCDC and King County to develop a representative data set for the study area covering the modeling period (Section 3.1.7).

D. Hydrologic Representation

Hydrologic representation refers to the LSPC modules or algorithms used to simulate hydrologic processes (e.g., surface runoff, ET, and infiltration). The LSPC PWATER (water budget simulation for pervious land segments) and IWATER (water budget simulation for impervious land segments) modules, which are identical to those in HSPF, will be used to represent hydrology for all pervious and impervious land units (Bicknell et al., 2001).

To account for the potential variability of hydrology characteristics throughout the watershed associated with different soil types or topography, the hydrologic soil groups would be reviewed. The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. The Natural Resources Conservation Service (NRCS) has defined four hydrologic soil groups, providing a means for grouping soils by similar infiltration and runoff characteristics. Typically, clay soils that are poorly drained have the worst infiltration rates (D soils), whereas sandy soils that are well drained have the best infiltration rates (A soils). Data for the watershed can be obtained from Washington State Geospatial Portal and would be supplemented by data from the State Soil Geographic Database (STATSGO) from NRCS, if necessary (Appendix A). The data would be summarized using the major hydrologic group in the surface layers of the map unit.

E. Pollutant Representation

An analysis of the water quality data and a review of previous studies indicate both point and nonpoint sources of pollutants. These would need to be accounted for in a watershed model.

- ***Industrial and Public/Private Permitted Facilities***: For permitted dischargers, flow and water quality limits, or water quality endpoints, will be used to represent flow and pollutant concentrations when point source discharge-related data (i.e., DMRs, other studies) is not available. When available, flow and pollutant concentrations obtained from DMRs and other applicable studies would be used. DMR data are limited.
- ***CSOs/SSOs***: CSO overflows are a source of pollutant loading due to large storm events and subsequent discharge to surface waters. Overflow events would be identified on the basis of monitoring data (pressure transducer, if available), and overflow structure height information. These records would help verify the water level at which an overflow, and subsequent pollutant loading, are occurring. Time series would be developed for discharging CSOs and sanitary sewer overflows (SSOs) according to the available monitoring data (note: these time series would likely be included directly as an input to the EFDC model; however, they are discussed here as a pollutant source that needs to be quantified). Discussions with Ecology note that CSO overflow data is available from King County and Seattle.
- ***Land Pollutant Loading Representation***: Loading processes for pollutants would be represented for each land unit (HRU) using the PQUAL modules (simulation of pollutants for pervious land segments) and IQUAL (simulation of quality constituents for impervious land segments) modules, which are also identical to those in HSPF. These modules allow for the simulation of pollutant loading as sediment-associated, as a buildup-washoff relationship, as an event mean concentration in land segment outflow, or a combination of the three.

  When using the buildup-washoff method, pollutants, including indirect atmospheric deposition, are modeled as accumulating and then washing off based on rainfall. Accumulation rates are assigned to HRUs to simulate buildup of pollutants on the land surface and removal during overland flow, which is simulated as being removed at a rate related to the volume of water flowing over the land surface. Accumulation rates can be estimated on the basis of typical pollutant production rates for sources associated with different HRU types, which can consider the age of development, and range of densities. These values serve as starting points for water quality calibration. The appropriateness of the values to the Green/Duwamish River watershed would be validated through comparison to local water quality data during the calibration process.

5.3.2.2.3 Hydrology Calibration and Validation

After initially configuring the watershed model, model calibration and validation for hydrology would be performed. Calibration is an iterative procedure of parameter evaluation and refinement as a result of comparing simulated and observed values of interest (Figure 5-5). It is required for parameters that cannot be deterministically and uniquely evaluated from topographic, climatic, physical, and chemical characteristics of the watershed and compounds of interest. Calibration would be based on a simulation to evaluate parameters under a variety of climatic conditions. The calibration procedure results in parameter values that produce the best overall agreement between simulated and observed flow (Section 3.1.6) throughout the calibration period. Validation is an independent assessment of the parameter values, using a separate time period at the same location or separate monitoring locations. The model results of the entire simulation period will be evaluated. The results can be presented all together, or can be presented for pre-defined calibration and validation periods. After the model calibration and validation, sensitivity analysis can be conducted to evaluate model response to selected parameters.

> *Model calibration: Iterative process of parameter evaluation and refinement through comparison of simulated and observed values. Develops model parameters that produce best overall agreement between simulated and observed values.*
>
> *Model validation: Independent assessment of the calibrated parameter values.*

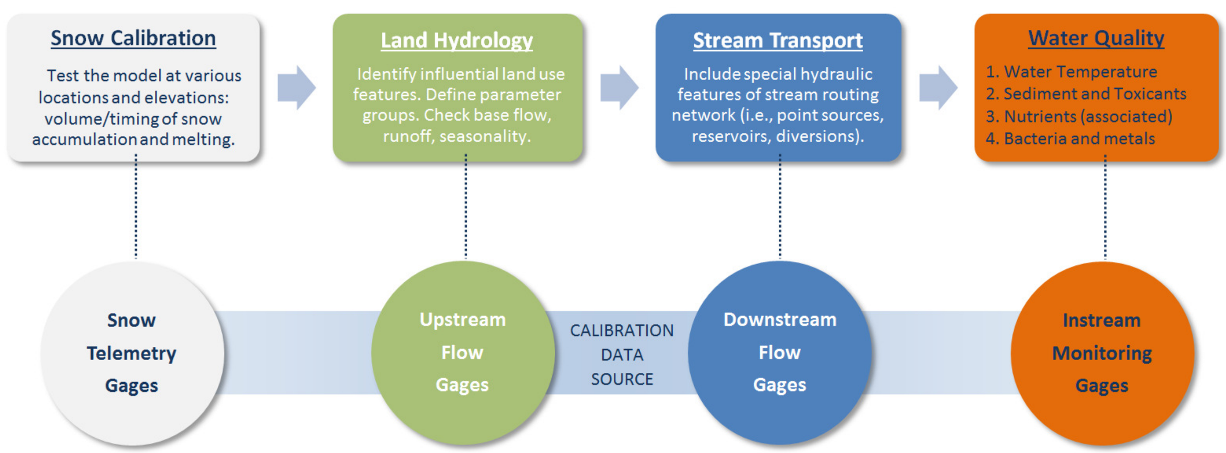

Figure 5-5. Watershed model calibration process

5.3.2.2.4 Water Quality Calibration and Validation

Pollutants loads are delivered to the tributaries with surface runoff, subsurface flows, and direct point source discharges. LSPC provides mechanisms for representing all these various pathways of pollutant delivery. A detailed water quality analysis would be performed with observed flow and in-stream monitoring data (Section 3.1.1). The confidence in the calibration process increases with the quantity and quality of the monitoring data. Section 3 of this document provides information regarding the availability of ambient and discharge-related watershed data (Section 3.1.1) that can be used during the water quality calibration/validation process. As noted above, validation would be performed using data for a separate time period at the same location or at separate monitoring locations. Sensitivity analysis of water quality results can be conducted after the water quality calibration and validation.

5.3.2.3 EFDC Model Configuration and Testing

An EFDC model would be configured for the tidally-influenced LDW, including open water boundary conditions. This effort would take advantage of the existing receiving water models, if they are made available, and incorporate additional source and pathway representation from the LSPC watershed model and pollutant simulations within the receiving water. Development and application of a receiving water model involves the following major steps, which are described below:

- Model Grid and Input File Development
- Model Calibration, Validation, and Sensitivity-Uncertainty Analysis
- Source Tagged Simulations

5.3.2.3.1 Model Grid and Input File Development

A multiple resolution curvilinear-orthogonal model grid system would be established to represent the EFDC modeling domain guided by previous EFDC applications to the LDW. Grid resolution will be driven by the need to run long-term simulations and balance computational costs. Various bathymetric datasets would be interpolated onto the grid defining different initial conditions and comparison points in time (Section 3.1.5). Since the curvilinear grid provides a natural bounded spatial coordinate system, it would also be used for spatial analysis of observational data (Figure 5-6).

