King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay

Volume 1: Overview and Interpretation

Prepared by the

Duwamish River and Elliott Bay

Water Quality Assessment Team

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LIST OF ACRONYMS

AET	Apparent effects threshold
AQUIRE	Aquatic Toxicity Information Retrieval Database
ATSDR	Agency for Toxic Substances and Disease Registry
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
COPC	Constituents of potential concern
CSO	Combined sewer overflow
DO	Dissolved oxygen
DNR	Department of Natural Resources
EFDC	Environmental Fluids Dynamic Computer Code
ER-L	Effects range-low
ER-M	Effects range-median
FDA	Food and Drug Administration
HQ	Hazard quotient
LOEC	Lowest observed effect concentration
N/AP	Not applicable
N/AV	Not available
ND	Not detected
NMFS	National Marine Fisheries Service
NOEC	No observed effect concentration
NRC	National Research Council
PAHs	Polycyclic aromatic hydrocarbons
PCBs	Polychlorinated biphenyls
SDN	Specific degenerative/necrotic
SCUBA	Self-contained underwater breathing apparatus
TBT	Tributyltin
TRV	Toxicity reference value
TSS	Total suspended solids
U.S. EPA	United States Environmental Protection Agency
WAC	Washington Administrative Code
WERF	Water Environment Research Foundation
WQA	Water Quality Assessment
WSDOE	Washington State Department of Ecology

ACKNOWLEDGMENTS

The Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay is the product of people who believe that science combined with an understanding of stakeholder values can inform policy decisions regarding protection of our environmental resources. As project leader, I would like to extend congratulations to the team of biologists, chemists, field samplers, toxicologists, modelers, planners, public involvement experts, and risk assessors who proved over and over again that any problem can be solved when the goal is clear. The team (Table A-1) included all the needed expertise and respect and collaboration were the operating norms.

Table A-1. Duwamish River and Elliott Bay Water Quality Assessment Project Team

Name	Role
City of Seattle	
Cheryl Paston*	Liaison with the City of Seattle CSO Control Program
Dolphin Technical Communications	
Cynthia Krepky	Technical editor
King County Department of Natural Resources	
Ben Budka	Sediment sampling task leader
Betsy Cooper*	Liaison with the KC Green Duwamish Watershed Team
Colin Elliott	Project QA/QC coordinator
Bob Kruger	Conventionals lab project lead
Cathy Laetz	Model post-processing
Kevin Li	Biological sampling lead
Wayne Liu/Colleen Rasmussen	GIS technicians
Diane McElhany	Organics lab project lead
Scott Mickelson*	Laboratory project manager for all sampling associated with the WQA, lab liaison
Sydney Munger*	Project manager, team leader
Marc Patten	CSO/storm sampling task leader
Jean Power	Hydrodynamics data collection task leader
John Rowan	Metals lab project lead
Kevin Schock*	Hydrodynamic and fate and transport lead modeler

Table A-1. Duwamish River and Elliott Bay Water Quality Assessment Project Team (continued)

Name	Role
Randy Shuman*	Monitoring program design and oversight, data analysis, interface between monitoring results and modeling needs
Jim Simmonds*	Human health risk assessment lead
John Strand*	Biological survey and interface with lab and consultants, ecological risk assessment lead
Bob Swarner*	Wastewater system lead flow modeler, modeling unit supervisor
Debbie Turner	Microbiology lab project lead
Laura Wharton*	CSO program manager
Kathryn White*	Stakeholder involvement lead
Dean Wilson*	Editor and report production lead
Pacific Rim Resources, Inc.	
Rita Brogan	Stakeholder involvement assistance and stakeholder report lead
Scarlet Tang	Stakeholder involvement assistance
Parametrix, Inc.	
Kevin Brix	Bioassay lead
David DeForest	Ecological risk assessor, aquatic toxicologist
Michael Kluck	Chemist
Debra MacLellan	Wildlife toxicologist
Steve McKay	Database manager
Sue Robinson	Senior human health risk assessor
Rick Rosario	Risk assessment modeler
Paul Seidel	Human health risk assessor
John Toll*	Consulting team project manager
Charles Wisdom*	Risk assessment lead
Striplin Environmental Associates, Inc.	
Pete Striplin	Benthic community analysis lead
TetraTech, Inc.	
John Hamrick	EFDC model developer
University of South Florida	
Joan Rose	Pathogen risk assessment advisor

Table A-1. Duwamish River and Elliott Bay Water Quality Assessment Project Team (continued)

Name	Role
Washington State Department of Ecology	
Laura Fricke	Liaison with the Department of Ecology
WEST Consultants, Inc.	
Ray Walton	Interface between modeling and risk assessment teams, model post-processing program developer

The entire project team sends kudos to the **King County Environmental Laboratory**. This project asked for extraordinary effort and the people working in the labs and on the boats responded by collecting a record number of storm weather samples, developing new sampling and analytical techniques, analyzing thousands of samples, and doing it with a smile!

The key component of this project that enhances its value for decision-making is the involvement of the **Stakeholder Committee** throughout the project. These 28 individuals (Table A-2) have spent countless volunteer hours in workshops, learning and providing substantive information to improve the overall quality of this report. In the end, the committee provided comment to King County decision-makers regarding their recommendations on the future of the combined sewer overflow (CSO) control program and future efforts to improve the quality of the Duwamish Estuary. These recommendations can be found in the stakeholders' report to King County, Volume 3 of the water quality assessment (WQA) document. The project team is grateful for the energy, knowledge, patience and persistence of each of these members.

Table A-2. CSO Water Quality Assessment Stakeholder Committee[a]

Name	Affiliation
Ms. Tamara Allen/Mr. David Bortz	Environmental Specialist, Washington State Dept. of Natural Resources/Aquatic Resources
Mr. Elliott Berkihiser	Environmental Program Administration, Boeing
Mr. Gerald Brown	Manager, Ash Grove Cement
Mr. Patrick Cagney	Biologist, U.S. Army Corps of Engineers
Dr. Patricia Cirone	Program Manager, Risk Evaluation Unit, U.S. EPA Region 10/Risk Evaluation
Ms. B.J. Cummings	Puget Soundkeeper, Puget Soundkeeper Alliance
Mr. Charles Cunniff	Director, Environmental Coalition of South Seattle

Table A-2. CSO Water Quality Assessment Stakeholder Committee (continued)

Name	Affiliation
Mr. Allan Davis	Duwamish Valley Neighborhood Preservation Coalition
Ms. Lorna Dove	Georgetown Crime Prevention & Community Council
Mr. Bruce Harpham	Rainier Audubon Society
Mr. Patrick Hawkins	Member, Regional Water Quality Committee
Mr. Doug Hotchkiss	Port of Seattle
Mr. Larry Kirchner	Principal Environmental Health Specialist, King County Dept. of Health
Ms. Kathy Minsch	Environmental Specialist, Puget Sound Water Quality Action Team
Mr. David Moore	Sierra Club
Dr. Mark Myers	Supervisory Research Fisheries Biologist, National Oceanic Atmospheric Administration, NW Fisheries Science Center
Mr. Tim O'Brian	Georgetown Crime Prevention & Community Council
Ms. Sandra O'Neil	Fish Biologist, Washington State Department of Fish and Wildlife
Mr. Bill Robinson	Trout Unlimited
Mr. Glen St. Amant	Muckleshoot Tribe
Ms. Lynn Schroder	Government Affairs Specialist, NW Marine Trade Association
Dr. Ruth Sechena	Director of Environmental Risk Information Service, University of Washington
Mr. Gary Shirley	Chair, Metropolitan Wastewater Pollution Abatement Advisory Committee
Ms. Chantal Stevens	Muckleshoot Tribe
Mr. Greg Wingard	Executive Director and President, Waste Action Project

[a] During the CSO WQA, several stakeholders that were a part of the original committee were unable participate to the end of the process. Some of these members were replaced by other representatives from their respective organizations. Those that were unable to send replacements include Mr. Walter Brown of the Sea Crest Boathouse, Mr. Stephen Wilson of Crowley Marine Services, Mr. Joe Smith, and Mr. John Macpherson of Foss Environmental & Infrastructure.

Collaboration with the **Washington State Department of Fish and Wildlife** to collect seafood samples allowed us to significantly increase the information available to assess risks to people who eat fish and other seafood from the study area. This help was greatly appreciated.

The modeling complexities of this project required significant computer power. We received a donation of time on the Boeing Cray computer, which allowed us to finish this project in time to be useful to our decision-makers. We want to thank the **Boeing Company** and their modeling experts who provided outstanding assistance.

A project of this complexity that employs methods which are not considered standard requires expert review and evaluation. We were fortunate to have a panel of national experts in the fields of risk assessment, toxicology, CSO management, and modeling to provide this expert comment. These experts were invited by the **Water Environment Research Foundation (WERF)**, an independent organization located in Alexandria, Virginia, to join this panel. We are grateful to WERF for coordinating this peer review and to the panel members who volunteered considerable review and meeting time to this project.

We also want to acknowledge the trust and support of the **King County decision-makers**, in agreeing to undertake this innovative project. This approach to gathering information with which to make policy decisions requires managers who believe in the value of science, the importance of stakeholder opinion and the ability of their staff to pull it all together. The WQA project team is grateful to have had this opportunity. We hope that the “customers” of this project find the outcomes to be useful.

Sydney Munger, Project Manager
King County Department of Natural Resources

1. INTRODUCTION

In a 1997 public opinion survey, King County's Wastewater Treatment Division learned that continued protection and enhancement of water quality in the region is a very high priority for people who live here. The citizens of the region would like their governments to protect and improve the quality of the Duwamish River and Elliott Bay while recognizing the diverse uses of this estuary. This study, the *Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay*, describes the health of the Duwamish River and Elliott Bay, with an emphasis on identifying the effects of discharges from combined sewer overflows (CSOs). The results of this study will provide a tool to assist the region's leaders in making decisions that will most effectively protect and enhance the Duwamish River and Elliott Bay estuary as they formulate plans for controlling the region's CSOs.

Over the past 100 years, human activities have eliminated most of the original habitat in the Duwamish River corridor and have affected fish runs, shellfish harvests, wildlife populations, as well as reduced recreation such as fishing, boating, clamming, and bird watching. Referring to a time before the urbanization of the Duwamish River, poet Richard Hugo wrote:

> *. . . The river was alive with salmon. They rolled and splashed everywhere. I could hear them in the fog, and some I could see, huge shadows that climbed the air and slipped back into the water so close to the boat I could have touched them.*
>
> From *The Real West Marginal Way*

The Duwamish River was formerly fed by the Black, White and Green Rivers. Human-caused changes include the diversion of the Black and White Rivers for navigation and flood control, so today the Green and Duwamish are upstream and downstream reaches of one river. Other changes include the dumping of ship ballast, dredged materials, and soils; the discharges of untreated sewage, storm water, and CSOs; and the discharges and runoff associated with shipbuilding and other industrial and manufacturing processes. In the 1980s, studies identified pollution problems in the river and the bay. To reduce pollution, King County and many other agencies, businesses, environmental groups, and Native American tribes undertook the following:

- Secondary treatment of wastewater
- Rerouting treatment plant discharge from the river to Puget Sound
- Sediment cleanup and capping of contaminated areas
- Controlling toxicants from industries and storm water runoff
- Restoring habitat

- Reducing the frequency and volumes of untreated sewage and storm water being discharged from CSOs

Combined sewers are pipes that were originally built in many cities, including Seattle, to collect a combination of storm water, street debris, horse manure, and sanitary sewage from homes and businesses. Before treatment plants were built, this mixture was discharged to the nearest water body. Today, these combined sewers carry sewage and storm water to King County's West Treatment Plant located in the City of Seattle. Figure 1-1 depicts such a combined system.

During dry weather and smaller rainstorms, CSOs do not occur because the wastewater system can usually channel the wastewater to a treatment plant. However, during heavy storms the capacity of the wastewater system may be exceeded because of the additional storm water. To avoid sewer backups into residences, businesses, and industries, the combined sewers can overflow through any of the CSO outfalls which discharge into Lake Washington, the Lake Washington Ship Canal, Lake Union, Elliott Bay, the Duwamish River, and Puget Sound. While the wastewater in CSOs is diluted by storm water, it does contain potentially harmful microorganisms and pollutants that could degrade water quality and potentially affect aquatic life, wildlife, and people who use the waterbodies. As shown on Figure 1-2, both the City of Seattle and King County manage CSO locations within the City of Seattle.

Upgrading the wastewater conveyance systems to reduce the number and volume of CSOs is a part of the larger Regional Wastewater Services Plan for King County (King County, 1998). The Regional Wastewater Services Plan is a comprehensive sewer plan that evaluates several means of providing wastewater treatment and related services to the growing population of King County over the next 30 years. These services include wastewater conveyance and treatment, CSO control, biosolids management, inflow and infiltration reduction and water reuse.

King County and the City of Seattle must meet Washington State CSO regulations that require CSO discharges be limited to no more than one untreated occurrence per year, in a year of average rainfall, at each CSO location. King County has had a CSO control program in place since 1988 and has completed several projects. CSO control is expensive-it will cost King County approximately $566 million dollars over the life of the program to control CSOs to one discharge per year. $255 million of this has been spent or committed to be spent to achieve the initial volume reductions. As outlined in King County's Executive's Preferred Plan for the Regional Wastewater Services released in May 1998, another $325 million is expected to be spent between 1998 and 2030, when the program will be completed. Costs here are expressed in 1998 dollars as cumulative capital.

As part of this larger planning effort, King County has undertaken the project described in this document, the Combined Sewer Overflow WQA for the Duwamish River and Elliott Bay (CSO WQA). We have collected extensive field data from CSO effluent, receiving water, sediment, benthic communities, and invertebrate tissue. We have developed a model of the river and bay and used the field data and additional data previously collected in the estuary to initiate and calibrate the model. The model helped us to understand how water, sediments, and pollutants from CSOs and “other” sources move throughout the system. We have used the results of the model to better understand the health risks to aquatic life, wildlife, and people who use the resources of this estuary.