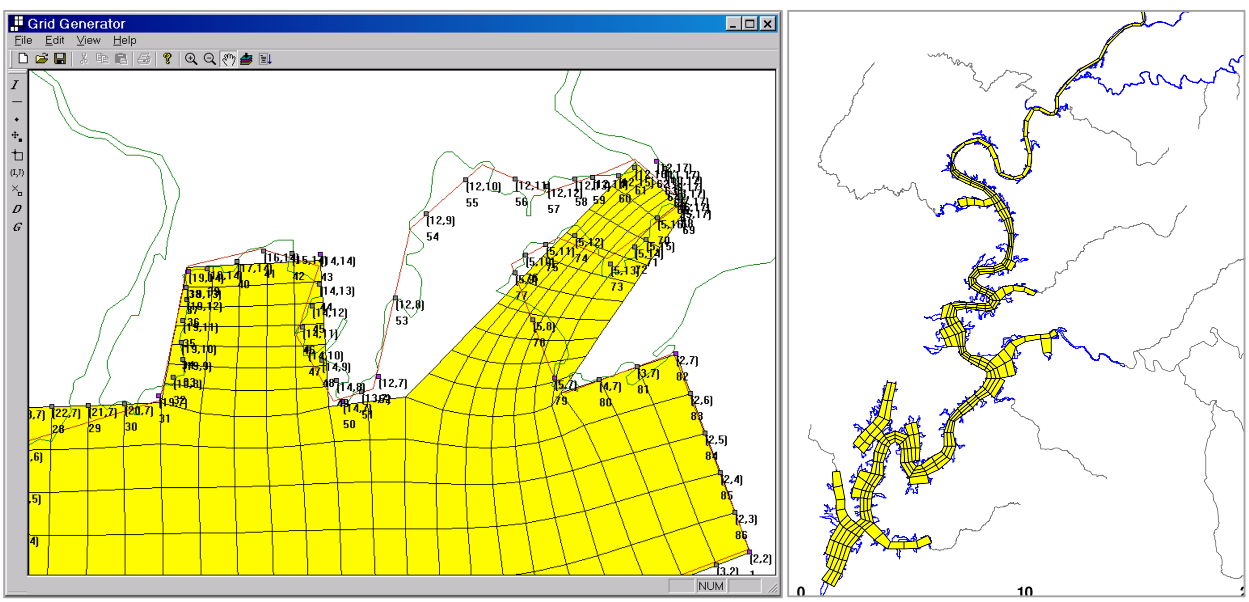

Figure 5-6. EFDC grid generation

Physical and chemical process options in the EFDC model would be selected during the development of model input files. Particular attention would be directed toward solids and pollutant processes, including selection of solids size or settling velocity classes and erosion formulations and pollutant adsorption characteristics, using the results of analyses conducted. Time series files describing boundary conditions and pollutant loading would be finalized into model input files (largely from the LSPC model output, but also including some direct discharges, i.e. CSOs to the LDW). Spatial initial conditions for sediment bed physical and chemical properties would also be finalized, consistent with selected processes options. With all the sources explicitly represented in the model, load reductions scenarios can be simulated using EFDC by directly adjusting the loadings from different sources.

The EFDC code includes internal submodels for simulating the transport and fate of toxic contaminants. The more complex submodel simulates the transport and fate of an arbitrary number of reacting contaminants in the water and sediment phases of both the water column and sediment bed, similar functionally to the WASP5 TOXIC model (Ambrose et al., 1993). The interaction between water and sediment phases may be represented by equilibrium or nonlinear sorption processes, permitting a realistic simulation of transformation processes. The model configuration for both LSPC and EFDC will be thoroughly assessed prior to the initiation of model.

5.3.2.3.2 Model Calibration and Validation

Calibration involves the adjustment of model parameters and forcing functions to achieve a best fit with observed hydrodynamic, sediment, and contaminant observational data (Section 3) under the constraint that the parameters and forcing functions remain within an accepted range. Sensitivity and uncertainty analysis would also be incorporated. The sensitivity analysis can be integrated into a formal model calibration approach using a parameter estimation framework and also used to identify the relative importance of individual model input parameters with respect to uncertainty in model predictions.

Calibration is approached sequentially beginning with hydrodynamics and ending with pollutant transport and fate. Hydrodynamic calibration would be based on comparison of model predicted and observed water surface elevation, current velocity, salinity and water temperature (Section 3.1.8). Adjustable parameters and forcing functions for the hydrodynamic model include water surface elevation and tracer open boundary conditions, bottom roughness, and ungauged fresh water inflow (Figure 5-7). Quantitative measures to be utilized in comparing observations and model predictions include time series and regression error measures.

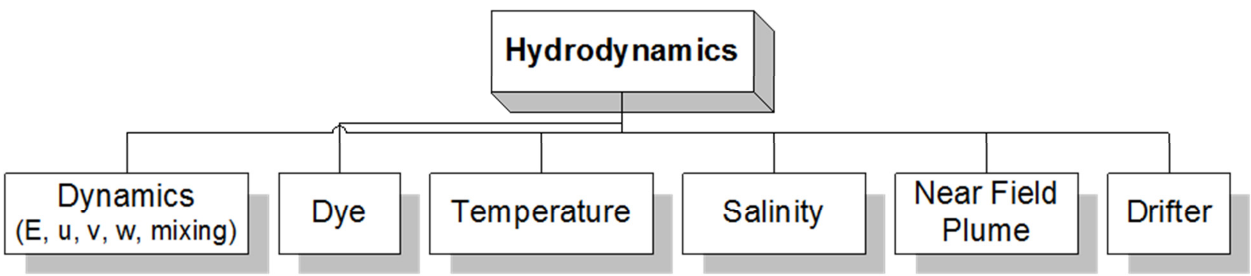

Figure 5-7. EFDC hydrodynamic module components

Sediment transport calibration would be based on a comparison of model-predicted and observed suspended sediment concentrations, bed morphology changes, and net flux at selected locations (Section 3.1.2, 3.1.8, and 3.1.9). Sediment transport calibration parameters include upstream river sediment load as a function of flow rate, open boundary suspended sediment concentration, effective particle diameters for non-cohesive sediment classes, settling velocities for cohesive sediment and organic particles, and erosion parameters, including critical stress and mass erosion rates for cohesive sediment. The analysis of field observed suspended sediment profiles and bed erosion potential test would be used to constraint the range of cohesive sediment settling velocity and parameterize erosion formulation in the model.

Pollutant transport and fate calibration would be based on model predicted and observed total and dissolved phase pollutant concentrations in the water column and sediment bed. Calibration parameters include partition coefficients in relation to solids classes, surface sediment mixing rates, and parameters used in various decay processes. Quantitative measures to be utilized in comparing solids and pollutant observations and model predictions include time series and regression error measures. Preliminary parameter sensitivity information would be accumulated in the calibration process and, if necessary, a least squares error minimization or other procedure utilizing formal sensitive analysis would be implemented for identification of critical, highly sensitive parameters (to be examined further using Monte Carlo analysis or other such approach).

Validation involves the demonstration that the calibrated model can achieve similar levels of predictive ability with respect to a different set of observations. Preferably the validation data set should represent a different set of conditions or if similar under similar conditions, a period of time sufficiently removed from the calibration period. Additional validation period would be included based on availability of data to extend the model configuration and evaluate model performance.

5.3.2.3.3 Sensitivity Analysis

During model calibration and validation, model parameters will be adjusted and model results will be compared against observed data. During this process, the model responses to various parameters are evaluated qualitatively to guide the parameter adjustment. Following model calibration and validation, model results represent average conditions of various processes in the modeling domain. Sensitivity analysis can be conducted to provide a more quantitative evaluation of the model response to certain key parameters. During sensitivity analysis, selected individual parameters are increased and decreased within a certain range while all other parameters remain unchanged. The model results of calibration and validation are the baseline results to compare. Differences between model results of sensitivity runs and baseline are calculated and percentage changes are computed.

5.3.2.3.4 Uncertainty Analysis

The sensitivity analysis provides information on the model response to certain key model parameters. However, it does not provide uncertainty information of predicted constituents. Uncertainty can be introduced to a model from different sources. Models are simplified representations of the real world, and such simplification can introduce uncertainty. Uncertainties are also caused by the lack of data and information (e.g., uncertainties associated with estimated boundary conditions, and by the intrinsic stochastic nature of the physical, chemical, and biological processes such as the partition of toxicants to sediment particles).

Various approaches are available to conduct uncertainty analysis. First order variance analysis (FOVA) is a widely used uncertainty analysis approach to estimate the range of predicted water quality constituents. It can also provide relative contributions of different uncertainty sources. A more advanced uncertainty analysis uses the Monte Carlo method to generate probability distributions of predicted constituents corresponding to probability distributions of the uncertainty sources. The Monte Carlo method usually involves significant amount of model runs to generate robust probability distributions of model results. Various methods are available to reduce the numbers of model runs. However, it remains computationally intensive and costly. Both the FOVA and the Monte Carlo method require the ranges of the uncertainty sources to calculate variances and probability distributions. Usually, the uncertainty analysis will focus on the parameters with high sensitivity selected during the sensitivity analysis. It is proposed to conduct FOVA instead of Monte Carlo simulation for uncertainty analysis due to the challenges in deriving probability distributions. Monte Carlo methods can be an option if sufficient data for certain important parameters are available to compute reliable probability distributions.

5.3.2.3.5 Source Tagged Simulations

Use source tagging to identify relative source contributions responsible for observed pollutant distribution.

The calibrated and validated model would be used to guide a number of hydrodynamic, sediment transport and pollutant transport and fate process studies as determined by the project team. These studies would be designed to investigate the physical and chemical processes responsible for the spatial distribution of pollutant in the LDW resulting from historical discharges from multiple sources. These could include hydrodynamic and sediment transport simulations to assess the importance of three-dimensional circulation on sediment and contaminant transport pathways or studies to assess degradation of cPAHs, PCBs and dioxins/furans under the site-specific conditions of the study area. Based on the aforementioned sensitivity and uncertainty analyses, additional process focused simulations may be conducted to better quantify and reduce uncertainty in model predictions.

The source tagging approach can be applied to the identification of relative source contributions responsible for observed pollutant distributions at a number of historical times of interest. When applying the source tagging approach, new state variables are created for constituents from certain sources. The new state variables will have the exact same rates. For example, to investigate the relative contributions of PCBs from one CSO, a new variable can be added to EFDC to represent only the PCBs from this specific CSO. The sum of the new variable and the rest PCBs should be equal to the total PCBs, and the relative contribution can be calculated. Comparing to sensitivity runs, source tagging allows checking multiple sources with one model run. However, the model run will take much longer time because of the added new state variables.

5.3.2.4 Food Web Model Configuration and Testing

Arnot and Gobas's FWM is selected to conduct the food web bioaccumulation of organic toxicants. The FWM can be configured to run a steady-state simulation with the assumption that the toxicant levels in fish tissue will reach equilibrium status during a certain time period. The FWM can also be configured to run time variable simulation if deemed necessary. It is anticipated that a steady-state simulation will be sufficient. For both the steady-state and time variable simulations, the configurations of FWM include reading in environmental conditions from EFDC such as toxicant concentrations in the water column and sediment and water temperature, and assigning rates and constants related to bioaccumulation. The previous FWM model can provide some useful information for initial rates and constants. These can then be further adjusted after comparing to tissue data.

The FWM has a component to conduct sensitivity analysis and uncertainty analysis. The uncertainty analysis is based on Monte Carlo simulation, which requires pre-defined probability distributions of rates and constants. However, the results from the uncertainty analysis should be interpreted cautiously because of the uncertainties associated with these pre-defined probability distributions.

The FWM only simulates the bioaccumulation of organic toxicants. For arsenic, the DYMBAM model is proposed. Similar to the configuration of the FWM, the environmental conditions for the DYMBAM model will be provided from the EFDC model. The rates and constants related to the arsenic bioaccumulation will be assigned as calibration and validation parameters in DYMBAM. The calibration and validation will be based on the arsenic tissue data.

5.3.2.5 Optional Near Field Modeling of LDW Discharges

There are significant CSOs and other point sources discharging to the LDW. In the receiving water model, the CSOs and other significant point source discharges are represented as direct point sources to the model. For each model cell that receives a point source to be evaluated in detail, it is assumed that the discharge is well mixed with the water immediately after discharging. This assumption introduces model errors for the areas near the outfalls. For areas near the discharge, the concentration gradient is high and spatially averaged concentrations do not represent the concentration decrease from the discharging outfall. Such model errors are usually neglected for large scale modeling studies. The areas near the outfalls need to be evaluated in greater detail for permitting needs, near field modeling is needed.

Near field modeling can be an add-on analysis to the base receiving water model. The LDW is influenced by tide and the velocity field changes all the time. During the high flow events when CSOs and stormwater discharges occur, the river flow also changes with the contributions of runoff and upstream flow. Wet weather discharges are also not continuous and consistent. Therefore, steady state conditions cannot be assumed for the near field. The EFDC model includes an embedded buoyant jet model, JPEFDC, based on JetLag and the UM3 module of Visual Plumes. The embedded model has capabilities well beyond Visual Plumes or Cormix as it continually updates the plume trajectory and dilution as the model runs under evolving tidal and stratification conditions. If a near field simulation is needed for specific outfalls, the EFDC model's JPEFDC can be implemented.

5.3.3 Management Scenarios

The recommended integrated watershed/receiving water/food web modeling approach described above can be applied to quantify source loadings, perform additional source reduction scenarios, and evaluate remedy performance following model calibration and validation. Management scenarios may include running all the models in sequence. The watershed model with any particular management scenario would be run first to provide updated flow and pollutant loading to the receiving water model. Next, the receiving water model would be run, with any additional management actions applied. The output would feed the FWM. Management scenarios can also be conducted with only part of the model system. For example, if an LDW management action is evaluated, only the receiving water and FWMs are employed, using a boundary condition representation from the watershed model. Specific management scenarios to be evaluated will be developed in future phases of the project.

5.3.4 Model Configuration Decision Process

As described above (Section 5.2), other approaches were considered including a data-driven approach or use of different modeling programs; however, given the work already completed in the study area, it was determined that the best technical approach would build upon previous efforts and that any other approaches would be a significant step backwards in detail. This detail will provide additional flexibility in allocating loads among sources and for considering implementation activities. It also adds the flexibility to refine the model in the future if additional data are collected (without having to go back to initial model configuration to incorporate the additional data). One limitation of the recommended approach is the limited available ambient water quality data in the upstream watershed for model calibration and validation. Despite this limitation, use of a watershed model would likely provide a more comprehensive estimate of watershed loads because it considers contributions from all land areas, where exclusive use of a data-driven approach to represent loads would exclude unmonitored areas.

The recommended approach can be scaled to consider available resources. Scaling can be based on the following considerations:

- How many parameters would be modeled directly with LSPC?
- Can event mean concentration (or similar) data be used to represent certain parameters in the watershed model (i.e., combine these constant values with time series flow for loading to the LDW)?
- How many parameters would be modeled directly with EFDC?
- For metals: should arsenic be the sole metalloid, or should other metals be considered, such as mercury, lead, zinc, copper, chromium, or vanadium, due to ecological concerns and to address other 303(d)-listed parameters?
- Will cPAHs, PCBs, and dioxin/furan be represented as individual compounds (or congeners for PCBs or dioxin/furans) or as generic groups?
- How will organic compound degradation best be handled?
- Which contaminants require food web bioaccumulation modeling?

5.3.5 Model Quality Objectives

To help guide the interpretation of the technical information provided by the watershed and receiving water models, several methods can be used to compare observed measurements and model results. These methods include:

- Graphical comparison for visual inspection and
- Statistical methods quantifying the comparison.

Options for evaluating model performance and comparing model predictions to observations that may be used in the analysis are discussed below. Appropriate uses of the model would be determined by the project team after assessing the types of decisions to be made, the model performance, and the available resources.

5.3.5.1 Visual Comparisons of Model Results

Model results would be compared with associated observed measurements using graphical presentations. Such visual comparisons are useful in evaluating model performance over the appropriate temporal range. For example, continuous monitoring data can be compared with continuous modeling results to ensure diurnal variation and minimum/maximum values are well represented.

5.3.5.2 Statistical Tests of Model Results

Model performance can also be evaluated using statistical tests when sufficient data are available. The exact statistical tests would be determined during model calibration and validation or during QA Project Plan development and may include any of the following:

- Mean error statistic
- Absolute mean error
- Root-mean-square error
- Relative error
- Coefficient of determination
- Nash-Sutcliffe coefficient of model fit efficiency if applicable.

Note that various factors can contribute to lack of model fit demonstrated by statistical measures, which is why a combination of statistical and visual tools are used to judge model performance. For example, in hydrology simulation, precipitation and ET are the major driving forces in the model. Yet the spatial variations can be high, especially for precipitation, and may not be fully covered by existing precipitation gauges. Other factors such as unique and spatially variable geology and groundwater flow paths can also contribute to discrepancies between observations and predictions.

Unlike flow, water quality parameters are not always observed continuously. In addition, any uncertainty present in the hydrologic or hydrodynamic calibrations will also propagate into the water quality simulation. For discrete observed samples, calibration must rely on comparison of continuous model output to point-in-time-and-space observations. This creates a situation in which it is not possible to fully separate error in the model from variability inherent in the observations due to limited data points. For example, a model could provide an accurate representation of an event mean or daily average concentration in a reach, but an individual observation at one time and one point in a reach itself could differ significantly from the average. In addition, data from point sources (e.g., DMR data) may be limited in temporal coverage. This imparts uncertainty in the model when this information is used to represent the particular point source.

5.3.6 Data Gaps

For this technical approach a preliminary identification of data gaps has been performed. The data sets will be evaluated in more detail during the next phase of this project to further identify additional data needs for the modeling approach.

Section 3 provided initial assessments of the data. Table 5-1 and Table 5-2 summarize potential data gaps for each parameter and data type. The largest identified data limitation for the technical approach is the availability of ambient water data, especially for many toxic compounds, throughout the study area.

Specifically, these data would help ensure the overall instream water quality for toxic compounds are well characterized by the models. Receiving water stations are needed in the LDW as well as instream stations throughout the Green/Duwamish River watershed.

Some additional observations, focused on some of the primary human health and ecological risk drivers identified in the PP, are as follows:

- Point source data are limited and DMR data for COCs are not available for many of the dischargers reporting to PARIS.
- There are a number of stations with arsenic data in sediment (ambient, discharge, and subsurface) and in tissue. However, less than two samples were taken at each station on average. More detailed analysis is needed to evaluate if sufficient time variable information can be obtained from these data.
- Dioxin/furan data are available primarily for sediment and within the LDW. Similar to arsenic, there are a large number of monitoring stations; however, less than two samples were taken at each station on average. More detailed analysis is needed to determine if time variable information can be obtained from the data. Dioxin/furan data are limited in all water sampling and tissue sampling throughout the LDW and Green/Duwamish River watershed.
- PAH and PCB data are available for ambient sediment and water for the LDW and some portions of the Green/Duwamish River watershed. However, more detailed analysis is needed to evaluate if sufficient time variable information can be obtained from data for these constituents. Alkylated PAHs are only available for ambient sediment and tissue, mostly in the LDW.
- Metals data are generally available for ambient sediment and water sampling. Organometals data are limited to ambient and subsurface sediment, and tissue within the LDW.