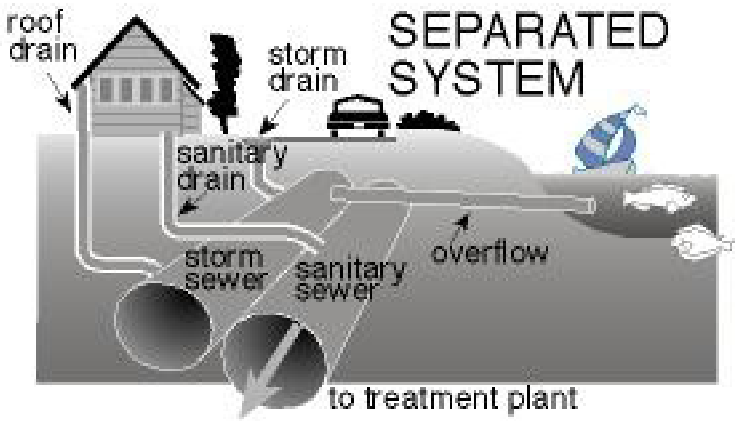

Figure 1-1.
Schematic Representation of Combined and Separated Sewer Systems

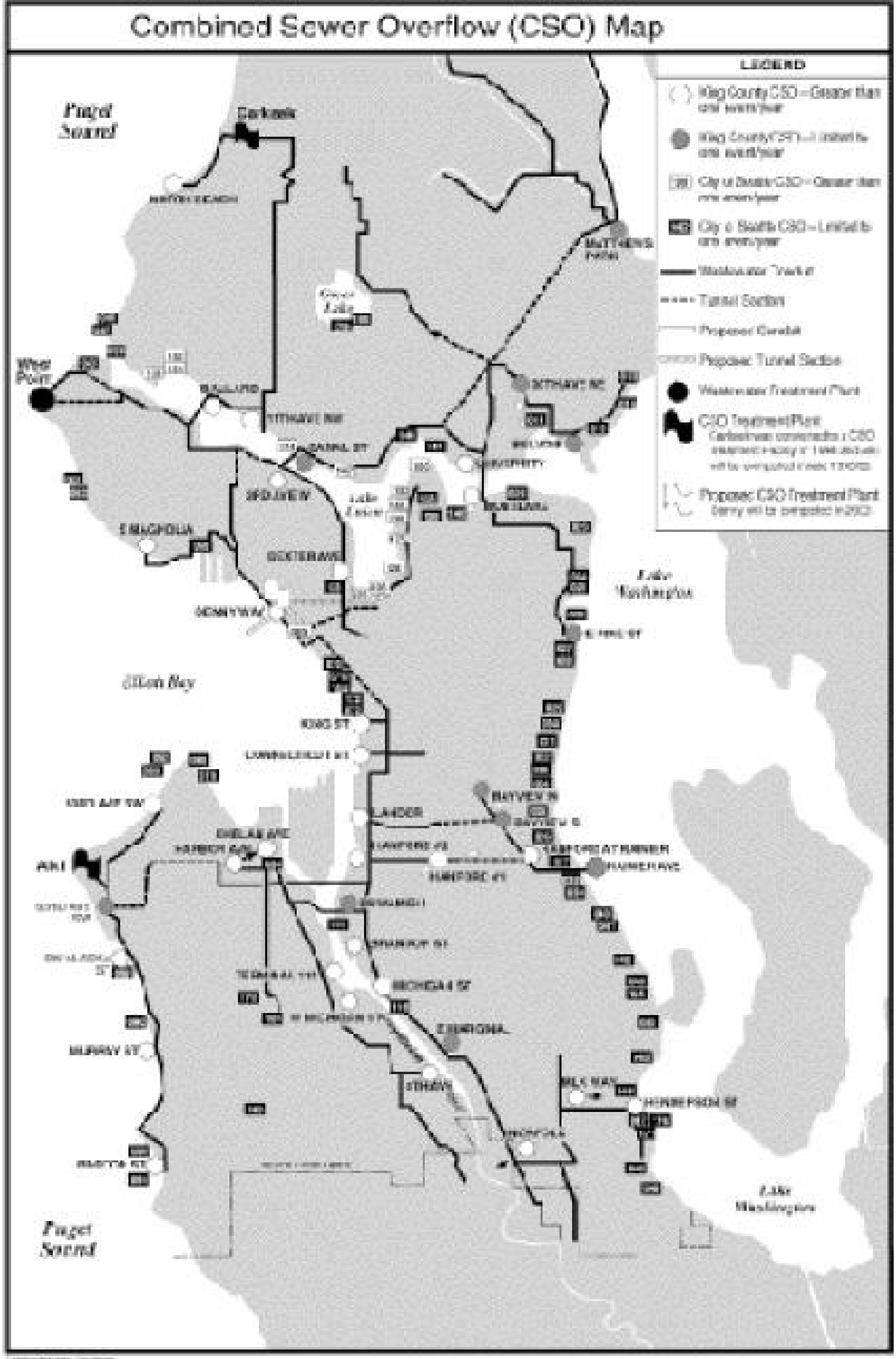

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Figure 1-2.
Combined Sewer Overflow Locations in the Seattle Metropolitan Area

The objectives of the CSO WQA are to:

- Understand baseline conditions in the Duwamish River and Elliott Bay,
- Determine significance of CSO pollutants compared to other sources,
- Obtain stakeholder recommendations as to what should be the next steps for the CSO control program, and
- Provide a tool for watershed level assessments.

The remainder of this report is organized as follows:

- **Overview of the Approach** focuses primarily on the reasons for selecting the approach we used in this project. This section should be of interest to the reader who wants to understand how the methods used derive from the specific goals and objectives of this assessment. It highlights the decision to use a risk assessment approach; the involvement of a stakeholder committee and peer review panel; the use of issue papers to engage our stakeholders and peer reviewers in the risk assessment process; the extensive field sampling program; and the use of a water quality model. Details of the methodology are found in the appendices. Overview of the Approach also provides a summary of where to find each piece of the detailed methodology.
- The **Problem Formulation** section summarizes the problem formulation and analysis plan we developed with our stakeholder committee. The problem formulation is where we decide what information we will provide the stakeholder committee to help it evaluate the significance of risks to aquatic life, wildlife and people who use the Duwamish River and Elliott Bay, and the significance of the CSO contribution to those risks. The complete problem formulation and analysis plan are found in Appendix A of this report. After completion of the problem formulation, the analysis plan was prepared to describe how we would obtain the information needed for the project.
- The **Findings** of the WQA are presented next. Here we describe the risks we found to aquatic life, wildlife and people. We have focused this section on the major findings of risk (or in some cases, the lack thereof). We have organized it around the different receptors we selected with the stakeholder committee during the problem formulation. A complete description of the methods and results of the risk assessment is found in Appendix B of this report.
- Finally, **Next Steps** offers our recommendations for future work, based on what we learned over the course of conducting this assessment.

2. OVERVIEW OF APPROACH

The purpose of this section is to explain how we did the CSO Water Quality Assessment, and why we did it that way. We needed an approach that would allow us to quantify and describe the harm that may be occurring to aquatic life, wildlife, and people who use the Duwamish River and Elliott Bay; and how the likelihood of that harm would be changed with the control of CSOs. The approach selected was ecological and human health risk assessment. Discussions between King County Management and the Washington State Department of Ecology (WSDOE) resulted in agreement that a risk assessment approach would provide a means of describing the potential benefits of controlling CSOs.

We used methodologies for ecological and human health risk assessment designed by the U.S. Environmental Protection Agency (U.S. EPA 1989; 1992; 1994; 1996; 1998a) and the Water Environment Research Foundation (WERF) (Parkhurst et al. 1996). These methods allowed us to describe risk that may be occurring to aquatic life, wildlife and people who use the Duwamish River and Elliott Bay.

Our guiding principles for conducting this project were:

- Listen to the needs of stakeholders and decision makers.
- Design and execute a scientifically credible risk assessment.
- Subject the work to peer review by national experts.
- Link science and stakeholder needs to policy-level decisions.

The remainder of this section describes the overall approach, rationale for the approach, elements of the approach, site-specific data, water and sediment quality modeling, stakeholder committee, peer review, and project team.

2.1 Overall Approach

Figure 2-1 presents a flowchart of the overall approach. It was decided at the outset that two other groups in addition to the project team were needed to do the CSO Water Quality Assessment. The first of these, the stakeholder committee, was formed to advise the project team and evaluate the significance of risks to people, wildlife and aquatic life in the Duwamish Estuary. While levels of risk can be estimated objectively, significance of risk is inherently a value decision, and therefore most appropriately addressed by stakeholders. We also had a peer review panel, whose job it was to evaluate and advise on the scientific aspects of the Water Quality Assessment. Once the project team, stakeholders, and peer reviewers were assembled, we started working together to define the goals and objectives of the study. Throughout the project, our stakeholders and peer reviewers came up with many questions about risk assessment. These we discussed through regular meetings and a series of Issue Papers, which we have included in this report as Appendix C.

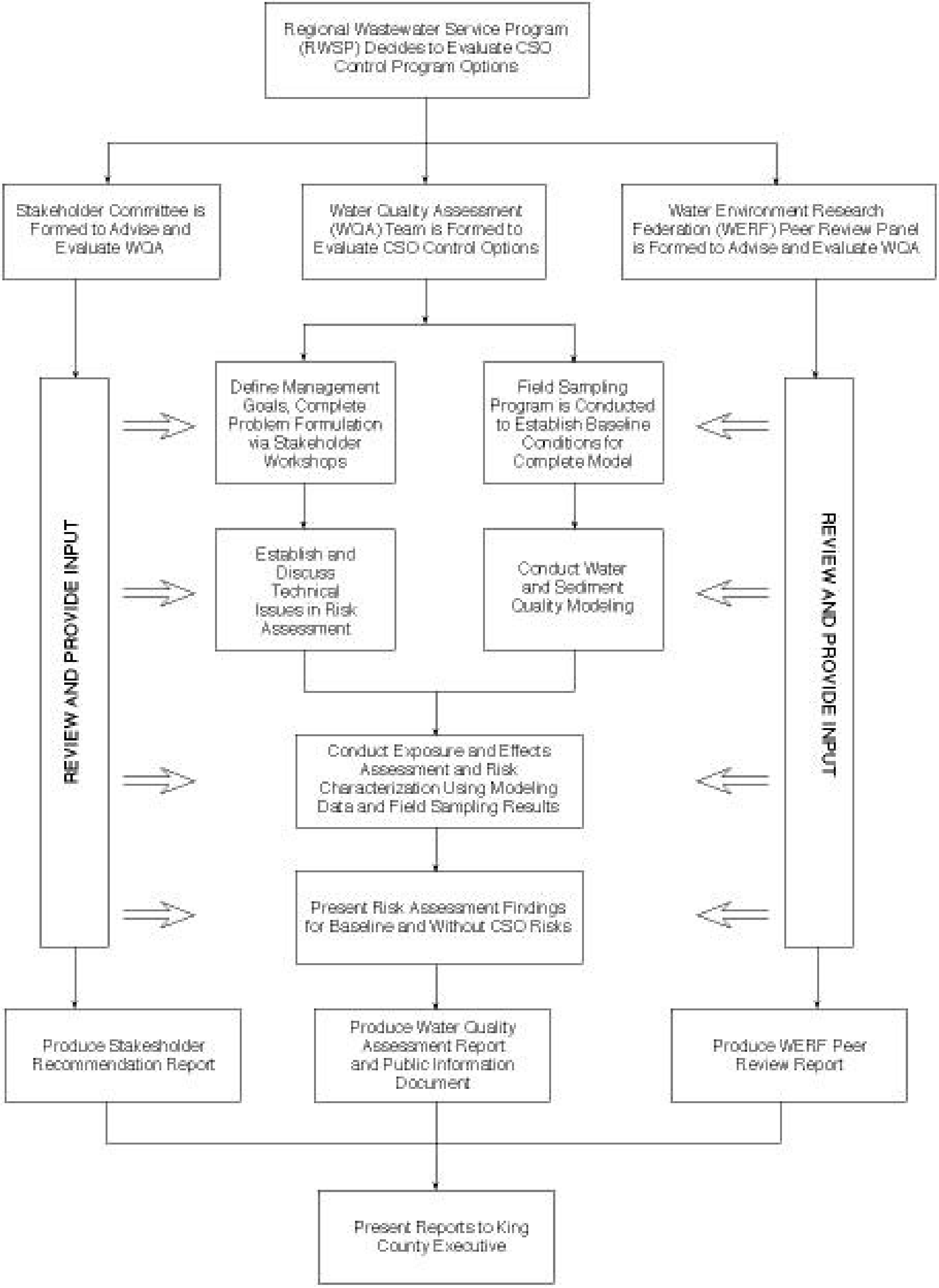

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Figure 2-1.
Flow Chart of the Duwamish River and Elliott Bay Water Quality Assessment Project

The project team initiated a field sampling program early in the project. Many of the data from the field sampling program went into development of the water and sediment quality model. Some data-for example, fish tissue concentrations and fishing survey data-were used directly for exposure assessment rather than model calibration. Other data, such as the CSO bioassay studies and the benthic community survey, were used directly to corroborate the risk predictions. The model was used for assessing exposure to chemical, pathogens, and physical stressors (for example total suspended solids). The project team also collected data to characterize the effects of chemical, pathogen and physical stressors on people, wildlife and aquatic life. The exposure and effects data were compared and interpreted to characterize risks.

The risk characterization results were reported to the stakeholders and peer reviewers, who prepared reports of their own. The project team report (Volume 1 - *Overview and Interpretation Report*) and a public information document (Volume 2 - *Public Information Document*) describing the risks in the Duwamish Estuary, the stakeholder report on the significance of the risks (Volume 3 - *Stakeholder Committee Report*), and the peer review report (Volume 4 - *WERF Panel Peer Review Committee Report*) were prepared for the King County Executive, who included his recommendation for the CSO program in the Executive's Preferred Plan for Regional Wastewater Services. This recommendation is being reviewed by the King County Council, who are expected to vote on the plan in June 1999. These reports were also used by the Regional Water Quality Committee and King County Council during their deliberations on the Regional Wastewater Services Plan.

2.2 Rationale for the Approach

We chose an approach for the CSO Water Quality Assessment that we thought best met the project's goals of determining CSO impacts to the Duwamish River and Elliott Bay relative to other pollutant sources, and understanding the possible benefits that could be achieved through eliminating CSOs from the estuary. As we formulated the specific approach to be used for the CSO Water Quality Assessment, it became apparent that to meet the project's goals and objectives we needed to understand not only *facts* but also *values* people placed on the Duwamish River and Elliott Bay. It also became apparent that the facts in this matter were highly uncertain (such as the amount of chemical loading to the estuary from storm water discharges), and people's values are not always the same. Therefore, the approach had to be designed to resolve uncertainties when possible, identify and avoid uncertainties that did not affect the study's findings, describe the uncertainties that could not be resolved or avoided, and separate matters of fact from matters of value. The facts we needed to gather included descriptions of:

- The biological communities and water and sediment quality of the Duwamish River and Elliott Bay
- How water and sediment quality affect the biological communities
- How CSOs affect water and sediment quality

The values we needed to understand focused on people's visions of the River and the Bay and how CSO control might help achieve these visions. Their viewpoints were expressed in terms of enhancing aquatic and wildlife communities, recreational, commercial, and cultural use of Duwamish River and Elliott Bay resources (e.g., fishing, boating and diving). We identified people's values through a preliminary survey and by working with our Stakeholder Committee in the development of vision statements.

2.3 Elements of the Approach

Once we identified the basic facts and values we needed to address in the CSO Water Quality Assessment, the elements of the approach we needed to follow became clear. Table 2-1 gives an overview of important elements of the approach and how each was addressed, and identifies where in the report each element is discussed in detail.