Table 5-1. Potential data gap summary matrix for the LDW

Parameter Group	Air	Ambient Surface Sediment	Ambient Surface Water	Point Source Solids/Sediment	Point Source Water	Groundwater	Ambient Subsurface Sediment	Tissue
Alkylated PAHs	•		•	•	•	•	•	
Arsenic								
Bacteria	•	•		•	•	•	•	•
Conventional	•							
Dioxin/Furan			•		•	•		•
Metals								
Organometals	•		•	•	•	•		
Other SVOCs	•							
PAHs								
PBBs	•	•	•	•	•	•	•	•
PBDE	•	•	•	•	•	•	•	•
PCBs								
Pesticides	•							
Petroleum	•		•		•			•
Phthalates	•							
VOCs	•		•					•

Notes: Gray shaded parameter cells represent primary human health risk drivers. A dot indicates less than 25 samples in the LDW representing a potential parameter data gap for this data set.

Table 5-2. Potential data gap summary matrix for the Green/Duwamish River watershed

Parameter Group	Air	Ambient Surface Sediment	Ambient Surface Water	Point Source Solids/Sediment	Point Source Water	Groundwater	Ambient Subsurface Sediment	Tissue
Alkylated PAHs	•	•	•	•	•	•	•	•
Arsenic	•			•	•	•	•	•
Bacteria	•	•		•	•	•	•	•
Conventional				•	•		•	•
Dioxin/Furan	•	•	•	•	•	•	•	•
Metals	•			•	•		•	•
Organometals	•	•	•	•	•	•	•	•
Other SVOCs	•		•	•	•	•	•	•
PAHs	•			•	•		•	•
PBBs	•	•	•	•	•	•	•	•
PBDE	•	•	•	•	•	•	•	•
PCBs				•	•	•	•	•
Pesticides	•		•	•	•	•	•	•
Petroleum	•	•	•	•	•		•	•
Phthalates	•		•	•	•	•	•	•
VOCs	•	•	•	•	•		•	•

Notes: Gray shaded parameter cells represent primary human health risk drivers. A dot indicates less than 25 samples in the LDW representing a potential parameter data gap for this data set.

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6 Numeric Targets for Assessment

EPA states that water quality standards define the goals for a waterbody by designating its uses, setting criteria to measure attainment of those uses, and establishing provisions such as antidegradation policies to protect water quality from pollutants (http://water.epa.gov/scitech/swguidance/standards/).

This section presents potentially relevant numeric assessment targets for water column, sediment, and fish tissue that have been identified based on existing screening tools, guidance and regulatory criteria. Many of the targets are specific to the designated uses (i.e., aquatic life, human health) and thus may have detailed language associated with them to specify what constitutes a harmful exposure, such as duration, frequency or the method used to calculate the target. This information is briefly discussed in this section and full text of the original source of many targets is provided in Appendix B. The targets presented throughout this section are associated with the pollutants in the 303(d) list presented in Section 1.3, regardless of medium, with emphasis placed on the Superfund primary human health pollutants (EPA, 2013).

Waterbody-specific designated uses are defined in WAC 173-201A (Washington State Legislature, 2013). Specifically, designated uses for freshwater rivers and streams are defined in WAC 173-201A-600 and 602 (Table 602) of the water quality standards. Table 602 is a listing of waterbodies and the uses assigned to those waterbodies. Section 600 outlines default uses for those waterbodies not specifically named in Table 602. It is important to note that the LDW from Harbor Island to approximately the turning basin is considered to be marine for both surface water and sediment based on salinity concentrations (see Figure 1-3 for the location of the turning basin). Depending on salinity concentrations upstream of the turning basin, the Duwamish River (downstream of the Black River) would be regulated under either the marine or fresh water criteria. Refer to Section 1.3.

Targets presented are associated with pollutants in the 303(d) list, regardless of medium, with emphasis placed on the Superfund primary human health pollutants.

Designated uses for waterbodies in the study area, identified as WRIA 9 in Table 602, are basin/reach-specific; there are six areas identified for WRIA 9, with 5 unique sets of designated uses. Designated uses for the freshwater portion of the Duwamish River (from the turning basin to the Black River [RM 11.0]; at the upstream edge of the Duwamish Estuary subwatershed [Figure 1-4]) include:

- Aquatic life
  - Rearing/migration only
- Recreation uses
  - Secondary contact
- Water supply uses
  - Industrial water
  - Agricultural water
  - Stock water
- Miscellaneous uses
  - Wildlife habitat
  - Harvesting
  - Commerce/navigation
  - Boating
  - Aesthetics

Designated uses for the marine waterbodies are defined in WAC 173-201A-610 and 612 (Table 612). The LDW (from Harbor Island to approximately the turning basin), which is regulated as a marine water because of the salinity measurements, is identified as area #8 (Elliott Bay east of a north/south line between Pier 91 and Duwamish head) in the map "Water Quality Standards for Marine Water" (Ecology, 2011). The designated uses for the LDW, as designated in Table 612 include:

- Aquatic life uses
    - Excellent: excellent quality salmonid and other fish migration, rearing, and spawning; clam, oyster, and mussel rearing and spawning; crustaceans, and other shellfish (crabs, shrimp, crayfish, scallops, etc.) rearing and spawning
- Shellfish harvest
- Recreational uses
    - Primary contact
- Miscellaneous uses
    - Wildlife habitat
    - Harvesting
    - Commerce/navigation
    - Boating
    - Aesthetics

6.1 Surface Water Quality Targets

Water column targets to protect surface water quality and designated uses have been compiled from the following state and federal sources and are discussed in the following sections:

- Washington State surface water quality standards
- Ecology NTR (40 CFR 131.36) for human health-based surface water quality standards
- EPA National Recommended Water Quality Criteria (NRWQC) for Aquatic Life and Human Health Protection (referred to as Ambient Water Quality Criteria (AWQC) in the Superfund PP)

The criteria from these sources may differ from one another, so it is useful to compare them. Section 6.1.4 presents a summary of surface water quality targets for the primary human health pollutants.

6.1.1 Washington State Surface Water Quality Standards

Washington State's surface water quality standards in WAC 173-201A are the basis for protecting and regulating the quality of surface waters in Washington State (Washington State Legislature, 2013). The standards implement portions of the federal CWA by specifying the designated and potential uses of waterbodies in the state, such as fishing, swimming, and aquatic life habitat. Numeric and narrative WQC are set to protect those uses and acknowledge limitations. Policies are established to protect high quality waters (antidegradation) and in many cases specify how criteria are to be implemented, for example in permits. Surface water quality standards are detailed on the Ecology website (Ecology, 2011).

Ecology provides WQC for conventional constituents (pH, temperature, turbidity, total dissolved gas, and dissolved oxygen), bacteria, nutrients, toxics, and radioactive substances. The toxics criteria for the protection of aquatic life contain criteria for compounds such as metals, pesticides, and other organic compounds found in the environment.

Ecology's toxics substances criteria for the protection of aquatic life (Table 240(3) of WAC 173-201A-240) are included in Appendix B.

Ecology provides criteria for conventional constituents, bacteria and nutrients in order to protect designated uses. Table 6-1 identifies the section of the WAC where freshwater and marine criteria are defined for specific parameters.

Table 6-1. Washington State numeric criteria for surface water

Parameter or Type	Freshwater Criteria	Marine Criteria
Temperature Waters Requiring Supplemental Spawning and Incubation Protection for Salmonid Species (Ecology publication)	WAC-173-201A-200 (1)(c) Table 200 (1)(c)	WAC-173-201A-210 Table 210 (1)(c)
Dissolved Oxygen	WAC-173-201A-200 (1)(d) Table 200 (1)(c)	WAC-173-201A-210 Table 210 (1)(d)
Total Dissolved Gas	WAC-173-201A-200 (1)(f) Table 200 (1)(c)	No Marine Criteria for Total Dissolved Gas
pH	WAC-173-201A-200 (1)(g) Table 200 (1)(c)	WAC-173-201A-210 Table 210 (1)(f)
Turbidity	WAC-173-201A-200 (1)(e) Table 200 (1)(c)	WAC-173-201A-210 Table 210 (1)(e)
Bacteria	WAC-173-201A-200 (2)(b) Table 200 (1)(c)	WAC-173-201A-210 Table 210 (3)(b)
Nutrients	WAC 173-201A-230 (Code Reviser) Table 230 (1)	
Toxics	WAC-173-201A-240 (Code Reviser)	WAC-173-201A-240 (Code Reviser) Table 240(3)
Radioactive Substances	WAC-173-201A-250 (Code Reviser)	
Natural Conditions and Narrative Criteria	WAC-173-201A-260 (Code Reviser)	

6.1.2 National Toxics Rule

Washington State's toxics substances criteria for the protection of human health are federally promulgated in the NTR (40 CFR1.131.36, 2006) and can be found on Ecology's website (); these human health criteria are presented in a table by priority pollutant name in Appendix B. These are regulatory criteria promulgated by EPA in 1992. Ecology has begun the rule-making process to adopt new state-specific human health criteria for toxic substances; information on this effort can be found at http://www.ecy.wa.gov/programs/wq/swqs/hhcpolicyforum.html . The NTR are the targets used in TMDLs (and other water cleanup plans) based on pollutants found in fish and shellfish tissue.