Table 2-1. Elements of the Approach Used in the Water Quality Assessment

Element	How Was It Addressed?	Where to Find It?
Baseline and Without CSO Risk Assessment		
Choose meaningful measures of exposure and effect	Stakeholders technical subcommittee and project team worked together to select endpoints	Appendix A
Collect model calibration data	Field sampling program October 31, 1996 through June 4, 1997 (1-3 sampling events per week at 21 sampling stations from Tukwila gauging station to Duwamish Head)	Appendix A
Collect tissue concentration data	Conducted joint sampling cruises with Washington State Department of Fish and Wildlife to collect fish and shellfish, tissue samples analyzed by King County Environmental Laboratory. Also sampled and analyzed wild and transplanted mussels.	Appendix A
Model water and sediment quality	EFDC model provides sophisticated, dynamic three-dimensional simulations of hydrodynamics and chemical transport & fate in water & sediment	Appendix B-1
Collect fishing data	Conducted field and phone surveys of human activities that could result in exposure of people to potential risks existing in the Duwamish Estuary, summer 1997	Appendix B-2
Evaluate toxicity of CSO effluent to sensitive	Conducted whole effluent toxicity bioassays on CSO effluent	Appendix B-4

Element	How Was It Addressed?	Where to Find It?
aquatic species		

Table 2-1. Elements of the Approach Used in the Water Quality Assessment (continued)

Element	How Was It Addressed?	Where to Find It
Evaluate abundance and diversity of benthic organisms	Conducted benthic community surveys at paired stations along transects from Duwamish/Diagonal outfall and Kellogg Island	Appendix B-4
Assess baseline risks in the Duwamish Estuary, and risks without CSO discharges	Aquatic ecological, wildlife and human health risk assessments for 1996-97 conditions ("baseline risks"), and for 1996-97 conditions with CSOs turned off ("without CSO risks")	Appendices B-2, B-3 and B-4 and Sections 4 and 5
Stakeholder Involvement		
Involve stakeholders in problem formulation	Stakeholder committee formed fall 1996, first convened November 1996	Appendix A and Section 3
Familiarize stakeholders with risk assessment methods	Issue papers, monthly working sessions with the stakeholder committee	Appendix C
Ask stakeholders to evaluate significance of findings	Stakeholder workshops July-August 1998	Volume 3
Provide stakeholder input to decision-makers	Stakeholder report to King County DNR to be completed September 1998	Volume 3
Peer Review		
Solicit peer review of modeling and risk assessment work	National peer review panel sponsored by WERF; publishing and presenting findings to the professional community	Volume 4

2.4 Site-Specific Data

Site-specific data were collected for two reasons: (1) to provide calibration data for the Duwamish Estuary water and sediment quality model, and (2) to provide other site-specific data for assessing exposures and risks to aquatic life, wildlife and people. A summary of types of samples and parameters measured are included here in Table 2-2.

The chemical and pathogen portions of the model were developed and verified with data taken from 39 water stations on a weekly schedule of non-storm samplings and more frequent sampling associated with storms. Most of these stations were grouped adjacent to CSOs, with three surface/subsurface pairs of stations located across the river. A station was located upstream of the study area to measure inputs to the study area from the river

Table 2-2. Summary of Site-Specific Data Collected

Sample type	Number of Stations	Frequency	Duration	Parameters
Geophysical sampling	8 velocity meters	15 minute intervals	1 year starting August 1996	Water velocity
	3 data loggers	Continuous	August 1996 to May 1997	Salinity temperature and water elevation
CSO effluent	5 CSOs	Sampling events triggered by flow conditions monitored by computerized flow monitoring system. Up to five storms sampled at each CSO.	1996-97 wet season	Organic and trace metal priority pollutants, fecal coliforms, nutrients, chemical oxygen demand, total organic carbon, solids, hardness, temperature, conductivity, pH, dissolved oxygen, chronic bioassays (at Brandon CSO only)
Ambient receiving waters (grab and semi-permeable membrane device samples)	21 Duwamish River and Elliott Bay locations	Once per week plus once per day for 3 days following CSO discharges	26 weeks (wet season)	Same as for CSOs plus butyltin s
Composite sediments (top 2 cm)	5 Duwamish River locations, 10 stations per location	Once per week	13 weeks (wet season)	Organic and trace metal priority pollutants, butyltins, methyl mercury, ammonia, sulfides, solids, organic carbon, grain size
Benthic community	1 CSO and 1 in-river reference site	Once	Once	Benthic community diversity and species abundance

Table 2-2. Summary of Site-Specific Data Collected (continued)

Sample type	Number of Stations	Frequency	Duration	Parameters
Tissues: English Sole Rockfish Dungeness Crab Shiner Perch Squid Amphipods Mussels	Elliott Bay (2 trawl areas), Duwamish River (1 trawl area) and 1 reference site	One trawl each during wet and dry seasons for fish and crab; squid collected from fishermen at Elliott Bay Fishing Pier; amphipods at Kellogg Island, native and deployed mussels near CSOs	Mussels deployed 6 to 8 weeks	Organic and trace metal priority pollutants; butyltins, percent lipids. Pathogenic bacteria and viruses in mussels at one site
Fishing Survey	Duwamish River and Elliott Bay shorelines and piers	N/AP	30 days in June, July August (10 each Saturday, Sunday and weekdays) 1,183 different individuals interviewed	Size and composition of catch, frequency of effort, meal size, meal frequency

N/AP = Not applicable

and a corresponding station on the Puget Sound boundary of the model. Over 2,000 water, sediment and tissue samples were collected for chemical analyses. Over 13,000 analyses were performed on these samples. Measurements were taken for conventional parameters such as nutrients and oxygen concentrations, as well as bacterial numbers, metals, and organic chemical concentrations. Sediment analyses included concentrations of metals, organic chemicals and physical characteristics such as sediment particle size. CSO effluent samples provided important information for the Water Quality Assessment. Automated samplers were installed in five of the most active CSOs in the study area. These samplers collected water samples both as sequential discreet samples and as composite samples. These samples were analyzed for most of the same parameters as the water and sediment samples.

In addition to the chemistry data just described, the sampling program collected site-specific data to calibrate the water flow portion of the model, site-specific data on what people catch and eat from the Duwamish Estuary, site-specific data on the diversity and abundance of benthic organisms near a CSO and storm water outfall and site-specific data on the toxicity of CSO effluent to aquatic species in the laboratory. The hydrodynamics data included information from water level sensors, meters that measure the speed and direction of water movement, and automated meters that record water temperature and salinity. Thirty days of fishing survey data from nearly 1,200 individuals provided information on what people catch and eat from the Duwamish River and Elliott Bay in the summer months. The benthic community survey provided information on the nearfield effects of CSO and stormdrain discharges on sediment-dwelling organisms relative to a reference site. The toxicity bioassay provided information on the potential for chronic effects on aquatic organisms from exposure to undiluted and diluted CSO effluent.

2.5 Water and Sediment Quality Modeling

The extensive hydrodynamic and water and sediment quality sampling data collected for this project were used to develop a dynamic three-dimensional hydrodynamic and chemical fate and transport model for the Duwamish River and Elliott Bay. This model was developed for three primary reasons:

- The model estimates concentrations at times and locations when no data were collected. Measured concentrations can be very site-specific, and highly variable over time. Daily and seasonally changing conditions in the Duwamish Estuary, along with the size and diversity of the study area further complicated the job. To collect sufficient numbers of samples to accurately describe concentrations in the study area throughout the year is unrealistic.

- The model allows for an identification of the source of the “constituents of potential concern” (COPCs). It is not otherwise possible to separate the results of the water and sediment sampling into CSO contributions and contributions from other sources.

- The model allows for the evaluation of water and sediment quality under conditions that have not yet occurred. Specifically, we needed to determine what the hydrodynamics and water and sediment quality would be in the study area would be if there were no CSOs (the “without CSO” condition). We had to evaluate this condition to assess the improvement that would occur were CSOs to be removed from the Duwamish Estuary.

The Duwamish Estuary model consists of two components. The first is a hydrodynamic component that describes water and particle flow. The second is a COPC fate and transport component that describes the addition, removal, movement and behavior of COPCs in the estuary, including those that reach the sediments. The model was calibrated to accurately predict measured hydrodynamics and water column COPC concentrations. The calibrated model was used to predict how COPCs from CSOs and other sources are transported through the Duwamish Estuary and Elliott Bay, providing a surrogate for a large-scale field monitoring program for estimating COPC exposure concentrations for the risk assessment. The physical area covered by the model includes the Green/Duwamish River from the Interstate 405 bridge to the outer bounds of Elliott Bay near Alki Point. The model divides this area into 512 smaller areas (cells) extending to the full depth of the estuary, and divides the depth into 10 water column layers and one sediment layer. Thus, the model simulates how COPCs from CSOs and other sources are distributed to 5,120 water and 512 sediment cell-layers and within the Duwamish Estuary.

The model was further refined to allow for evaluation of different spatial scales at which various effects occur in the study area. For example, the immediate impacts of CSO discharges are observed directly in front of each discharge pipe, such as scouring, sedimentation, and changes in chemical concentrations and conventional water quality parameters. To address these nearfield effects, a nearfield model was developed that examined the twelve cells into which CSOs discharge. The nearfield model was used only to assess stressors in the CSO plume during discharge. Changes in sediment quality immediately next to the CSO discharges were not modeled, but were instead assessed using the results of the sampling program. Other impacts of CSOs can be observed quite removed from the immediate discharge environment, such as long-term transport of waterborne chemicals throughout the study area and into the Puget Sound. The farfield model examined water and sediment quality in each of the 512 cells (at all layers) in the study area.

Presently, the computer model is the best available tool for predicting hydrodynamic flows and COPC concentrations. We used the model to help us assess the level to which aquatic life, wildlife, and people who use the river and bay are exposed to COPCs, both under baseline conditions and under a hypothetical scenario with no CSO discharges. Future data could be used to verify the computer model's predictions, refine its calibration, and/or test the validity of its underlying principles. For a further discussion of the model, please see Appendix B-1.

2.6 Stakeholder Committee

The project team recognized early that to achieve our objectives, a major component of our work would be focused on supporting, educating and listening to people from the region who have a stake in the outcome. We also realized that because this is a complex project, in which highly technical information would be used to make policy-level decisions, it would be necessary to work with a committed group of stakeholders from the beginning to allow them to learn the process and be able to provide significant input. A stakeholder committee was formed in the fall of 1996. The committee included 28 individuals representing government agencies, Native American tribes, community councils, environmental groups, businesses, and industries (Table A-2). This committee includes individuals who work in the environmental field and are technically able to advise the project team, as well as community members who are aware of the issues and share a vision for how the Duwamish River and Elliott Bay could be in the future.

Work with the stakeholder committee has centered on full-day workshops as well as half-day working sessions to go over specific details of the project in greater depth. Over the duration of the project, we held six workshops and eight working sessions. The first working session was dedicated to selecting the species to be studied in the risk assessment. Other working sessions focused on one or two technical issues, typically presented to the stakeholder committee a few days before the working session.

The first full-day workshop, held in November 1996, was used to describe the project and the role of the stakeholder committee. We also asked the members to describe in writing their vision for the Duwamish River and Elliott Bay, which was subsequently helpful in developing the management goal and guiding the selection of assessment endpoints. The second workshop, held in March, 1997, focused on the problem formulation and receiving input on the species to be studied in terms of health impacts. In the third workshop, held in July 1997, we presented the plan for the risk assessment and asked the stakeholders for help obtaining information about how people use the Duwamish River and Elliott Bay. Three more workshops were held in July and August 1998. At these workshops the results of the risk assessment (including a draft version of this report) were presented and discussed during a series of three workshops in the summer of 1998. The stakeholders used these workshops to develop their recommendations about how to protect the Duwamish Estuary, additional studies that might need to be undertaken, and possible refinements to be made to the CSO control program. Throughout the assessment, stakeholders have provided significant amounts of time and their expertise in not only attending meetings and workshops, but also in gathering information and reviewing and commenting on papers and reports.

2.7 Peer Review

The King County CSO Water Quality Assessment was fortunate to be part of the WERF Wet Weather peer review program. Because of the innovative approach and complexity of this project, the need for an in-depth peer review of the project was essential. WERF coordinated the development of a national panel of experts in the fields of risk assessment, CSO management, mathematical modeling and aquatic toxicology. The members of this panel are:

John Marr (Chair)	Mathematical Modeler; Limnotech, Inc.
George Barnes	CSO Program Development; Jordan, Jones & Goulding
Patricia Billig	Risk Assessor; Camp Dresser & McKee, Inc.
Edwin Herricks	Aquatic Toxicologist; University of Illinois
Suzanne Marcy	Risk Assessor; U.S. EPA

The panel's roles and responsibilities were agreed to by the panel and the project team during the first site visit and project workshop. These roles were:

- Review assessment plans and resulting data.
- Advise the project team regarding potential problems and opportunities for improvements in the WQA project elements.
- Report findings and recommendations regarding WQA results and conclusions to the project team, decision-makers, and stakeholders.

- Help the project team resolve issues that arise in the areas of project design and execution.

The Peer Review Panel has provided credibility to the assessment through their objective viewpoint and knowledge of other studies and projects across the nation and the world.

2.8 Project Team

The project team was formed in 1996-97. The individuals who played key roles on this project are shown in Table A-1, at the beginning of this report. The fourteen starred members represent those individuals who designed, implemented, adapted, interpreted and problem solved with each other for the duration of the project on a weekly basis. The achievements of this project reflect the active participation of the project team in decision-making and problem solving through all phases of the project. Individuals brought expertise in aquatic and human health toxicology, environmental field sampling, oceanography, mathematical modeling, wastewater engineering and planning, environmental microbiology, public outreach and risk assessment.

3. PROBLEM FORMULATION

A summary of the problem formulation developed by the project team and stakeholder committee is presented below. This problem formulation was developed following the first stakeholder workshop, held on November 14, 1996. The peer review draft of the analysis plan, which described how the problem formulation was to be implemented, was issued in June 1997. The complete problem formulation and analysis plan are provided as Appendix A of this report.

This section of the report presents an overview of the study area, CSOs, stressors and risk hypotheses.

3.1 The Study Area

The study area (Figure 3-1) includes the Green-Duwamish River from just upriver of King County's East Treatment Plant at Renton, downstream to where the river empties into Elliott Bay, a distance of about 24 kilometers. The study area also includes the portion of Elliott Bay east of a line drawn northward from Duwamish Head to Magnolia Bluff. The study area is a mixture of residential, commercial and industrial development, and a small amount of undeveloped land. In the past, shipyards, sewage treatment plants and other industries discharged to the Duwamish River and Elliott Bay, which lead to much of the historical contamination we see today.

The entire study area can be considered an estuarine system, that is, an aquatic system that exhibits both marine and freshwater characteristics. The upriver portion of the study area is primarily a freshwater river with tidal influence, while the seaward boundary of the study area in Elliott Bay is primarily marine with a variable freshwater layer, especially in the winter months during periods of higher river flow. The open portion of Elliott Bay is dominated by Puget Sound marine water masses with the freshwater layer from the Duwamish River limited to the upper five meters (about 5 percent of the water column). In winter months the brown color of this sediment-laden layer can be seen clearly in Elliott Bay. The river water is mixed with incoming Puget Sound water and enters the greater Puget Sound circulation. Sediment falls from the surface layer to the bottom in both Elliott Bay and Puget Sound.

Over the last 125 years, the drainage area of the Duwamish River has been reduced by about 70 percent due to development and diversion of streams and lakes out of the estuary. Most (98 percent) of approximately 1,270 acres of tidal marsh and 1,450 acres of flats and shallows, and all of about 1,250 acres of tidal wetland have been eliminated from the estuary (Blomberg et al. 1988). The intertidal habitat that remains in the Duwamish River is important for the survival of juvenile salmon, other predator fish, birds, and mammals that feed on invertebrates and small fish found in shallow areas of the study area.

Kellogg Island is the largest remnant of intertidal habitat remaining in the Duwamish River estuary (Tanner 1991). Habitat associated with the island includes high and low marsh, intertidal flats, and filled uplands (Canning et al. 1979). Kellogg Island provides important nesting and feeding habitat for waterfowl and other birds. Small patches of other intertidal areas occur in the estuary as marsh and unvegetated intertidal beaches.

Sections of natural shoreline only occur in the Duwamish River above the head of navigation at about river mile 6 (Tanner 1991).

The nearshore environment of Elliott Bay once consisted of 2,100 acres of eelgrass and marsh habitats. Because of harbor development, eelgrass and marsh habitat have been reduced to about 54 acres (Stober and Pierson 1984). Nearshore habitats include the waterfront along downtown Seattle, with pilings, riprap, and other human-made submerged structures. Remaining natural habitat includes the eelgrass beds along the shoreline northeast of Alki Point and the kelp beds off the northern shore of the bay. The marine waters of Elliott Bay provide habitat for demersal and pelagic marine fishes, invertebrates, marine mammals, and birds, several commercially important anadromous fish (chinook, coho, and chum salmon), and shellfish (geoduck clam, crab, and shrimp). The Duwamish River and Elliott Bay waterfront is devoted to waterborne commerce.

The Port of Seattle is the fifth largest container port in the United States. It is the twentieth largest in the world (Trade Development Alliance 1994). Seattle competes with Los Angeles, San Francisco, Portland, Tacoma, and Vancouver, British Columbia for trans-Pacific maritime trade. The value of trade through the Port of Seattle in 1992 was $26.89 billion, of which trade with Japan, Korea, Taiwan, and China accounted for $21.93 billion. In terms of value, the top five exports were hides, paper products, industrial equipment, fishery products, and heavy machinery. Seattle is also a major distributor of Alaskan products, especially canned salmon. Seattle's own large fishing fleet is noted for its salmon, halibut, and crab catch (Kurian 1994). Shipbuilding, a large industry in World Wars I and II, is now limited to construction of ferryboats, barges, fishing boats, and pleasure boats.

In addition to commerce, fishing (both recreational, commercial, and tribal) and boating are pursued in both the Duwamish River and Elliott Bay, along with beach activities and limited swimming, wading, and scuba diving. Fishing activities in the Duwamish River include treaty gillnet fishing by the Muckleshoot and Suquamish Tribes and recreational angling from boats, fishing piers, and marinas. Public shoreline and water access occurs on the Duwamish River and along the Seattle waterfront. Commercial harvesting of shellfish is not allowed in Elliott Bay because of high fecal coliform bacteria counts (Stober and Pierson 1984). The King County Health Department and the Washington Department of Health recommend against collecting fish and shellfish from urban shorelines (Washington Department of Health 1993).

3.2 CSOs

City of Seattle and King County CSOs occur within the study area in both the Duwamish River and Elliott Bay. Other CSOs occur in Lake Washington, Lake Union, and the Ship

Canal. These locations are shown in Figure 1-2. From 1981 to 1988, nearly 2.4 billion gallons of untreated sewage were discharged from King County's CSOs each year. As a result of control efforts, this volume was reduced to 1.6 billion gallons per year on average (King County 1995). Table 3-1 summarizes the discharge characteristics for the CSOs evaluated in this study.

Table 3-1. Annual Average Frequency and Volume of Study Area CSOs in the King County Sewage System

CSO Location	CSO Frequency (Events/Year)	CSO Volume (Millions of Gallons)
8^{th} Avenue	5	12
West Michigan	13	2
Harbor Avenue	33	58
Chelan Avenue	41	65
Norfolk Street	4	9
Michigan Street	40	173
Brandon Street	40	57
Hanford at Rainier (Duwamish/Diagonal)	5	60
Hanford #2	24	207
Lander	23	164
Connecticut	25	93
King Street	31	33
Denny Way	51	455
South Magnolia	21	15
Terminal 115	8	5

3.3 Stressors

A basic premise of the problem formulation is that chemicals, physical disturbances, changes in conventional water quality parameters, and microbial contaminants may occur in the Duwamish River and Elliott Bay at levels that could harm aquatic life, wildlife or people who use the estuary. In risk assessment terminology, these COPCs are termed stressors. The specific stressors that were evaluated in the WQA are presented in Table 3-2, along with the contributing sources of these stressors to the model and their potential impacts on the receptors we evaluated. Although not noted in the table, the metal stressors are naturally occurring, and also enter the estuary through weathering of natural materials. A detailed discussion of the process used to select the chemicals evaluated is presented in Appendix A.

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Chemicals			
Arsenic	Pesticides, manufacturing, electronics industry, weathering of igneous rocks	CSOs, Puget Sound marine waters, surface runoff, Green River	Aquatic: Reduced growth and reproduction, mortality Wildlife: Mortality and reproductive and development effects People: Carcinogen[a], skin effects
Benzo(a)anthracene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects[b] People: Carcinogen, reproductive effects
Benzo(a)pyrene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects[b] People: Carcinogen, reproductive effects
Benzo(b)fluoranthene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects People: Carcinogen, reproductive effects
Benzo(g,h,i)perylene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects People: Carcinogen, reproductive effects

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Chemicals			
Benzo(k)fluoranthene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects People: Carcinogen, reproductive effects
Bis(2-ethylhexyl) phthalate	Plastics manufacturing, present in plastic toys, vinyl upholstery, shower curtains, adhesives, and coatings	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Mortality and reduced growth and reproduction Wildlife: Reproductive effects People: Possible carcinogen, liver effects
Cadmium	Used in metal plating, pigments, batteries, plastics. Released by burning fossil fuels and metal smelting.	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, decreased growth, and mortality People: Kidney and lung damage, lung cancer from inhalation, high blood pressure, bone effects
Chrysene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects People: Carcinogen, reproductive effects

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Copper	Metal or alloy used in manufacturing of wire, sheet metal and other metal products, preservative, fungicide	CSOs, surface water, historic sediment contamination, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reduced growth and reproduction, mortality People: Essential nutrient, very high doses can cause gastric distress, liver and kidney damage, and death
Dibenzo(a,h)anthracene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, surface runoff, historical sediment contamination	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects People: Carcinogen, reproductive effects
1,4-Dichlorobenzene	Toilet deodorizing blocks, mothballs, fumigants, chemical manufacturing	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Liver degeneration People: Impacts on liver, kidney, blood, possible carcinogen[a]
Fluoranthene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, surface runoff, historical sediment contamination	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, mortality People: Possible carcinogen, reproductive effects
Indeno(1,2,3-cd)pyrene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, surface runoff, historical sediment contamination	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, reduced growth, mortality People: Carcinogen, reproductive effects

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Lead	Used in batteries, gasoline additives, paints, roofing materials, caulks, ammunition, and solder	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, reduced growth, mortality People: Fetal effects, brain damage, reproductive effects
Mercury	Chlorine-alkali manufacturing, electrical equipment, dental fillings, historically used as a fungicide, weathering of igneous rocks	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive and kidney effects, mortality, neurological effects People: Brain, kidney, and fetal damage, nervous system effects
4-Methylphenol	Disinfectant, deodorant, fuel component	Historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Mortality, decreased growth and reproductive effects People: Possible carcinogen
Nickel	Steels, metal alloys, electroplating, Ni-cad batteries, ceramics	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reduced growth and reproduction, mortality People: Micronutrient[c], skin rashes, immune and lung effects from inhalation only

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Phenanthrene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, mortality People: Possible carcinogen, reproductive effects
Pyrene	Produced by residential wood burning, combustion processes, and automobile and truck exhausts	CSOs, historical sediment contamination, surface runoff	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, kidney effects People: Possible carcinogen, reproductive effects
Total PCBs	Coolants and lubricants in transformers, capacitors, and other electrical equipment	Historical sediment contamination	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, tumors, liver degeneration People: Possible carcinogen, liver, kidney, and skin damage
Tributyltin (TBT)	Antifouling agent in marine paints, wood and paper preservative, disinfectants	Historical sediment contamination	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reproductive effects, immunosuppression People: Skin irritant, immune effects
Zinc	Rust preventatives, dry cell batteries, and metal alloys. Used in pennies.	CSOs, historical sediment contamination, surface runoff, Green River, Puget Sound Marine	Aquatic: Reduced growth and reproduction, mortality Wildlife: Reduced growth and reproduction, mortality People: Essential nutrient. Large doses cause gastric distress, anemia, low levels of HCL cholesterol, copper deficiency

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Physical Disturbances			
TSS	Discharges from pipes, increasing flooding frequencies and durations, resuspension due to currents and flows	CSOs, currents and flows, flooding, Green River, Puget Sound Marine	Aquatic: Reproductive effects and mortality Wildlife: No impacts People: No impacts
Scouring	Discharges from pipes, increasing flooding frequencies and durations, currents and flows	CSOs, currents and flows, flooding	Aquatic: Physically being displaced from sediment Wildlife: No impacts People: No impacts
Sedimentation	Discharges from pipes, increasing flooding frequencies and durations, resuspension due to currents and flows	CSOs, currents and flows, flooding	Aquatic: Mortality from burying Wildlife: No impacts People: No impacts
Displacement	Discharges from pipes, increasing flooding frequencies and durations	CSOs, currents and flows, flooding	Aquatic: Increase vulnerability to predators, osmotic stress [d] Wildlife: No impacts People: No impacts
Changes in Conventional Water Quality Parameters			
Salinity	Not Applicable	CSOs, surface runoff Puget Sound	Aquatic: Osmotic stress[d] leading to mortality Wildlife: No impacts People: No impacts
Dissolved Oxygen	Not Applicable	Not modeled	Aquatic: Reduced growth, reproduction, and mortality Wildlife: No impacts People: No impacts

Table 3-2. Use/Causes and Contributing Sources of Stressors Assumed in the EFDC Model and the Impact of Stressors on Primary Receptors (continued)

Stressor	Uses/Causes	Contributing Sources of Stressors	Primary Receptor Impacts
Microbial Contaminants			
Fecal Coliforms	Human and animal wastes	CSOs, surface runoff, and upstream sources (e.g. septic systems, wild and domestic animals) Green River, Puget Sound Marine	Aquatic: Unknown Wildlife: Unknown People: Indicators of the potential for human diseases
Viruses	Human and animal wastes	CSOs	Aquatic: Unknown Wildlife: Unknown People: Gastrointestinal disease, respiratory, hepatitis
Protozoans	Human and animal wastes	CSOs	Aquatic: Unknown Wildlife: Unknown People: Human diseases, primarily gastrointestinal

[a] A carcinogen is a chemical capable of causing cancer in people.

[b] Examples of reproductive effects are reduced egg number and hatchability in birds and fetal resorption, abortion, and reduced pup growth in river otters.

[c] A micronutrient is an element that is essential to human health at very low concentrations in the diet.

[d] Osmotic stress occurs when marine organisms are exposed to freshwater, and they are unable to maintain the required balance of cellular ions.

3.3.1 Chemicals

The chemical COPCs include polycyclic aromatic hydrocarbons (PAHs) from fuel combustion; polychlorinated biphenyls (PCBs) from transformer coolants; organic solvents (chloroform, trichloroethane); phthalic acid esters (phthalates); phenolics; 1,4-dichlorobenzene (1,4-dichlorobenzene), and metals (mercury, arsenic, lead, copper, butyltins, cadmium, zinc). Chemicals may enter the study area from point sources (permitted industrial discharges, treatment plants, storm water drains, CSOs, accidental spills, leaks, etc.) and non-point sources (runoff from pavement, roofs, etc.; groundwater discharges; and atmospheric dispersion and deposition of non-local sources).

Specific information on the distribution and extent of toxic chemicals in sediments below CSOs are from previous studies, such as those conducted at Denny Way by Metro (Romberg et al. 1984) and the more recent but unpublished studies conducted by King County (Shuman 1997 personal communication). These data suggest that chemicals discharged from CSOs are adsorbed to sediment particles that settle to the bottom at varying distances from the end of the pipe depending on particle size and hydrodynamic conditions. There is also the possibility of overland flow across intertidal mud flats during low tides. The area of deposition is known as the footprint and varies in size.

3.3.2 Physical Disturbances

The physical disturbances evaluated in this risk assessment included benthic infaunal habitat loss due to sediment scouring or sedimentation (burial), and displacement of outmigrating salmon by high water velocities. Resuspension of sediments during scouring also can result in the re-dissolution of sediment-bound chemicals. Prior to this study, there were almost no data on current levels of physical disturbance (aside from engineered disturbances such as channel dredging in the Duwamish River and sediment capping at Denny Way CSO and Pier 53), either in the Duwamish River and Elliott Bay as a whole or proximal to CSOs.

3.3.3 Changes in Conventional Water Quality Parameters

Conventional water quality parameters evaluated in this risk assessment included salinity, dissolved oxygen (DO) concentration, pH, and water temperature. Surface runoff and CSO discharges can change conventional water quality parameters, for example, lowering the salinity of receiving waters. If either of these sources contains organic materials or nutrients, they also have the potential to affect DO concentrations and pH. Additionally, CSOs discharges may be warmer or colder than the receiving waterbody. Lowered salinity, DO, changes in pH and changes in temperature can affect most aquatic life.

3.3.4 Microbial Contaminants

Microbial contaminants enter the upper watershed in surface runoff and in groundwater contaminated by failed septic systems. CSOs are the primary source of untreated domestic wastewaters in the lower Duwamish River and Elliott Bay. Microbial contaminants of most concern are human pathogens including protozoa, bacteria, viruses, and possibly helminths (tapeworm, round worms). Human pathogens persist for varying lengths of time in water, sediments, and shellfish. CSOs are probably the primary source of pathogens entering the Duwamish Estuary, but the upper watershed is also a potential source of pathogens.