6.1.3 National Recommended Water Quality Criteria

Beginning in the 1970s, EPA published the NRWQC with continuous updates to provide guidance for states and tribes use in adopting their own WQC. These criteria recommendations are published pursuant to Section 304(a) of the CWA. Recommended criteria, published in 2009, are also presented for comparison in this assessment (EPA, 2009a) (Appendix B). The compilation includes a table of criteria for the protection of aquatic life, human health, and organoleptic effects (e.g., taste and odor). Aquatic life criteria include values for freshwater and saltwater systems to protect associated designated uses. Aquatic life criteria are provided for acute and chronic exposures. The criteria maximum concentration (CMC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed briefly without resulting in an unacceptable acute effect. The criterion continuous concentration (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed for a longer time period (generally up to 4 days on average) without resulting in an unacceptable chronic effect.

Human health criteria are based on either:

- Consumption of water (domestic water supply) plus aquatic organisms. Current designated uses in Washington make these criteria applicable to most freshwaters. OR
- Consumption of the aquatic organisms only. Current designated uses in Washington make these criteria applicable to estuarine and marine water and some freshwaters. Note that designated uses for the Duwamish River (from the turning basin RM 11.0) do not include domestic water supply.

The NRWQC also play a role within the CERCLA process. CERCLA [Section 121(d)(2)] generally requires that remedial actions comply with Federal and State environmental laws that are ARARs. Under CERCLA, the remedial action must require a level of control or standard which attains at least the NRWQC values.

EPA is currently in the process of updating the 304(a) human health recommendations. The 2014 Draft Updates to Human Health Criteria are available on the EPA website (EPA, 2014).

6.1.4 Summary of Surface Water Targets for Primary Human Health Pollutants

Table 6-2 and Table 6-3 present summaries of surface water quality targets applicable to freshwater and saltwater, respectively, for the primary human health pollutants identified in the PP (EPA, 2013). Targets associated with other pollutants on the 303(d) list are identified in Table 6-1 and/or presented in Appendix B.

Table 6-2. Summary of surface water quality targets for primary human health pollutants in freshwater where domestic water supply is a designated use

Parameter Group	Constituent	Freshwater with Domestic Water Supply Use					
		WA Aquatic Life Acute[1]	WA Aquatic Life Chronic[1]	NRWQC Aquatic Life Acute[2]	NRWQC Aquatic Life Chronic[2]	NTR Human Health (Water + Organisms)[3]	NRWQC Human Health (Water + Organism)[2]
		µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PCBs	PCB	2	0.014	NT	0.014	0.00017	0.000064
Metals	Dissolved Arsenic	360	190	340	150	NT	NT
Metals	Inorganic Arsenic	NT	NT	NT	NT	NT	0.018
Metals	Total Arsenic	NT	NT	NT	NT	0.018	NT
cPAHs	Benzo[a]anthracene	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Benzo[a]pyrene	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Benzo[b]fluoranthenes	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Benzo[k]fluoranthenes	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Benzofluoranthenes, Total (b+k+j)	NT	NT	NT	NT	NT	NT
cPAHs	Chrysene	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Dibenzo[a,h]anthracene	NT	NT	NT	NT	0.0028	0.0038
cPAHs	Indeno(1,2,3-cd)pyrene	NT	NT	NT	NT	0.0028	0.0038
Other SVOCs	Dibenzofuran	NT	NT	NT	NT	NT	NT

NT = No target available.
[1] See WAC 173-204 Table 240(3) for notes on duration of exposure.
[2] See EPA 2009 NRWQC for exceedance considerations and basis for standards.
[3] 40 CFR 131.36; See Ecology's Toxics Standards and Criteria web Page: (http://www.ecy.wa.gov/programs/wq/swqs/toxics.html).

Table 6-3. Summary of surface water quality targets for primary human health pollutants in saltwater

Parameter Group	Constituent	Saltwater					
		WA Aquatic Life Acute[1]	WA Aquatic Life Chronic[1]	NRWQC Aquatic Life Acute[2]	NRWQC Aquatic Life Chronic[2]	NTR Human Health (Organisms Only)[3]	NRWQC Human Health (Organism Only)[2]
		µg/L	µg/L	µg/L	µg/L	µg/L	µg/L
PCBs	PCB	10	0.03	NT	0.03	0.00017	0.000064
Metals	Dissolved Arsenic	69	36	69	36	NT	NT
Metals	Inorganic Arsenic	NT	NT	NT	NT	NT	0.14
Metals	Total Arsenic	NT	NT	NT	NT	0.14	NT
cPAHs	Benzo[a]anthracene	NT	NT	NT	NT	0.031	0.018
cPAHs	Benzo[a]pyrene	NT	NT	NT	NT	0.031	0.018
cPAHs	Benzo[b]fluoranthenes	NT	NT	NT	NT	0.031	0.018
cPAHs	Benzo[k]fluoranthenes	NT	NT	NT	NT	0.031	0.018
cPAHs	Benzofluoranthenes, Total (b+k+j)	NT	NT	NT	NT	NT	NT
cPAHs	Chrysene	NT	NT	NT	NT	0.031	0.018
cPAHs	Dibenzo[a,h]anthracene	NT	NT	NT	NT	0.031	0.018
cPAHs	Indeno(1,2,3-cd)pyrene	NT	NT	NT	NT	0.031	0.018
Other SVOCs	Dibenzofuran	NT	NT	NT	NT	NT	NT

NT = No target available.
[1] See WAC 173-204 Table 240(3) for notes on duration of exposure.
[2] See EPA 2009 NRWQC for exceedance considerations and basis for standards.
[3] 40 CFR 131.36; See Ecology's Toxics Standards and Criteria web Page: (http://www.ecy.wa.gov/programs/wq/swqs/toxics.html).

6.2 Sediment Targets

Sediment targets have been compiled from the following state and local sources and are discussed throughout this section:

- Ecology Marine Sediment Quality Standards (SQS)
- Ecology Marine Benthic Sediment Cleanup Screening Levels (CSLs)
- LDW Superfund PP PRGs

Section 6.2.5 presents a summary of surface sediment targets associated with the primary human health pollutants identified in the PP (EPA, 2013), while Appendix B presents targets for other parameters including those on the 2012 303(d) list (Section 1.3).

6.2.1 Washington State Marine Sediment Quality Standards

Washington State SQS found in Part III of the SMS are approved by EPA as water quality standards. A revision to Part V of the SMS became effective September 1, 2013; no substantive changes to Part III were made. The LDW is subject to the marine SQS, as salinity measurements indicate that the LDW is marine from Harbor Island to the turning basin. Marine SQS are defined in WAC 173-204-320, and include criteria which are used to identify sediments that have no adverse effects on biological resources, and correspond to no significant health risk to humans. Marine sediment criteria are available for 303(d)-listed parameters and include:

- ***Chemical concentration criteria***: The chemical concentrations establish the marine SQS chemical criteria for designation of sediments. These criteria are provided in Appendix B.
- ***Biological effects criteria***: For designation of sediments pursuant to WAC 173-204-310(2), sediments are determined to have adverse effects on biological resources when any one of the confirmatory marine sediment biological tests of WAC 173-204-315(1) demonstrate the following results:
    - Amphipod: The test sediment has a higher (statistically significant, t test, p≤0.05) mean mortality than the reference sediment and the test sediment mean mortality exceeds twenty-five percent, on an absolute basis.
    - Larval: The test sediment has a mean survivorship of normal larvae that is less (statistically significant, t test, p≤0.05) than the mean normal survivorship in the reference sediment and the test sediment mean normal survivorship is less than eighty-five percent of the mean normal survivorship in the reference sediment (i.e., the test sediment has a mean combined abnormality and mortality that is greater than fifteen percent relative to time-final in the reference sediment).
    - Benthic abundance: The test sediment has less than fifty percent of the reference sediment mean abundance of any one of the following major taxa: Class Crustacea, Phylum Mollusca or Class Polychaeta, and the test sediment abundance is statistically different (t test, p≤0.05) from the reference sediment abundance.
    - Juvenile polychaete: The test sediment has a mean individual growth rate of less than seventy percent of the reference sediment mean individual growth rate and the test sediment mean individual growth rate is statistically different (t test, p≤0.05) from the reference sediment mean individual growth rate.
    - Microtox: The mean light output of the highest concentration of the test sediment is less than eighty percent of the mean light output of the reference sediment, and the two means are statistically different from each other (t test, p≤0.05).
- ***Marine sediment human health criteria***: There are currently no specific numeric marine sediment human health criteria, however WAC 173-204-320(1)(a) states that the SMS established in Table 1 of the standard shall not result in adverse effects, including no significant health risk to humans. Human health sediment cleanup standards are to be established during the cleanup process.
- ***Marine sediment other toxic, radioactive, biological, or deleterious substances criteria***: Other toxic, radioactive, biological or deleterious substances in, or on, sediments shall be at or below levels which cause no adverse effects in marine biological resources, and below levels which correspond to a significant health risk to humans, as determined by the department. The department shall determine on a case-by-case basis the criteria, methods, and procedures necessary to meet the intent of this chapter pursuant to WAC 173-204-310(3).
- ***Nonanthropogenically affected sediment quality criteria***: Whenever the nonanthropogenically affected sediment quality is of a lower quality (i.e., higher chemical concentrations, higher levels of adverse biological response, or posing a greater health threat to humans) than the applicable SQS assigned for said sediments by this chapter, the existing sediment chemical and biological quality shall be identified on an area-wide basis as determined by the department, and used in place of the SQS of WAC 173-204-320.

It is important to note that the marine SQS values in Part III of the SMS are the same as benthic SCO numbers in Part V of the SMS. However, each part of the SMS rule uses these values differently. For the purpose of explaining the range of potential targets in this technical approach document, references to the marine SQS values are to Part III.

6.2.2 Washington State Freshwater Sediment Quality Standards

Washington adopted new chemical and biological criteria for freshwater sediments which became effective September 1, 2013. The narrative freshwater SQS (WAC 173-204-340) are approved by EPA as water quality standards. These narrative criteria were not revised. EPA has neither approved nor disapproved the numeric freshwater sediment criteria in Part V as water quality standards.

Sediment cleanup levels based on protection of the benthic community in freshwater sediment are presented in WAC 173-204-563. The process used to determine sediment cleanup standards for a site are presented in WAC 173-204-560. The freshwater benthic sediment cleanup levels are one factor used in determining the sediment cleanup objectives (SCOs) and cleanup screening levels (CSLs) for a contaminant for the site. Although the freshwater criteria do not apply to the LDW, the criteria are relevant further upstream, and should be considered in the long term planning for the watershed. Freshwater sediment criteria include:

- ***Freshwater sediment – chemical criteria:*** The chemical concentration criteria establish the benthic sediment cleanup objectives and benthic cleanup screening levels chemical criteria for freshwater sediment. These criteria are presented in Appendix B.

- ***Freshwater sediment – biological criteria:*** The biological effects criteria establish the benthic sediment cleanup objectives and benthic cleanup screening levels biological criteria for freshwater sediment. The criteria apply to freshwater sediments for toxicity to the benthic invertebrate community.

- ***Freshwater sediment other toxic, radioactive, biological, or deleterious substances criteria***: "Other toxic, radioactive, biological or deleterious substances" means substances not addressed under "chemical criteria" that are in, or on, sediments and cause minor adverse effects to biological resources. The department shall determine on a case-by-case basis other criteria, methods, and procedures necessary to meet biological criteria.

6.2.3 Washington State Marine Sediment Impact Zone Maximum Level and Sediment Cleanup Screening Level

In addition to the "no effects" level chemical concentration criteria defined in WAC 172-204-320, which are used as sediment quality goals for Washington State sediments, there are other numeric chemical criteria used in Puget Sound marine sediment cleanup projects and permits based on minor adverse effects to benthic organisms.

The Sediment Impact Zone (SIZ) Maximum Level, WAC 173-204-420, establishes minor adverse effects as the maximum level allowed within authorized SIZs due to an existing or proposed discharge.

The CSL means the maximum allowed concentration of any contaminant and level of biological effects permissible at the site or sediment cleanup unit per procedures in WAC 173-204-560(4) after completion of the cleanup action. Cleanup screening levels are also used to identify and assess the hazard of sites under WAC 173-204-510 and 173-204-520. The published benthic CSLs (and benthic SCOs) would be one factor used in determining the SCO and CSL for contaminants at any specific sediment cleanup site (WAC 173-204-560).

These chemical criteria for marine sediments are provided in Appendix B. To understand the context in which the criteria are used, see the SMS regulation (WAC 173-204).

6.2.4 Superfund PRGs

The LDW is a Superfund Site regulated under the CERCLA. A RI (Windward Environmental, 2010) and FS (AECOM, 2012a) were conducted on the LDW. The RI report provides information on the extent of contamination and the risks to humans and the environment, and includes an ERA as Appendix A to the RI (Windward Environmental, 2007a) and a baseline HHRA as Appendix B to the RI (Windward Environmental, 2007b). The FS used the results of the RI and the baseline risk assessments to identify RAOs, develop PRGs and cleanup objectives, and develop and evaluate LDW-wide remedial alternatives. The FS lays the groundwork for selecting a cleanup alternative that best manages risks to both human health and the environment. The Superfund PP discusses the cleanup alternatives considered and presents EPA's preferred alternative to address risks.

The PP presents PRGs, which are contaminant concentrations to measure the success of cleanup alternatives in meeting the RAOs (EPA, 2013). The PRGs represent concentrations that are believed to provide adequate protection of human health and the environment. PRGs are not final CERCLA/MTCA cleanup levels and the PRGs will be refined in the final ROD into contaminant-specific cleanup levels. The PRGs are listed in Section 7 of the PP (EPA, 2013) and specific tables are included in Appendix B. For the PRGs that protect ecological conditions, the values are consistent with the 1991 version of the SMS. As noted earlier, the SMS rule was updated and became effective September 1, 2013. The PP was published prior to the effective date of the 2013 SMS rule, and therefore the PP's PRGs were based on the 1991 version of the SMS rule.

6.2.5 Summary of Sediment Targets for Primary Human Health Pollutants

Table 6-4 presents a summary of the range of surface sediment criteria for the primary human health pollutants identified in the PP (EPA, 2013). These include the SQS, the benthic cleanup screening levels (benthic CSLs) for marine and low salinity sediment, and the LDW Superfund PRGs. Targets associated with other pollutants on the 303(d) list are presented in Appendix B, including Ecology Sediment Standards that Apply to Puget Sound Marine Sediments (B.5) and PP PRGs for Sediment and Fish Tissue (B.6). With the exception of arsenic, it is difficult to compare the sets of criteria. Ecology provides criteria that are total organic carbon (TOC) normalized, which is to say that the target is quantified by multiplying the concentration by the decimal fraction of the percent TOC content of the sediment. The PRGs are provided in toxic equivalent (TEQ) units which are a common unit used to indicate the risk associated with the contaminant. The TEQ is calculated by multiplying the concentration by the toxic equivalency factor (TEF) to provide a relative measure of toxicity.

Additional data analyses are possible to make these targets more comparable. Specifically, average TOC values for specific segments can be determined and applied to the applicable sediment criteria to develop site-specific sediment targets and TEFs can be removed from the PRG values, resulting in dw sediment concentration values. However, conversion analyses and their subsequent application should be considered to ensure the results will truly be comparable and their results are still accurate representations of the target(s).

Table 6-4. Summary of sediment targets for primary human health pollutants

Parameter Group	Constituent	Marine Sediment: WA SQS[1]	Marine Sediment: WA Benthic CSL[2]	All Sediment: CERCLA PRG for Seafood Consumption (top 10 cm)[3]	All Sediment: CERCLA PRG for Human Contact (top 10 cm)[3]	All Sediment: CERCLA PRG for Ecological (top 10 cm)[3]	All Sediment: Basis of PRG
		ppm dw					
Metals	Arsenic	57	93	NT	7	57	background
		µg/kg OC		µg/kg			
PCBs	Total PCBs	12,000	650,00	2	1,300	128-159	Background (RAO 1) RBTC (RAO 2) RBTC (RAO 4)
		µg/kg OC			µg/ TEQ/kg dw	mg /kg OC	
cPAHs	Benzo[a]anthracene	110,000	270,000	NT	380 (LDL wide) 150 (clamming areas) 90 (individual beaches)	110,000	RBTC (RAO 2) SQS (RAO 3)
cPAHs	Benzo[a]pyrene	99,000	210,000	NT		99,000	RBTC (RAO 2) SQS (RAO 3)
cPAHs	Benzo[b]fluoranthenes	NT	NT	NT		NT	RBTC
cPAHs	Benzo[k]fluoranthenes	NT	NT	NT		NT	RBTC
cPAHs	Benzofluoranthenes, Total (b+k+j)	230,000	450,000	NT		230,000	RBTC (RAO 2) SQS (RAO 3)
cPAHs	Chrysene	110,000	460,000	NT		110,000	RBTC (RAO 2) SQS (RAO 3)
cPAHs	Dibenzo[a,h]anthracene	12,000	33,000	NT		12,000	RBTC (RAO 2) SQS (RAO 3)
cPAHs	Indeno(1,2,3-cd)pyrene	34,000	88,000	NT		34,000	RBTC (RAO 2) SQS (RAO 3)
		ng/kg OC		ng TEQ/kg dw			
Dioxins/ Furans	Total Dioxins/Furans TEQ	NT	NT	2	37	NT	Background (RAO 1) RBTC (RAO 2)

Notes: SCO = Sediment Cleanup Objectives, CSL = Cleanup Screening Levels, ppm = parts per million, µg/kg = micrograms per kilogram, ng/kg = nanograms per kilogram, OC = organic carbon

Ecology standards and the CERCLA ecological PRGs need to be met as point values, whereas the human health-based PRGs need to be met as a 95% upper confidence limit on the mean.