3.4 Measures of Assessment

Measures of assessment are defined by the U.S. EPA (1996) as "explicit expressions of actual environmental values that are to be protected." For example, survival of outmigrant salmon or risk from getting cancer from eating fish could be assessment endpoints. Assessment endpoints provide direction for a risk assessment and are the basis for developing questions, predictions, models, and analyses. This risk assessment evaluated ten assessment endpoints (Table 3-3):

- Survival of outmigrant salmon
- Survival and health of resident fish species (e.g., English sole)
- Survival, growth and reproductive success in at least 95 percent of aquatic species
- Abundance and richness (community structure) of benthic invertebrates
- Survival of spotted sandpipers
- Survival of great blue herons
- Survival and reproduction of bald eagles
- Survival of river otters
- Absence of non-cancer health effects from chemicals and pathogens among people using the Duwamish River or Elliott Bay
- Absence of a one-in-a-million chance (excess probability) of getting cancer among people using the Duwamish River or Elliott Bay

The selection of assessment endpoints was based on societal values expressed in the management goal, as well as an evaluation of available information to ensure that the endpoints were ecologically relevant and susceptible to identified stressors. The assessment endpoints are measurable attributes of valued resources that include both an entity (e.g., benthos) and a measurable attribute (e.g., diversity).

The WQA Project Team selected assessment endpoints with key input from the WQA Stakeholder Committee. Each assessment point is described below by receptor group to highlight its ecological relevance, potential for exposure to known stressors, and importance to society.

Table 3-3. Receptors, Assessment Endpoints, Exposure Pathways and Stressors Evaluated in the CSO Water Quality Assessment

Receptor	Assessment Endpoint	Exposure Pathway	Stressors
Aquatic Life	Percent species at risk	Direct contact with stressors in the water column	Chemicals[a], water temperature, low dissolved oxygen, total suspended solids, water velocity
	Survival[b] and health of resident fish	Direct contact with stressors in the water column and sediments	Chemicals[a], water temperature, low dissolved oxygen, total suspended solids, water velocity
	Survival[b] of salmon outmigrants (chinook, coho, chum)	Direct contact with stressors in the water column, food ingestion	Chemicals, water temperature, low dissolved oxygen, total suspended solids, water velocity
Benthos	Community structure, Washington State standards	Direct contact with sediments and pore water; ingestion of food, water and sediment	Chemicals[a], smothering, scouring
Shorebirds	Survival[b] of spotted sandpipers	Ingestion of food, water and sediment	Chemicals[a]
Wading Birds	Survival[b] of great blue herons	Ingestion of food, water and sediment	Chemicals[a]
Raptors	Survival[b] and reproduction of bald eagles	Ingestion of food, water and sediment	Chemicals[a]
Mammals	Survival[b] of river otters	Ingestion of food, water and sediment	Chemicals[a]
Seafood Consumers	Cancer, other chronic illness and infectious disease	Eating fish, shellfish, and other organisms from the Duwamish River and Elliott Bay	Chemicals[a] and pathogens
Net Fishers	Cancer, other chronic illness and infectious disease	Direct contact with and incidental ingestion of water and sediment	Chemicals[a] and pathogens
Swimmers	Cancer, other chronic illness and infectious disease	Direct contact with and incidental ingestion of water and sediment	Chemicals[a] and pathogens
Scuba Divers	Cancer, other chronic illness and infectious disease	Direct contact with and incidental ingestion of water	Chemicals[a] and pathogens
Windsurfers	Cancer, other chronic illness and infectious disease	Direct contact with and incidental ingestion of water	Chemicals[a] and pathogens

[a] See Table 3-2 for a complete list of all stressors evaluated in this project.

[b] By survival, we mean the continued presence and success of these species in the study area, as measured by survivorship, growth and reproduction (see Appendix A1 - *Problem Formulation*).

3.4.1 Fish

Salmon survival was selected as an assessment endpoint because salmon have commercial, recreational, and cultural value and they are ecologically important. Freshwater communities are sustained by nutrients and energy derived from salmon carcasses deposited to stream bottoms after spawning. The juvenile, or outmigrant smolt, is recognized as the most sensitive lifestage found within the study area. While several species of salmon (chinook, coho, chum, pink) and trout (steelhead, cutthroat, possibly Dolly Varden) use the study area, chinook and chum salmon have a greater estuarine reliance than the other species. Juveniles of both species do not immediately go to sea upon entering the estuary but appear to linger over a period of two to three months (Warner and Fritz 1995). Juvenile chinook outmigrants are present in the Duwamish Estuary from early April to mid-July. Juvenile chum outmigrants are found in the estuary in significant numbers from early February to mid-July. CSO discharges occur predominantly over a period extending from October through April, so both salmon species are likely to be present in the estuary when CSOs occur.

Resident fish, whose potential exposure to chemicals discharged from CSOs and other sources is essentially year-round, were also selected as an assessment endpoint. A particular resident fish species was not selected but it was assumed that the proposed assessment approach would be protective of all resident fish species. A number of resident fish species (e.g., English sole, starry flounder) are commercially or recreationally important. Other fish species (e.g., shiner perch and sandlance) are important as prey for commercially or recreationally important species. English sole were also evaluated for the development of liver lesions that are a measure of their exposure to sediment PAHs (Myers et al. 1994).

3.4.2 Benthos

Both epibenthic and infaunal species are recognized as sensitive indicators of chemical and physical impacts. Benthic communities inhabiting sediments in the vicinity of CSOs can be subjected to both chemical and physical stress following discharge events. Chemicals and organic debris tend to accumulate and persist in depositional areas downstream from CSOs and sedimentation can smother shellfish and other benthos. Altered water and sediment quality may affect the abundance of individuals of a species as well as the numbers of species present. Benthic communities are an important food resource for commercially and recreationally important salmon and other fish and wildlife, which have significant societal value.

3.4.3 Shore Birds, Wading Birds, Raptors, and Aquatic Mammals

Endpoints have been included for shore birds (e.g. spotted sandpiper), wading birds (e.g., great blue heron), and raptors (e.g., bald eagle). All are present on the Duwamish River and Elliott Bay either seasonally or year-round. Spotted sandpiper are protected by the Migratory Bird Treaty Act. The bald eagle has threatened status in Washington under provisions of the Endangered Species Act of 1973, as amended. The great blue heron has been listed as a priority species by the Washington Department of Wildlife (1991).

The river otter was included as a representative aquatic mammal. A family of river otters lives year-round on Kellogg Island. The river otter, a species once harvested for its fur, is a "charismatic" species, i.e., a species that people tend to notice and care about. River otters feed largely on fish but also will feed on crabs and sometimes mussels or clams.

3.4.4 People

To address human health risks, assessment endpoints have been included for cancer and other chronic illnesses and infectious diseases. People are likely to receive their largest exposures to chemicals in the Duwamish River and Elliott Bay eating seafood from the study area. Chemicals also can be absorbed through the skin from direct contact with water or sediments, for example while net fishing. Intake of chemicals by swallowing water or sediment when swimming is another potential pathway for exposure. Pathogens found in surface water or edible shellfish, mostly clams or mussels, also are of concern.

3.5 Risk Hypotheses

Following U.S. EPA's Ecological Risk Assessment Guidelines (U.S. EPA 1998a), a final step in the problem formulation is to state the risks being assessed as hypotheses. The risk assessment evaluates whether the risk hypotheses are true or false. Based on the problem formulation, we developed several hypotheses concerning the effects of CSOs and other sources of stressors in the Duwamish River and Elliott Bay.

3.5.1 Hypothesis #1

Elevated baseline chemical concentrations cause reduced survivorship, growth and/or reproduction of aquatic life and wildlife in the Duwamish River and Elliott Bay. The baseline effect on survivorship, growth, and reproduction would be lessened if there were no CSO discharges into the estuary.

3.5.2 Hypothesis #2

Total suspended solids (TSS) loads in CSO discharges and other sources and sedimentation and scouring resulting from baseline conditions cause reduced survivorship, growth, and/or reproduction of aquatic life and wildlife in the Duwamish River and Elliott Bay. The baseline effect on survivorship, growth, and reproduction would be lessened if there were no CSO discharges into the estuary.

3.5.3 Hypothesis #3

Changes in water quality parameters (salinity, temperature, pH, DO) in the Duwamish River and Elliott Bay resulting from baseline conditions cause reduced survivorship, growth, and/or reproduction of aquatic life and wildlife. The baseline effect on survivorship, growth, and reproduction would be lessened if there were no CSO discharges into the Duwamish River and Elliott Bay.

3.5.4 Hypothesis #4

People using the Duwamish River and Elliott Bay for recreation (e.g., swimming, fishing, scuba diving or windsurfing) or food gathering for recreation and subsistence are at greater risk of non-cancer and cancer health effects due to elevated chemical baseline concentrations in surface waters, sediment, fish, and shellfish than people who do not use the estuary for these purposes. People using the Duwamish River and Elliott Bay for recreation or subsistence food gathering would have a lower risk of non-cancer and cancer health effects if there were no CSO discharges into the estuary.

3.5.5 Hypothesis #5

People using the Duwamish River and Elliott Bay for recreation or food gathering are at greater risk of infection and symptomatic illness from elevated concentrations of microbial contaminants present under baseline conditions in surface waters, sediment, and shellfish than people who do not use the estuary for these purposes. People using the Duwamish River and Elliott Bay for recreation or subsistence food gathering would have a lower risk of infection and symptomatic illness from elevated concentrations of microbial contaminants if there were no CSO discharges into the estuary.

4. FINDINGS

The purpose of this section of the report is to describe our findings about risks to aquatic life, wildlife and people who use the Duwamish River and Elliott Bay, from exposure to the stressors identified in the problem formulation. Our goal was to describe our findings in a way that would help the Stakeholder Committee and decision makers with their deliberations on the question of significance of baseline and CSO risks. To that end, our findings are a distillation of a much larger pool of information. It is our hope and intent that (1) we have clearly and concisely captured the most salient information about risks and (2) the Stakeholder Committee were familiar with the assumptions and analyses we have used to achieve this distillation – through the problem formulation, field sampling work plan and analysis plan (Appendix A), the detailed methods and results (Appendix B), the issue papers (Appendix C), and our full-day workshops and half-day working sessions.

4.1 Key Findings

Section 4.1 provides a concise summary of the project team's key findings from the WQA. In it we use terms like high, medium and low to describe levels of risk. These terms are not meant to imply value judgments about the significance of risks. That was the job of the Stakeholder Committee – and other readers of this report. Some readers may find risks we have characterized as "low" to be significant, while others may find "high" risks insignificant. We based our high, medium and low risk characterizations on the probability of the exposure exceeding effects thresholds, and the magnitude of exceedance. In Sections 4.2 (Risks to Aquatic Life), 4.3 (Risks to Wildlife) and 4.4 (Risks to People), we discuss the findings in greater detail. There we provide specific explanations of what we mean by high, medium or low in each instance. Section 5 specifically addresses uncertainties in the key findings.

4.1.1 Overall Findings

We found clear evidence of potential risks to aquatic life, wildlife, and people, under both baseline and without CSO conditions.

Most baseline risks are not expected to be reduced by removal of CSOs from the system, however:

- Risk of infection from direct contact with viruses and *Giardia* in CSO discharges, during and soon after CSO events, are predicted to be reduced with removal of CSOs throughout the Duwamish River and along the Elliott Bay shoreline.

- In the immediate vicinity of CSOs,[1] risks to sediment dwelling organisms from organic enrichment, and possibly from 1,4-dichlorobenzene and bis(2-ethylhexyl) phthalate, are predicted to be reduced by removal of CSOs.

4.1.2 Aquatic Life

The WQA found minimal risks to aquatic life from chemicals in the water column, no risks to juvenile salmon from direct exposure to chemicals in the water, and no risks to salmon smolt from consuming amphipods in the Duwamish Estuary.

- Risks to water column dwelling organisms, from exposure to COPCs in the water of the Duwamish River and Elliott Bay, appear to be minimal. Any potential risks are below the level used by U.S. EPA to develop water quality criteria. These predicted risk levels were confirmed by the observed lack of chronic toxicity to sensitive organisms from undiluted effluent from the Brandon St. CSO.

- Risk estimates do not change when CSO discharges are removed from the system.

- There do not appear to be risks to aquatic life from total suspended solids concentrations in the estuary, although there were some low exceedances of TSS thresholds because they were based on data for sensitive freshwater species.

- We found no apparent risks to salmon from exposure to chemicals in the water column.

- We found no apparent risk to salmon from concentrations of copper, lead, zinc, TBT or PCBs (Aroclors 1254 and 1260) in their prey. There were no data available for estimating dietary risks to salmon from the other COPCs.

- Salmon exposure to CSO flows are believed to be minimized because water column velocities, both in the plume of CSOs and in the river channel, regularly exceed sustainable swimming speeds for juvenile salmon. Other studies suggest that salmon have strategies for avoiding this stressor, for example, by seeking refuge along the banks.

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[1] Approximately 1 percent of the total study area.

The WQA found potential risks to the benthic community from chemicals in the sediments, and localized areas of risk from sedimentation and scouring.

- There are potential risks to benthic organisms from several chemicals in sediments, most notably bis(2-ethylhexyl)phthalate, 1,4-dichlorobenzene, mercury, PAHs, PCBs, and TBT.
- PCBs and TBT pose the greatest potential risks to benthic organisms. PCB and TBT risks will not be changed by control of CSOs because CSO discharges are not significant current sources of PCBs and TBT compared to other sources in the estuary.
- There are localized areas of sedimentation and scouring that would affect the sediment dwelling community, in some cases due to CSOs. The sedimentation and scouring risks from CSOs occur over less than 1 percent of the study area.

Eliminating CSO discharges could increase benthic diversity in the CSO footprint. The effects of other nearby discharges (i.e., storm drains) could at least partially offset the nearfield benefits of removing CSOs.

- A benthic community survey conducted at the Duwamish/Diagonal CSO and stormdrain indicated localized increases in abundance of organic enrichment-tolerant species and an overall reduction in diversity from organic enrichment and grain size.
- Comparisons of sediment concentrations to sediment management standards indicate possible risks to sediment dwelling organisms from 1,4-dichlorobenzene and bis(2-ethylhexyl)phthalate in CSO footprints, however no cause and effect relationships have been established.
- Removing CSOs will likely create some improvements in sediment quality near the CSOs. However, separated storm drains will provide a continuing source of chemicals at some CSO locations.

4.1.3 Wildlife

The WQA found relatively high risks to spotted sandpipers from lead in their food, and lower risks to bald eagles, great blue herons and river otters. The WQA found no discernible differences in risks to wildlife under baseline and without CSO conditions.

- There appear to be relatively high risks to spotted sandpipers from chemicals in their food, particularly lead but also copper, PCBs, and zinc.
- Risks to other wildlife receptors appeared to be much lower than risks to spotted sandpipers.

- Risks to wildlife that use the resources of the Duwamish Estuary are not predicted to change when CSOs are removed from the system.

4.1.4 People

The WQA found relatively high cancer and non-cancer risks from arsenic and PCBs to people that eat seafood every day. PCB risks are higher in the Duwamish Estuary than in Puget Sound, and arsenic risks are the same in the Duwamish Estuary and Puget Sound. No differences were discerned in risks to people from eating seafood under baseline and without CSO conditions.

- There are potential risks to people from eating Duwamish River and Elliott Bay seafood, most notably from exposure to PCBs and arsenic. Relatively high risks of cancer and of non-cancer effects were predicted for people who eat seafood from the estuary every day.

- Our fishing survey found several people who eat seafood daily from the Duwamish River and Elliott Bay.

- Health risks are also predicted for people who catch and eat seafood from the Duwamish River and Elliott Bay on average about two times per month. These risks are much lower than those predicted for people who eat seafood from the estuary every day.

- The risks caused by arsenic are approximately the same for eating fish from Puget Sound reference sites as for eating fish from the Duwamish River and Elliott Bay.

- Cancer risks caused by PCBs in sole are about 20 times higher in the Duwamish River than Elliott Bay and nearly 10 times higher in Elliott Bay than from the Puget Sound reference areas.

The WQA found some health risk to net fishers on the Duwamish River and Elliott Bay, and to swimmers at Duwamish Park and Duwamish Head from arsenic and PCBs, but no health risk from chemicals to SCUBA divers at Seacrest Park or to windsurfers in Elliott Bay. No differences were discerned in the health risks to net fishers or swimmers under baseline and without CSO conditions.

- Potential lifetime cancer risks of about 1 in 100,000 are predicted from arsenic and PCBs for those people who net fish in the Duwamish River 90 times per year due to direct contact with the sediment.

- Lifetime cancer risks above 1 in 1,000,000 from arsenic and PCBs in sediments were predicted for young children that swim 24 times per year for six years at Duwamish Park in the Duwamish River and Duwamish Head in Elliott Bay.

- No risks from chemical exposures were predicted to windsurfers in Elliott Bay or SCUBA divers at Seacrest Park, to people that engage in these activities as frequently as 24 times per year.

- Removing CSOs is not predicted to reduce chemical risks to people because CSO discharges are not significant current sources of PCB and arsenic compared to other sources in the estuary.

The WQA found risks from CSO viruses and Giardia to people who swim during or immediately after a CSO event, primarily in the Duwamish River and along the shore of Elliott Bay.

- Risks of infection from direct contact with viruses and *Giardia* throughout the Duwamish River and along the Elliott Bay shoreline are predicted to be reduced with removal of CSOs relative to baseline conditions.

- Risks of infection from direct contact with viruses and *Giardia* attributable to CSO discharges decrease quickly after CSOs stop discharging.

- Predicted fecal coliform concentrations throughout the Duwamish River and along the Elliott Bay shoreline indicate frequent potential risks of infection from consumption of shellfish under baseline and without CSO conditions.

- Predicted fecal coliform concentrations throughout the Duwamish River indicate frequent potential risks of infection from swimming under baseline and without CSO conditions. Predicted fecal coliform concentrations along the Elliott Bay shoreline indicate occasional potential risks of infection from swimming under baseline and without CSO conditions.

- Predicted fecal coliform concentrations near the Denny Way CSO are noticeably reduced under without CSO conditions, indicating reduced potential risk at this location with removal of CSOs.

- Fecal coliform concentrations in the Duwamish River and along the Elliott Bay shoreline attributable to CSO discharges indicate occasional potential risks of infection from swimming associated with CSO discharges.

The remainder of this section provides an overview and interpretation of the data and analyses supporting these key findings. The complete results of the human health, wildlife and aquatic ecological risk assessments can be found in Appendices B-2, B-3 and B-4.

4.2 Risks to Aquatic Life

The aquatic ecosystem is potentially at risk not only from chemicals in the waters and sediments of the Duwamish River and Elliott Bay, but also from changes in water quality parameters (DO, pH, salinity, temperature, and TSS) and physical impacts (scouring, sedimentation, and displacement). Figure 4-1 is the conceptual model for aquatic life exposure to chemicals in the Duwamish River and Elliott Bay. Figure 4-2 shows the conceptual model for risks from changes in water quality parameters and physical impacts (collectively referred to as physical stressors) in the Duwamish River and Elliott Bay.

4.2.1 Risks to Aquatic Life in the Water

We found no apparent risk to aquatic life in the water column from chemicals and little risk from physical stressors, under either the baseline or without CSO scenario. Table 4-1 provides a summary of the risks to aquatic life in the water column of the Duwamish River and Elliott Bay. We evaluated risks in two stages. First, we compared chemical concentrations to screening thresholds (U.S. EPA water quality criteria[2]), then we did a more detailed evaluation of each stressor that exceeded its criterion, along with the physical stressors. The screening thresholds were designed to be protective of sensitive and commercially valuable species. Chemicals that never exceeded their screening threshold concentrations during the course of the one-year simulation, at any location in the Duwamish River or Elliott Bay, were considered not to pose risk to aquatic life in the water column. Note that exceedance of a screening level does not indicate risk; it only means that presence or absence of risk cannot be determined without further investigation. Chemicals that exceeded screening levels at any location, at any time during the one-year simulation were evaluated in the risk assessment. Risks to salmon were evaluated separately and are discussed separately below.

Table 4-1. Summary of Duwamish River and Elliott Bay Water Column Risks to Aquatic Life

	Baseline	Without CSOs	Reference Locations
Is risk present?	Probably not	Probably not	Probably not
What is the magnitude of risk?	Low-none[a]	Low-none[a]	-
Where are the risks?	Throughout the Study Area	Dispersed throughout the Study Area	-
How is the risk harmful?	Potentially chronically impacting the larvae of sensitive species	Potentially chronically impacting the larvae of sensitive species	-
What's causing the risk?	TSS	TSS	Reference site TSS data are not available

[a] Water column risks are deemed low to none for aquatic life because TSS exceedances were based on data for freshwater species which are generally more sensitive than estuarine species to TSS. The percentage of species affected by chemicals ranges from less than 1 percent to 3 percent.

[2] In some cases we updated criteria values using new data meeting standard U.S. EPA quality criteria, and standard U.S. EPA criteria development methods (Stephan et al. 1985).

The evaluation of physical stressors revealed no risks from most of the water quality parameters (DO, pH, salinity, or temperature). The risk characterization for these stressors is described in Appendix B-4. We did find some potential water column risk to aquatic life from TSS. The TSS concentrations in the estuary appear to be high enough to affect the larvae of species that are sensitive to TSS. There are no water quality criteria for TSS so we developed the TSS thresholds for this analysis, using data on duration of exposure to TSS concentrations from the scientific literature (see Appendix B-4). We found that TSS risks decline marginally when CSOs are removed from baseline conditions. We do not believe that the change in TSS between baseline and without CSO conditions is significant because we expect the Duwamish Estuary ecosystem to be at least partially adapted to somewhat turbid waters naturally observed in this system.

The evaluation of physical stressors also revealed that flow velocities, both in CSO plumes and the river channel itself, regularly exceed sustainable swimming speeds for juvenile salmon.

The chemicals that exceeded their screening thresholds (as described in Section 4.2.1) are shown in Table 4-2. These were evaluated further using the WERF Tier 3 methodology. The WERF Tier 3 methodology is a process that calculates the percent of species whose acute or chronic toxicity thresholds were exceeded by the exposure concentrations. This methodology is described in Appendix B-4. To perform this analysis, it was necessary to make a series of assumptions and decisions, detailed below:

Table 4-2. Chemicals that Exceed Their Water Column Acute and Chronic Aquatic Life Screening Levels in the Duwamish River and Elliott Bay

Water Column Aquatic Life Chemical COPCs	Duwamish River		Elliott Bay	
	Acute	Chronic	Acute	Chronic
Arsenic	X[a]		X	
Benzo(a)anthracene	X			
Benzo(g,h,i)perylene		X		
Copper	X	X	X	X
Fluoranthene	X			
Lead	X	X		X
Nickel	X	X		X
PCBs		X		X
TBT		X		X
Zinc	X			

[a] X indicates that the screening threshold is exceeded at least one location and time.

- The measure of risk was the percentage of species whose toxicity thresholds were exceeded by the exposure concentration (Appendix B-4). We evaluated both acute and chronic risk.

- We used the logistic regression method described in the WERF methodology (WERF 1996) and Appendix B-4 to fit distributions to the toxicity threshold data.

- For estimating acute exposure, we used monthly maximum one-hour concentrations (Stephan et al. 1985) in each model grid element with salinity greater than five parts per thousand (‰) (Appendix B-4). We did not estimate risks from chemical exposures in waters at less than 5‰ because at those salinities, estuarine organisms either have a mechanism to avoid water exposure, or the freshwater itself is the toxicant.

- To estimate chronic exposure, we used monthly maximum four-day running average concentrations (Stephan et al. 1985) in each grid element with salinity greater than 5‰, as described in Appendix B-4.

- We used site-specific data in the water and sediment quality model whenever available. That included CSO loading data (times, volumes, flow rates, COPC concentrations), estuary hydrodynamics, initial sediment and water quality conditions, sediment and suspended solids characteristics, and water quality conditions at measured locations and times. Data that generally were not site-specific included chemical reaction rate and phase partitioning coefficients.

- We used dissolved chemical concentrations derived from model output to estimate exposure concentrations in the water column.

- For each model cell, we estimated the percentage of species whose toxicity thresholds were exceeded by the monthly maximum exposure concentration. Toxicity thresholds were obtained from the scientific literature using U.S. EPA rules for data quality (Appendix B-4).

Within a given month, we used the spatially averaged percentage of species whose toxicity thresholds were exceeded by the monthly maximum exposure concentration. We evaluated the Duwamish River separately from Elliott Bay. In other words, we calculated the average across all Duwamish River model grid elements with salinity greater than 5 percent – of the percentage of species whose monthly maximum acute exposure concentration exceeded their acute toxicity thresholds. We did the same for Elliott Bay, and for chronic exposure concentrations in both the Duwamish River and Elliott Bay. These results are presented in Table 4-3. Values in this table start in September as this was the starting point for the water and sediment quality model on the Environmental Fluids Dynamic Computer Code (EFDC) model. This was based on the calibration data produced by the field sampling program which was initiated in September 1996.

Table 4-3. Percent Aquatic Life Species at Acute and Chronic Risk from Exposure to COPCs[a] in the Study Area (Values Presented are Baseline, Without CSOs)

Chemical	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Duwamish River, Acute Risks												
Arsenic	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Copper	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%
Lead	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Nickel	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Zinc	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Duwamish River, Chronic Risks												
Copper	1%,1%	2%,2%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%
Lead	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Nickel	1%,1%	1%,1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	1%,1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
TBT	N/AV[b]	N/AV[b]	2%,2%	1%,1%	1%,1%	<1%,<1%	1%,2%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Elliott Bay, Acute Risks												
Arsenic	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	1%,1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Copper	1%,1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	1%,<1%	<1%,<1%	1%,1%	<1%,<1%	<1%,<1%	<1%,<1%
Elliott Bay, Chronic Risks												
Copper	1%,1%	1%,1%	1%,1%	<1%,<1%	<1%,<1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%	1%,1%
Lead	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
Nickel	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	3%,3%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%
TBT	2%,2%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%	<1%,<1%

[a] Only chemicals that exceeded their screening thresholds are presented here.

[b] N/AV – Not available due to model irregularities

There are two things to note in the Table 4-3 results. The first is the general absence of risk. In most cases exposure concentrations are low enough to potentially affect 1 percent of species or less. For acute risks, this is true in all months of the year, for all chemical COPCs, in both the Duwamish River and Elliott Bay. For chronic risks, this is true in all months of the year, for all chemical COPCs, in both the Duwamish River and Elliott Bay except for nickel in Elliott Bay in March. Nickel in March has slightly higher chronic risks, but is still below the level of protection afforded by U.S. EPA water quality criteria, which generally try to protect 95 percent of species (Stephan et al. 1985). This finding has been partially corroborated by Brandon Street CSO effluent bioassays, the results of which are summarized in Table 4-4. The bioassays found no chronic toxicity of CSO effluent to *Ceriodaphnia* or fathead minnows, two test species selected in part because of their sensitivity to chemical toxicants.

Table 4-4. Toxicity of Brandon Street CSO Effluent to *Ceriodaphnia* and Fathead Minnows

Evaluation	***Ceriodaphnia dubia***		**Fathead minnows *(P. promelas)***	
	Survival	**Reproduction**	**Survival**	**Reproduction**
NOEC[a]	100%	100%	100%	100%
LOEC[b]	>100%[d]	>100%	>100%	>100%
LC_{50}[c]	>100%	N/A[e]	>100%	N/A

[a] NOEC = No Observed Effect Concentration

[b] LOEC = Lowest Observed Effect Concentration

[c] LC_{50} = Median lethal concentration

[d] By indicating that the response was >100 percent for an LOEC, this says that the lowest observable effect would be greater than the undiluted effluent concentration. In other words, pure, undiluted effluent does not cause any observable toxicity for this organism.

[e] N/A = Not applicable

The second thing to notice in Table 4-3 is that the risk estimates are generally the same for the baseline and without CSO conditions. The chronic risk estimate for nickel in March, for example, is 3 percent for both baseline and without CSO conditions.

So far we have been discussing the average risks to species across the Duwamish River and across Elliott Bay. This is a useful way of expressing the risks to populations, which are spatially dispersed and therefore may not be "at risk" *as populations* from locally elevated exposure concentrations. Nonetheless it is important also to look at the spatial pattern of risks, for two reasons:

- To get a sense of how much risks vary spatially, and
- To identify locally elevated risks at important habitat areas.

Figures 4-3, 4-4, and 4-5 are maps showing the spatial pattern of baseline risks in the Duwamish River and Elliott Bay in March, a month with several storms, including one big storm and CSO event in late March with the highest recorded river flow during the modeled year ($261m^3/s$). We have mapped baseline risks for copper acute risks (see Figure 4-3), copper chronic risks (see Figure 4-4) and TBT chronic risks (see Figure 4-5).

The detailed results of the risk characterization for aquatic life are presented in Appendix B-4. In summary, our overall conclusion from the analysis of risks to aquatic life in the water column is that there is little or no risk under baseline or without CSO conditions. This finding has been partially corroborated by CSO effluent bioassays, the results of which are summarized in Table 4-4 and a complete report of these tests included in Appendix B-4. The bioassays found no toxicity of CSO effluent to *Ceriodaphnia* or fathead minnows, two test species selected in part because of their sensitivity to chemical toxicants.