[1] See WAC 173-204-320 (Marine SQS) and WAC 173-204-562 (Sediment Cleanup Levels) for notes on exceedance considerations and basis for criteria. With the exception of arsenic, the listed chemical parameter criteria represent concentrations "normalized," or expressed, on a TOC basis. To normalize to TOC, the dwconcentration for each parameter is divided by the decimal fraction representing the percent TOC content of the sediment. The benthic SCO is one factor used in determining sediment cleanup standards for a site. WAC 173-204-560(3).

[2] See WAC 173-204-420 (SIZ Maximum Criteria) and WAC 173-204-562 (Sediment Cleanup Levels) for notes on exceedance considerations and basis for criteria. With the exception of arsenic, these criteria are also normalized on a TOC basis. The benthic CSL is one factor used in determining sediment cleanup standards for a site. WAC 173-204-560(4).

[3] See the PP LDW Superfund Site, February 28, 2013 (EPA, 2013); for the ecological sediment PRGs are based on benthic invertebrates; except for Total PCBs which is based on the river otter risk.

6.3 Fish Tissue Targets

Fish tissue targets have been compiled from the following sources:

- Ecology Marine Fish Tissue Equivalent Screening Levels
- Superfund PP Fish Tissue PRGs

For comparison, Section 6.3.3 presents a summary of the tissue quality targets for the Superfund primary human health pollutants.

6.3.1 Ecology Fish Tissue Equivalent

Ecology Water Quality Program Policy 1-11 describes the use of fish tissue equivalent concentrations as a listing trigger for the 303(d) list (Section 1.3). Ecology calculated tissue equivalent values of the federal NTR water criteria (40 CFR1.131.36, 2006) (http://www.ecy.wa.gov/programs/wq/swqs/NTRbyPriorityPollutantName.pdf). These tissue equivalent concentrations were developed by multiplying the NTR criteria by a bioconcentration factor. The bioconcentration factors were taken from an EPA Region 3 document entitled "Origin of Human Health Criteria." The calculated tissue equivalent values are not regulatory targets, but are discussed here due to their use as a screening tool for 303(d)-listing purposes. The tissue equivalents are presented in the same table as the NTR criteria by priority pollutant name in Appendix B.

6.3.2 Superfund Proposed Plan Fish Tissue PRGs

Table 6-5 lists the LDW resident fish and shellfish tissue PRGs from EPA's PP (EPA, 2013). The PP identifies that these values are uncertain because of a limited background data set and states that additional background data will be collected during the remedial design phase (EPA, 2013). As additional data are generated, the fish tissue PRGs may be adjusted and documented in a ROD Amendment.

Table 6-5. EPA proposed plan fish tissue PRGs

Species/Group and Tissue Type	Species[1]	PRG	Source of PRG[2]
PCBs (µg/kg ww)			
Benthic fish, fillet	English sole	12	background
Pelagic fish, whole body	Perch	1.8	RBTC
Crab, edible meat	Dungeness crab	1.1	background
Crab, whole body	Dungeness crab	9.1	background
Clams	Eastern soft shell clam	0.42	background
Inorganic arsenic (mg/kg ww)			
Clams	Eastern soft shell clam	0.09	background
cPAH TEQ (µg/kg ww)			
Clams	Eastern soft shell clam	0.24	RBTC
Dioxin/furan TEQ (ng/kg ww)			
Benthic fish, whole body	English sole	0.35	background
Crab, edible meat	Dungeness crab	0.53	background
Crab, whole body	Dungeness crab	2.0	background

Species/Group and Tissue Type	Species[1]	PRG	Source of PRG[2]
Clams	Eastern soft shell clam	0.71	background

Notes: RBTC = risk based threshold concentration, ww = wet weight
[1] Substitutions of similar species may be made if sufficient numbers of the species listed here are not available.
[2] Background – see Table 5 in Section 3.6.2 of the PP (EPA, 2013).

6.3.3 Summary of Fish Tissue Targets for Priority Pollutants

Table 6-6 presents a summary of the two identified sources of fish tissue targets for the primary human health pollutants. The calculated fish tissue equivalent screening values are provided for both freshwater and saltwater fish, and values for many pollutants are presented in Appendix B. The Superfund PP values are presented for multiple groups or species (Table 6-5); however, the table below just presents PRG concentrations for the eastern soft shell clam, which are associated with the lowest PRG concentrations.

Table 6-6. Summary of fish tissue targets for primary human health pollutants

Parameter Group	Constituent	Freshwater	Saltwater	Based on Species/Group[2]
		Ecology Fish Tissue Equivalent[1]	Ecology Fish Tissue Equivalent[1]	CERCLA PRG for Resident Fish and Shellfish
		µg/kg	µg/kg	µg/kg
PCBs	PCB	5.304	5.304	0.42[3]
Metals	Total Inorganic Arsenic	0.792	6.16	0.09
cPAHs	Benzo[a]anthracene	0.084	0.93	0.24[4]
cPAHs	Benzo[a]pyrene	0.084	0.93	
cPAHs	Benzo[b]fluoranthenes	0.084	0.93	
cPAHs	Benzo[k]fluoranthenes	0.084	0.93	
cPAHs	Benzofluoranthenes, Total (b+k+j)	NT	NT	
cPAHs	Chrysene	0.084	0.93	
cPAHs	Dibenzo[a,h]anthracene	0.084	0.93	
cPAHs	Indeno(1,2,3-cd)pyrene	0.084	0.93	

NT = No target available.
[1] Screening values used in Washington's 303(d) listing process.
[2] See Table 6-5 above or the PP for species-specific PRGs.
[3] Only for eastern softshell clams
[4] Based on total cPAH TEQ

6.4 Application and Selection of Targets

The targets presented in this Section are intended to represent potential goals and/or milestones to be used in a comprehensive strategy for evaluating designated use attainment, remedial action effectiveness, and the effects of source control and toxics reduction measures within the Green/Duwamish River watershed and the LDW. Ultimately, the selected targets in a PLA will, when fully implemented, result in attainment of designated uses as measured by waterbody compliance with numeric regulatory criteria. In addition, interim targets may be chosen in order to show progress towards attainment and to prioritize management of the most significant sources. The proposed technical approach's comprehensive loading analysis will help characterize sources and pathways, and provide a tool by which management actions for such sources and pathways can be evaluated for the likelihood of meeting numeric regulatory targets (and thus, attain designated uses).

6.4.1 Target Application and Selection

Selection of appropriate targets throughout the watershed and across the various media will be complex and will require thoughtful analysis and documentation of the decisions made (see below for some recent examples from other toxics studies). The final targets will likely be based on the application of multiple targets. EPA Region derived targets from sediment, water column and fish tissue during the development of toxics TMDLs for Dominquez Channel and Greater Los Angeles and Long Beach Harbor waters which is presented as a case study in Section 6.4.2 (EPA Region 9, 2011). Other factors that influence target selection include whether or not the pollutants are bioaccumulative, applicable averaging periods, and conditions where the target(s) apply (e.g., marine vs. freshwater, sediment depth).

6.4.2 Numeric Target Decision-Making Case Studies

Target selection to address toxics impairments may take additional factors into consideration. This is especially true when considering toxic compounds that are bioaccumulative. This section provides examples and a discussion of TMDL numeric target selection in watersheds where more than one numeric target were applicable both within and outside Washington State. This discussion may assist in the selection of numeric targets within the LDW.

In the toxics TMDLs for Dominguez Channel and Greater Los Angeles and Long Beach Harbor waters, EPA Region 9 and the Los Angeles Water Board considered multiple targets during TMDL development. The TMDL was divided into pollutants with direct effects and those with bioaccumulative effects (i.e., bioaccumulate in tissue). Model simulations evaluated attainment of water and sediment targets in the impaired waters. In addition BSAFs were determined for the various bioaccumulative compounds. The BSAFs determine the desired sediment concentration, using the associated food web, to attain the desired fish tissue level needed to protect wildlife or human health consumption. The direct effects portions of the TMDLs were based on the published sediment quality targets. The more protective value between BSAF or sediment quality targets was used for determining TMDLs for bioaccumulative compounds.

Compliance with the TMDL is based on achieving the load and waste load allocations (WLAs) and/or demonstrating attainment of the sediment quality objectives as multiple lines of evidence. Compliance with the TMDLs for bioaccumulative compounds is based on achieving the assigned loads and WLAs or, alternatively, by meeting fish tissue targets. Compliance will require various clean up actions, including the elimination of toxic pollutants being loaded to and cleanup of contaminated sediments lying at the bottom of the impaired waters. Dischargers and responsible parties may implement structural and or non-structural BMPs and work collaboratively to achieve the numeric targets and allocations. Also, the WLAs and LAs may not be attainable without reducing loadings from storm water discharges, nearshore and on water discharges, and river influences, and removal of contaminated sediment areas (EPA Region 9, 2011).

In the Palouse River Chlorinated Pesticide and PCB TMDL, the numeric targets for the TMDL were based on fish tissue targets rather than on the Ecology WQC because the fish tissue targets are more directly related to the human health concerns. The fish tissue targets were derived from EPA bioconcentration factors and the water column criteria established for fish consumption under the NTR. The TMDL describes that, in essence, the fish tissue targets are the NTR WQC expressed in tissue form (Ecology, 2007).