4.2.2 Risks to Salmon

We have compared available toxicity reference values (TRVs) for salmon and trout species to predicted water concentrations, and there do not appear to be any risks to salmon from direct exposure to chemicals in the water column (Appendix B-4). Additionally, comparison of dietary toxicity values with measured concentrations in the amphipods *Corophium* sp. and *Eogammarus confervicolus* collected from the vicinity of Kellogg Island indicated no risk of increased salmon mortality or reduced salmon growth from direct exposure to chemicals in their diet. Displacement of smolts could occur by exposure to increases in current velocities in CSO plumes, yet plume velocities do not differ greatly from reference velocities of the river. Evidence suggests that smolts seek refuge in protected access along the shoreline.

4.2.3 Risks to Aquatic Life in the Sediments

The evaluation of risks to benthos was based on a comparison of measured nearfield and model-predicted farfield sediment COPC concentrations to state sediment management standards[3]. There are no state standards for sedimentation and scouring, so we derived criteria for these two stressors, as described in Appendix B-4. The model-predicted sediment concentrations were for the top ten centimeter layer, at the end of the one year baseline and without CSO simulations. We also re-ran the one-year simulation for ten sequential years, to discern whether differences between baseline and without CSO concentrations in the top ten centimeters increased from the first simulated year to the

tenth. In addition, we conducted a benthic survey comparing a nearfield site at the Duwamish/Diagonal CSO and storm drain to a farfield site at Kellogg Island.

There are potential risks to benthic organisms in the sediments of the Duwamish River and Elliott Bay (Table 4-5). These risks are fairly widespread. Chemicals contributing to these risks include mercury, the organometalloid TBT, and several organic compounds (PAHs, PCBs, bis(2-ethylhexyl)phthalate, and 1,4-dichlorobenzene). The sediment concentrations of a few other chemicals exceeded sediment management standards occasionally (Table 4-5). These included arsenic (1 percent of cells) cadmium (4 percent of cells), copper (2 percent of cells), lead (less than 1/10 of 1 percent of cells). Nickel slightly exceeded its sediment management standard (maximum HQ = 2.3) over a large portion of the study area (82 percent of cells), but its maximum concentration was three times higher in reference sediments than in the study area.

Table 4-5. Summary of Duwamish River and Elliott Bay Sediment Risks to Aquatic Life

	Baseline	Without CSOs	Reference
Is risk present?	Yes	Yes	Yes
What is the magnitude of risk?	Low – Moderate[a,b]	Low – Moderate[a,b]	Low
Where are the risks?	Dispersed through the study area[b]	Dispersed through the study area[b]	Dispersed through Puget Sound
How is the risk harmful?	Loss of diversity and increased abundance of organic enrichment-tolerant species near CSOs	Loss of diversity	Loss of diversity
What's causing the risk?	Metals, organics, physical impacts, and organic enrichment	Metals, organics, and physical impacts	Metals
Is risk reduction from removing CSOs greater after ten years than after one or two years?	No		

[a] Sediment risks are identified as low to moderate as maximum hazard quotients (HQs) range from 0.1 (low) to 27.5 (moderate) with 0 percent of cells with HQs > 1 (low) to 63 percent of cells with HQs >1 (moderate).

[b] TBT is an exception to the general pattern for sediment risks, in that it has been measured in sediments in the localized area around the north end of Harbor Island at concentrations up to 5,000 times the TRV. We still consider the potential risk to be moderate because the TBT is in an area also impacted by shipping activity, and likely to have low bioavailability because it is associated with paint chips.

To reiterate, these risk predictions are based on either current conditions in the nearfield or predicted conditions in the farfield one year after removing CSOs. These results indicate that CSO removal would provide little or no reduction in sediment based risks in areas of the Duwamish River and Elliott Bay not directly adjacent to CSOs. However, it can sometimes take longer than a year to detect any changes in sediment concentrations after source elimination (Allen 1995; NRC 1997).

To investigate whether surface[4] sediment quality would continue to improve without CSOs relative to the baseline scenario for more than a year after CSOs were eliminated, we ran the simulation ten consecutive times. We used the end-of-year conditions from the previous year's run as the initial conditions for the next year's run. We compared the difference between average surface sediment concentration (baseline – without CSOs) after one year's simulation[5] to the difference between average surface sediment concentration after ten years' simulation. The ten-year simulation was run for seven chemicals that posed risk to one or more of the receptors from sediment exposure—1,4-dichlorobenzene, bis(2-ethylhexyl)phthalate, chrysene[6], copper, lead, mercury, and total PCBs.

If surface sediment quality continued to improve without CSOs relative to baseline for more than a year after the simulation was started, we hypothesized that the difference between baseline and without CSO concentrations be greater after ten years than it was after one year. Therefore, we did a statistical comparison[7] of the average ten-year surface sediment concentration difference to the average one-year difference, to test whether the difference was increasing. If the differences were not increasing, the one-year simulation would be expected to be sufficient to evaluate the significance of CSOs to sediment risks. If it was increasing, a longer simulation might be needed.[8]

The ten-year difference between predicted baseline and without CSO concentrations was greater than the one-year difference for only one of the seven chemicals tested-copper. This indicates that CSOs are contributing a higher copper concentration to sediments than are other sources. However, the analysis also found that copper sediment concentration, both baseline and without CSO are generally lower than the Washington State sediment management standard of 390 mg/ kg_{dry}. The average estimated copper sediment concentration at the end of the one-year baseline simulation was of approximately 80 mg/kg_{dry},. The copper concentration exceeded the sediment management standard in

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4 We used the top ten centimeters.

5 Due to difficulties in initializing the model for 1,4-dichlorobenzene, bis(2-ethylhexyl)phthalate, and chrysene, differences were calculated for the 2-year simulation results.

6 Chrysene was chosen to represent the suite of sediment PAHs as chrysene concentrations were highly correlated with the concentrations of the remaining PAH ($r^2 \geq 0.8$).

7 We used the Wilcoxon signed-rank test ($p = 0.05$).

8 We said "might be needed" because if COPC's baseline – without CSOs concentration difference was increasing, but both baseline and without CSO risks were low, then one might not need a longer simulation to evaluate the significance of CSOs to sediment risk for that COPC.

approximately 2 percent of the study area cells, with a maximum HQ of 2.1 (Table 4-6). However, the difference between baseline and without CSO copper concentrations was small (approximately two mg/ kg_{dry} after one year, and four mg/ kg_{dry} after ten years).

Table 4-6. Maximum and Average Aquatic Life Sediment Hazard Quotients and the Percent Cells with Hazard Quotients >1 after One-Year of Model Simulation in the Duwamish River and Elliott Bay Compared with the Range of Maximum and Minimum Hazard Quotients in Reference Sediments

Chemicals	Study Area Baseline Condition			Reference Sediments	
	Maximum	Average	% Cells with HQs > 1	Maximum	Minimum
Arsenic	1.3	0.2	1%	0.4	<0.05
Benzo(a)anthracene	6.7	0.4	9%	<0.1	<0.1
Benzo(a)pyrene	0.8	0.1	0%	<0.1	<0.1
Benzo(b)fluoranthene	2.2	0.2	2%	<0.1	<0.1
Benzo(g,h,i)perylene	0.8	0.1	0%	0.1	<0.1
Benzo(k)fluoranthene	1.8	0.1	1%	<0.1	<0.1
Bis(2-ethylhexyl)phthalate	10.8	1.2	34%	N/AV	N/AV
Cadmium	1.5	0.3	4%	0.6	<0.1
Chrysene	7	0.4	9%	<0.1	<0.1
Copper	2.1	0.2	2%	0.1	<0.1
Dibenzo(a,h)anthracene	0.1	<0.11	0%	0.2	<0.1
1,4-dichlorobenzene[a]	3.3	0.5	14%	N/AV	N/AV
Fluoranthene	10.3	0.4	9%	<0.1	<0.1
Indeno(1,2,3-c,d)pyrene	0.3	<0.13	0%	0.1	<0.1
Lead	2.1	0.1	<0.1%	<0.1	<0.1
Mercury	8.3	0.8	23%	N/AV	N/AV
4-Methylphenol	4.9	0.2	4%	N/AV	N/AV
Nickel	2.3	1.3	82%	6.7	0.4
Phenanthrene	4.5	0.3	4%	0.2	<0.1
Pyrene	1.5	0.1	1%	<0.1	<0.1
TBT [a,] (In-House Criterion)	4776.60[b]	N/AV	N/AV	N/AV	N/AV
TBT[a] (Roy F. Weston Criterion)	8439.85[b]	N/AV	N/AV	N/AV	N/AV
Total PCBs[a]	27.5	2	63%	N/AV	N/AV
Zinc	1.4	0.3	1%	0.2	<0.1

a The hazard quotients for these four chemicals are the initial conditions rather than the result of the one-year simulation. Initial conditions for these chemicals were regenerated with new data after the model simulations had been completed.

b The maximum hazard quotient represented is based on an actual measurement of TBT in sediments located just north of Harbor Island.

Because the copper sediment risks are low and the difference between baseline and without CSO copper sediment concentrations slight, a longer simulation would probably provide little additional useful information for evaluating the significance of CSOs to sediment copper risks. Because the baseline – without CSOs difference was not increasing for 1,4-dichlorobenzene, bis(2-ethylhexyl)phthalate, chrysene, lead, mercury or total PCBs, a longer simulation is not expected to provide useful information for evaluating the significance of CSOs to sediment risks for these COPCs.

In addition to the risks from chemical stressors, there are local areas (e.g., upper Duwamish River at the Turning Basin, intertidal flats receiving CSO or storm water discharges at low tide, CSO footprints) where sedimentation and scouring will likely affect the benthic community.

The benthic community survey conducted in the Duwamish River at the Duwamish/Diagonal CSO and storm drain suggested that impacts also occur near CSOs from both chemicals and organic enrichment. The impacts included reduced community diversity and an increase in abundance of organic opportunist species (e.g., *Capitella capitata* [marine polychaete]). Changes in abundance and diversity were demonstrated by pairwise comparisons of the benthic community found at the Duwamish/Diagonal CSO and storm drain discharge area with the benthic community from the nearby in-river reference area at Kellogg Island (Figure 4-6). For example, comparing the number of taxa in sediment samples of similar grain size[9] and organic carbon content at each sampling site indicated that an overall reduction in number of taxa occurred at the stations closest to the outfall. It was concluded that the cumulative effects of the Duwamish/Diagonal CSO and storm drain discharges led to a distinct infaunal community grading from impacted at the CSO and storm drain station nearest the outfall to relatively unimpacted at the station furthest from shore. The benthic survey report is included in Appendix B-4.

The areal extent of these impacts appears to be limited to the footprint[10] of the CSOs. At the Duwamish/Diagonal CSO and storm drain, the footprint is characterized by elevated sediment concentrations of bis(2-ethylhexyl)phthalate and 1,4-dichlorobenzene. Concentrations of bis(2-ethylhexyl)phthalate exceed the Puget Sound marine sediment cleanup screening level of 78 mg/kg organic carbon (WAC 173-204-520) while concentrations of 1,4-dichlorobenzene exceed the marine sediment management standards chemical criterion of 3.1 mg/kg organic carbon (WAC 173-204-320). Based on

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9 Grain size (the percentages of sand, silt, and clay) strongly influences the number and type of taxa present in a sediment. Comparisons between target and reference sediments are always made for samples of similar grain size to control for this influence.

10 The footprint of a CSO is an area of deposition of chemicals adsorbed to sediment particles that settle to the bottom at varying distances from the end of the pipe depending on particle size and

exceedances of the sediment management standard for bis(2-ethylhexyl)phthalate and 1,4-dichlorobenzene, the footprint at the Duwamish/Diagonal CSO and storm drain covers and area of approximately 21,000m^2 (King County 1997). Based on exceedances of the sediment management standards for 1,4-dichlorobenzene, bis(2- ethylhexyl) phthalate, and PCBs, the size of the footprint at the Norfolk CSO is approximately 1,850m^2 (King County 1996).

1,4-dichlorobenzene is used in toilet block deodorizers (its other main use is in mothballs), and it has been detected in a sediment footprint around the Macaulay Point marine municipal sewage outfall in Victoria, British Columbia (Chapman et al. 1996) at concentrations comparable to those in Duwamish Estuary sediments. Therefore, it is very likely that sediment 1,4-dichlorobenzene concentrations are at least partially attributable to CSOs, and would be reduced in the long run by removing CSOs.[11] 1,4-dichlorobenzene exceedances of the Washington State sediment management standard occur over an estimated 14 percent of the study area. Baseline 1,4-dichlorobenzene sediment risks are mapped in Figure 4-7.

The sediment management standard for 1,4-dichlorobenzene is based on the apparent effects threshold[12] (AET) for benthic abundance.[13] It is important to keep in mind that AET does not establish a causal relationship between a stressor and an effect (e.g., between 1,4-dichlorobenzene and reduced benthic abundance); it establishes a correlation based on field observations (Spies 1989). The AET method cannot separate the effects of individual stressors when multiple stressors are present (Adams et al. 1992). For example, one would expect sediment-bound chemicals from CSOs to be correlated with organic enrichment, which could be the cause of an apparent effect like reduced benthic abundance. Studies to date of 1,4-dichlorobenzene generally have been observational and correlational (Chapman et al. 1996), and direct experimental evidence demonstrating that 1,4-dichlorobenzene in sediments causes risks is lacking. The water toxicity database for 1,4-dichlorobenzene is limited as well; U.S. EPA's criterion document contains only two data points: an acute LC_{50} for sheepshead minnow, and an acute LC_{50}

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[11] People in King County also use mothballs on their lawns to control moles and crane flies, although we have not quantified the extent of this practice. This use would contribute 1,4-dichlorobenzene to both storm drains and CSOs.

[12] The AET approach was developed specifically to assess and manage the quality of sediments in Puget Sound. It uses empirical data (field and laboratory) to identify concentrations of chemicals above which biological effects are always expected. AET values are derived using a comparison of biological effects and chemical data in paired data sets from field-collected samples. In a given data set, the AET for a particular chemical is the sediment chemical concentration above which biologically adverse effects are always observed (based on statistical significance, $p < 0.05$) relative to an appropriate reference sediment (Adams et al. 1992).

[13] Test sediment has less than 50 percent of the reference sediment mean abundance of any one of the following major taxa: Class Crustacea, Phylum Mollusca or Class Polychatea, and the test medium abundance is statistically different (*t*-test, $p < 0.05$) from the reference sediment abundance (Ch 173-204 WAC, page 17).

for mysids. Searches of the aquatic toxicology literature revealed no additional 1,4-dichlorobenzene aquatic toxicity data. If 1,4-dichlorobenzene is found to cause (rather than correlate with) sediment risks, then source control (e.g., reducing its use in toilet block deodorizers) may be the most cost-effective way to manage the risks.