The Santa Monica Bay TMDL for DDT and PCBs addresses the impairments to human health associated with the consumption of tissue and protection of aquatic life associated with DDT and PCBs in Santa Monica Bay (EPA Region 9, 2012). Santa Monica Bay also includes an area that has been listed on the Superfund National Priority List. The numeric targets established in the TMDL in water, sediment, and fish tissue are based on state standards and established Superfund RAOs. The TMDL established different targets for the area outside of the Palos Verdes Shelf Superfund Restoration effort and kept the Superfund RAOs in place for the applicable areas. TMDL targets not within the Superfund action, in all cases, are more conservative than the Superfund RAOs. The TMDL targets are based on EPA recommended values using a excess cancer risk of 1 in 100,000, while the Superfund RAO targets are based on an excess cancer risk of 1 in 10,000. Superfund used a regression model developed by the USEPA Superfund Division to relate the concentrations of p,p-DDE and PCBs in sediment to the concentrations of p,p-DDE and PCBs in fish tissue. However, given the uncertainty associated with the bioaccumulation model, the Superfund targets are interim targets. Under the selected remedy additional studies will be conducted to allow the bioaccumulation model to be refined to predict more accurately the contaminant levels in sediment correlated to contaminant levels in fish. These studies will contribute to the development of the final remediation plan and re-evaluation of the TMDL targets.

While numeric targets were set in the Santa Monica Bay TMDL for water, sediment, and fish tissue, the loading capacity assessment and corresponding load allocations were based on sediment and water targets. The critical condition was based on fish consumption and was established based on a critical consumption rate and time period of consumption. WLAs for publicly owned treatment works (POTWs) and permitted industrial facilities were concentration-based and set equal to the applicable water quality objectives. On the other hand, WLAs for stormwater were based on sediment and were set equal to the existing sediment toxic loads to prevent further degradation (the existing loads were lower than the loads calculated from the existing sediment loads and the sediment targets). EPA Region 9 Water Division acknowledges that monitoring and Superfund studies will provide new information which may result in new PCB and DDT sediment and fish consumption targets and which could trigger the need to revise this TMDL.

6.4.3 Numeric Endpoint Target for Modeling Recommendations

Based on the evaluation of possible targets and the complicated nature of the LDW and the Green/Duwamish River watershed, it is recommended that a multiple endpoint target approach be considered. The multiple numeric targets would include values for water, fish tissue and sediment concentrations, based on EPA and State water quality and cleanup criteria. This approach can be implemented through a series of scenarios using the proposed coupled watershed/receiving water model, with each scenario evaluating the actions needed to meet different targets. For example, one scenario could establish the reduction needed from the Superfund site and other sources in order to meet the Ecology marine water quality targets and corresponding sediment targets (based on protection of the benthic community). If, under this scenario, the marine water quality targets are not met, then further scenarios could be configured to determine the site-specific surface water and sediment reductions needed to meet targets, or to identify the need for additional management strategies. Modeling scenarios could also be utilized to evaluate the reductions needed to meet freshwater system targets (including Ecology freshwater surface WQC and freshwater sediment – chemical criteria) at some point or points upstream of the LDW. Upon completion of the desired watershed/receiving water model runs, results for various scenarios can then be used to evaluate fish tissue targets using the FWM.

7 Conclusions and Recommendations

This report presents a technical approach for development of a comprehensive PLA tool to quantify all potential sources, minimize recontamination of post-cleanup sediments, and address 303(d) listings in the Green/Duwamish River watershed and the LDW. Conceptual models (CM)s were first developed to guide the overall approach using a scientifically-sound process. These CMs consider applicable sources, pathways, pollutant characteristics and potential transformations. To further inform the technical approach, available data and information were compiled and evaluated for use in the PLA tool. This evaluation process considered the spatial and temporal resolution of the available data and identified potential data gaps. Previous modeling studies were evaluated and collectively considered in the design of the recommended technical approach.

The proposed PLA tool is comprehensive in design in order to effectively address impairments found in numerous mediums. Conclusions made during the technical approach development process are presented below. Development and implementation of this tool is the ultimate recommendation; however, several interim and specific activities are also recommended (see *Recommendations and Next Steps* below).

Conclusions:

- ***Study Area***: To quantify all potential sources, minimize recontamination of post-cleanup sediments, and address impairments, a watershed-based approach is recommended. The two-part study area consists of the Green/Duwamish River watershed and the LDW (receiving water). Pollutant loading to the East and West Waterways will also be included because of the tidal influence of these loads on the study area. Details on cleanup efforts in and around the East and West Waterways and Elliott Bay will not, however, be included. The model domain will begin downstream of the Howard Hanson Dam (dam discharge data will be used to represent the upper boundary).
- ***Pollutants***: The technical approach is designed to address all 303(d)-listed impairments; however, the following contaminants are presented as examples throughout the report: the primary human health risk drivers associated with the LDW Superfund in-waterway cleanup (arsenic, dioxins/furans, cPAHs, and PCBs) and general conventional pollutants.
- ***Conceptual Model***: A properly designed and applied technical approach provides source-response linkage and enables the estimation of existing and allowable loadings to attain designated uses, and the distribution of those loads among sources and pathways.
- ***Technical Approach***: Development of a comprehensive linked watershed/receiving water modeling/food web system was deemed necessary to represent the LDW and the Green/Duwamish River watershed. Previous efforts provide a strong basis for using an EFDC hydrodynamic and water quality framework for the receiving water model of the LDW. Use of other simpler models would be inadequate to address source loading and reduction scenarios. Two bioaccumulation models will be used to simulate tissue concentrations from bioaccumulation of human health risk driver pollutants up the aquatic food chain including the Arnot and Gobas's FWM for PCBs, cPAHs, and dioxin/furans, and DYMBAM for arsenic. An LSPC model of the Green/Duwamish River watershed would provide inputs to the EFDC receiving water model. LSPC provides advantages in model efficiencies and complexity over other commonly used watershed models.
- ***Link to Source Control and Sediment Cleanup***: The proposed approach will be calibrated to existing conditions (i.e., existing at the time of data collection). 'Existing' conditions change over time as source control and cleanup activities are carried out. However, management activities will be incorporated into the approach using modeling scenarios that account for different input

conditions. Various combinations of scenarios can be performed to investigate the impacts of ongoing and planned activities. The benefit of remediation activities can be quantified over time through various scenarios and the results can inform future source control and other management efforts and characterize changes over time.

- ***Data Availability***: Most data types have good spatial and temporal coverage, with the exception of certain ambient water quality data including toxics and point source water quality data.

Recommendations and Next Steps:

- ***Additional Data Collection or Compilation***: Certain ambient water quality data may be insufficient to adequately calibrate and validate the models described in the technical approach. This data gap should be addressed prior to full implementation of the technical approach. More detailed evaluation should be conducted in the next tasks of the project.
- ***Hydrology and Hydrodynamic Simulations***: Given the hydrologic and hydrodynamic complexity of the system, initial modeling efforts can commence during the period of additional data collection or compilation. A first step in the approach is to calibrate and validate watershed hydrology, including groundwater inputs and lateral flows, such as point source discharges. Subsequent to this effort, hydrodynamic calibration and validation of the LDW can be performed, allowing for sufficient time to collect ambient water quality data for the pollutants of interest if necessary.
- ***Pollutant Simulations***: Water and sediment quality modeling must be performed after hydrology and hydrodynamic calibration are complete (note: this process can be conducted for the watershed simultaneous to receiving water hydrodynamic calibration). This step is also influenced by the availability of additional ambient water quality data. While pollutant model configuration can be performed without additional data, final calibration will be dependent on these data if collected. It is also recommended that the BCM tool used in conjunction with previous models be replaced with the more physically realistic pollutant transport and fate module in EFDC, allowing direct interaction with hydrodynamic and sediment processes.
- ***Target Selection***: It is recommended that a multiple endpoint target approach be considered. This approach can be implemented through a series of modeling scenarios using the proposed coupled watershed/receiving water/FWMs. Scenarios to be evaluated should be developed in the next phase(s) of the project.
- ***Fish Tissue Estimation***: The concentrations of contaminants in fish tissue will be modeled using the proposed FWMs. Modeled concentrations will be compared against monitoring data. Based on the data summary, fish tissue data are limited. Therefore, BSAF values will also be calculated to compare with the FWM estimated concentrations.
- ***Adaptive Management***: Periodic monitoring of conditions within the watershed and LDW in the future should be used to refine the comprehensive modeling tool and assess progress in meeting applicable regulatory targets.

The most time sensitive next step is to address the data gap associated with ambient water quality data (for most pollutants other than conventional parameters) because several subsequent steps rely on these data. The next phase of the project will identify exactly what data may need to be collected to address current modeling limitations. It is possible that additional data are available, but have not yet been obtained. Additional monitoring and/or data compilation from other sources could serve to fill this gap. Overall, these specific recommendations should streamline implementation of the technical approach, help achieve the objectives, and provide a general foundation to develop a step-by-step work plan for subsequent phases of the PLA.

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