Bis(2-ethylhexyl)phthalate[14] is a common plasticizer. It has been used since the 1930s to make plastics more flexible (Kirk-Othmer's Encyclopedia). It is found in polyvinyl chloride plastic products such as toys, vinyl upholstery, shower curtains, adhesives, and coatings (ATSDR ToxFAQs 1993). It is a persistent environmental chemical commonly present in fish, water, and sediments (Jobling et al. 1995; Bis(2-ethylhexyl)phthalate Fact Sheet 1986). Based on its widespread use, both CSOs and other sources are likely contributors of this chemical to the environment. This is consistent with the chemical's relatively widespread and uniform distribution across the study area (Table 4-6, Figure 4-8). In light of the contributions from other sources and the baseline distribution of bis(2-ethylhexyl)phthalate in Duwamish Estuary sediments, we expect removing CSOs will reduce bis(2-ethylhexyl)phthalate sediment concentrations only proximal to CSOs not located near storm drains. We do not expect changes in farfield bis(2-ethylhexyl) phthalate sediment concentrations as long as it remains in widespread use in plastics. We expect storm drain loads will continue to effect nearfield sediments, so we do not expect sediment concentrations to decline near CSOs proximal to storm drains.

Bis(2-ethylhexyl)phthalate is predicted to exceed the Washington State sediment management standard in 34 percent of the model cells. The sediment management standard is based on the Microtox bacterial luminescence bioassay[15] (47 mg/kg[16]), although the benthic abundance AET is only slightly higher at 60 mg/kg. As noted above, the AET method does not establish a causal relationship between a stressor and an effect; it only establishes a correlation based on field observations (Spies 1989). In the case of bis(2-ethylhexyl) phthalate, we note that the TRV estimated from the proposed U.S. EPA water quality criterion by equilibrium partitioning theory (see Appendix B-4) is approximately 700 times the Washington State sediment management standard, suggesting the sediment management standard may underestimate the toxic effects threshold for bis(2-ethylhexyl)phthalate (and therefore overestimate risk).

PAHs enter the estuary both in CSOs and storm drains (METRO 1983). The baseline estimate is that one or more PAHs exceeds its TRV in 10 percent of the model cells (and Figure 4-9). The spatial distributions of the different PAHs in the Duwamish Estuary sediments are very similar, suggesting they have similar sources. Washington State

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[14] Also known as di(2-ethylhexyl)phthalate or DEHP.

[15] 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 (*t*-test, $p<0.05$) from each other (Ch 173-204 WAC, page 17).

[16] Normalized to organic carbon.

sediment management standards for PAHs are based on the oyster larval[17] and Microtox[18] AETs. The AETs generally are similar to other toxicity threshold values (Effects Range – Low (ER-L), Effects Range – Median (ER-M) (Long et al. 1995) and equilibrium partitioning-derived values (DiToro et al. 1991); see Appendix B-4), so we consider them to be reasonably reliable TRVs.

The Washington State sediment management standard for mercury is comparable to toxicity thresholds estimated by other methods. It falls between the ER-L and ER-M and is within a factor of three of the Ecotox (equilibrium partitioning) threshold (see Appendix B-4). All the AETs for mercury are within a factor of three. In light of the high level of consistency across methods for setting the toxicity threshold, we consider the sediment management standard for mercury to be a reliable TRV. Sediment mercury concentrations are predicted to exceed the TRV in 23 percent of the model cells under baseline conditions (Table 4-6, Figure 4-10). The toxic effects of inorganic and methyl mercury, based on available estuarine data, include population growth reduction, decreased reproductive success and developmental inhibition (AQUIRE 1995, U.S. EPA 1985). Extensive deposits of mineable mercury are known to exist adjacent to the upstream reach of the Green River; those deposits could be a principal source of mercury to the Duwamish Estuary (Valentine 1971, METRO 1983). Both CSOs and other sources are likely contributors of this chemical to the environment. In light of the contributions from other sources and the baseline distribution of mercury in Duwamish Estuary sediments, which does not suggest a strong CSO source, we consider it unlikely that removing CSOs will affect mercury sediment concentrations. The ten-year simulation results, which found no change in baseline versus without CSO sediment mercury risks, provides further evidence that removing CSOs will not affect mercury sediment concentrations.

Although TBT and PCBs do pose the most important potential risks to sediment-dwelling organisms in the Duwamish Estuary, PCBs are primarily an historical source and were not detected in the CSOs in this study area. TBT was not monitored in the CSOs – it is a chemical used in antifouling paints on ships. Its use is regulated and becoming less common in the Duwamish Estuary. Sediment TBT concentrations are high at the north end of Harbor Island, relative to a TRV derived using equilibrium partitioning theory

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[17] 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) (Ch 173-204 WAC, page 17).

[18] 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 (*t*-test, $p<0.05$) from each other (Ch 173-204 WAC, page 17).

(DiToro et al. 1991).[19] The risk estimates for TBT in the Duwamish Estuary are highly uncertain due to uncertainty about the partitioning of TBT between sediments and water,

[19] We used an equilibrium partitioning-derived threshold because is no sediment management standard, ER-L (Effects Range-Low) or ER-M (Effects Range-Median) for TBT.

and uncertainty about the bioavailability of particulate-bound TBT. Cardwell et al. (1997) provides a review of TBT partitioning and bioavailability issues. The WQA may have underestimated the TRV and, therefore, overestimated sediment TBT risk by a factor of 10 to 100 or more. Nonetheless, the sediment TBT concentrations at the north end of Harbor Island are high enough to potentially pose risk to sensitive species, even if we underestimated the TRV by a factor of 1,000. The risks associated with TBT include imposex in snails (the imposition of male sexual organs in female snails) and chambering in shells and/or decreased growth (U.S. EPA 1997).

PCBs present in the aquatic environment are primarily from point source discharges of industrial and urban wastes (Chan et al. 1998) and industrial spills. For example, a recent study of the Delaware Estuary identified low levels of PCBs in municipal point sources (Fikslin 1998). An earlier study of the Duwamish Estuary (Pavlou and Dexter 1979) found that surface sediments in the Duwamish River contain some of the highest PCB concentrations in Puget Sound. The Duwamish River is the site of a known 1974 spill of Aroclor 1242. PCBs are of particular concern based on their ability to bioaccumulate (Field and Dexter 1988). Total PCBs in the study area pose low to moderate risks to aquatic organisms (average and maximum sediment HQs of 2 and 27.5, respectively, with 63 percent of the model cells having sediment HQs greater than 1.0; Table 4-6, Figure 4-11).

The Washington State sediment management standard used to identify the potential PCB risks to benthic organisms is the Microtox bacterial luminescence bioassay (12 mg/kg[20]). The benthic abundance AET is over five times higher at 65 mg/kg.

In summary, we believe there are potential risks to benthic organisms in the sediments of the Duwamish River and Elliott Bay. There are potential risks from bis(2-ethylhexyl) phthalate, 1,4-dichlorobenzene, mercury, and PAHs; localized effects (reduced benthic diversity, increased abundance) from organic enrichment near CSOs; and potential risks from PCBs and TBT, which are probably not CSO-related. The potential risks to aquatic life from sediments are clearly higher in the Duwamish River and Elliott Bay than at the reference sites (Table 4-6) (WSDOE 1998). Sediment HQs were calculated for reference sites for comparison to the Duwamish River and Elliott Bay HQs. Maximum HQs were less than 1.0 for all COPCs except for nickel, which exceeded ER-L and ER-M values derived by Long et al. (1995) (no State of Washington sediment management standards are available for nickel). Nickel concentrations were comparable at the reference sites and in the Duwamish Estuary. Thus, while 82 percent of cells have HQs greater than 1.0, this appears to be similar to risks in other, non-urban parts of Puget Sound.

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[20] Normalized to organic carbon.

4.2.4 Sediment PAH Biomarkers

Our analysis of prevalence of liver lesions in English sole from exposure to sediment PAHs is presented in Appendix B-4. Table 4-7 presents the predicted prevalence of liver lesions, under baseline conditions, without CSOs, and the naturally occurring rates of liver lesion formation present in populations not exposed to sediment PAHs (Horness et al. 1998). Elevated liver lesions are predicted for the Duwamish River and Elliott Bay, both baseline and without CSOs. It is interesting to note that we did see a difference between baseline and without CSO biomarkers, indicating that CSOs are a source of PAHs to the study area. However, we included chrysene in the ten-year simulation[21] and found that the difference between baseline and without CSO concentrations was statistically significantly decreasing[22] between the first and tenth year.[23] Therefore, the differences between baseline and without CSO incidences of liver lesions shown in Table 4-7 would decrease as well. Predicted PAH concentrations in sediments tend to fall right around the Washington State sediment management standards.

Elevated occurrences of liver lesions have been associated with exposure to PAHs in enclosed embayments in the Puget Sound area as well as in other areas of the coastal waters of the United States (Myers et al. 1994; Johnson et al., 1998). Research conducted by the Northwest Fisheries Science Center has established a predictive relationship between bulk sediment PAH concentrations and the prevalence of a number of different types of liver lesions (Horness et al. 1998). The predictions based on the model of Horness et al. (1998) are somewhat higher than data reported by Johnson et al. (1998) in Elliott Bay English sole. Predicted neoplasms were approximately 10 percent, whereas the observed incidence reported by Johnson et al. (1998) for Elliott Bay English sole is 3 percent. Predicted specific degenerative/necrotic (SDN) lesions were approximately 53 percent, whereas the observed incidence (Johnson et al. 1998) is 22 percent. The incidence of liver lesions has not been correlated with any population-level effects on English sole, but it is a biomarker of exposure of English sole to PAHs in the Duwamish River and Elliott Bay sediments.

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[21] We chose chrysene for the ten-year comparison because the SPMD data showed the highest average concentration in the water column, and sediment data showed good spatial correlation ($r^2 > 0.8$) of chrysene with all the other measured PAHs (phenanthrene, pyrene, benzo(k)fluoranthene, chrysene and benzo(b)fluoranthene.

[22] Using a two-sided Wilcoxon signed rank test, $P = 0.05$.

[23] Again, the purpose of the ten-year simulation was to determine whether the differences between baseline and without CSO conditions were increasing over time.

Table 4-7. Predicted Incidence of English Sole Liver Lesions. Each Column is the Percent of the Population Predicted to Develop a Specific Type of Liver Lesion

Specific Liver Lesion Types Formed by English Sole	Baseline, Annual Average[a]	Without CSO, Annual Average[a]	Change in Prevalence with CSO Removal	Percentage of Unexposed Populations with Liver Lesions[b]
Neoplasms	10%	9%	1%	0.40%
Foci of Cellular Alteration	11%	11%	0%	0.80%
Specific Degenerative/ Necrotic Lesions	53%	50%	3%	1.30%
Megalocytic Hepatosis	30%	28%	2%	0.20%
Nuclear Polymorphism	42%	40%	2%	0.10%
Proliferative Lesions	21%	20%	1%	2.40%
Risk of Forming Any Lesion	52%	49%	3%	2.40%

[a] These data are predicted by the model developed by Horness et al. (1998) using sediment data from the EFDC model.

[b] Data directly taken from Horness et al. (1998).

4.3 Risks to Wildlife

Four wildlife receptors were evaluated in the WQA—spotted sandpipers, river otters, bald eagles, and great blue herons. Each of these receptors is exposed to chemicals in the Duwamish River and Elliott Bay from both CSOs and other sources (Figure 4-12). COPCs move from these sources through the sediment and water of the study area and are concentrated in fish, shellfish, and invertebrates. Additionally, each animal is exposed to chemicals through drinking water and incidentally from eating sediment (see Figure 4-12). Last, great blue herons can be exposed to chemicals through uptake across the skin (dermal contact)[24], but this exposure pathway is of unknown significance and could not be evaluated. A critical element of any risk assessment is that for risk to occur, a receptor must first be exposed. For our wildlife receptors, exposure to chemicals is

[24] Dermal contact is only expected to occur for wildlife that have exposed bare skin. Thus, great blue heron can be exposed to dermal contact during periods of extended wading. Otters, sandpipers, and eagles do not experience this same level of exposure.

Figure 4-12. Conceptual Model for Wildlife Exposure to Chemicals in the Duwamish River and Elliott Bay

Figure 4-12, page 2 (11x17)

limited by their spatial and temporal use of the study area. Each receptor has important habitat and seasonal requirements that will determine whether and how they will use a particular area of the Duwamish River, Elliott Bay, or both. We have summarized the important habitat requirements in Appendix B-3 for each receptor as well as the specific model cells that contain these requirements. With the exception of the bald eagle, which uses the entire study area, the areas used by each wildlife receptor are presented in Figure 4-13a and b.

Exposure to chemicals is also influenced by the characteristics of each receptor—their body weights, how much they eat, what they eat, and how much they drink. Each of these characteristics varies in the population and will result in different amounts of chemical exposure. At the same time, the concentrations of chemicals in the areas of the estuary used by each receptor will vary. Therefore, chemical doses for each receptor will cover a specific range, and any assessment of risks should account for this range.

Wildlife risks were evaluated by calculating the doses received from water, sediments, and food from the study area. These doses were compared with toxicity data using the risk characterization methods. Chemical doses were calculated using all possible combinations of the varying exposure parameters—body weights, drinking and eating rates of bald eagle populations—along with the variable concentrations of chemicals in water, sediment, and food. The possible chemical doses were compared to the uncertainty range for the toxicity reference value to generate a probability distribution of risk estimates for each wildlife receptor. The percentile of the risk probability indicates what proportion of exposure combinations result in a specific HQ. A detailed discussion of the wildlife risk assessment methods is presented in Appendix B-3.

We found that, overall, risks are low for bald eagles, great blue herons, and river otters. COPCs with HQs exceeding one for these species were arsenic (river otter only) and lead (all three species). The probability of the arsenic HQ exceeding one for the river otter was less than 10 percent, with an estimated minimum of 0.2 and maximum of 2.5. The results were the same for baseline and without CSOs. The lead HQs for river otter ranged from about 0.5 to 6, with about a two-thirds probability of exceeding one. The lead HQs for the great blue heron ranged from about 0.4 to 4 during fledgling season, with about a 25 percent probability of exceeding one. The lead HQs for the bald eagle ranged from about 0.3 to 3, and also had about a 25 percent probability of exceeding one.

In contrast, risks to spotted sandpipers are moderate to high from dietary exposure to metals and PCBs. Interestingly, risks to spotted sandpipers from reference site metals concentrations were moderate, also from the dietary exposure pathway. The primary pathway for risks to spotted sandpipers appears to be prey bioaccumulation of metals and PCBs from sediments, as well as direct incidental ingestion of sediments. No risks to wildlife were predicted from chemicals in the water column in the study area. Wildlife risk characterization results are presented in Appendix B-3. Risks for each receptor are reviewed in the following sections.

Figure 4-13a. Wildlife Assessment Areas

Figure 4-13a, page 2 (11x17)

Figure 4-13b. Wildlife Assessment Areas

Figure 4-13b, page 2 (11x17)

4.3.1 Spotted Sandpipers

Individual spotted sandpipers in the Duwamish River are at potential risk from exposure to chemicals from CSOs and other sources. Spotted sandpipers are exposed to chemicals in the Duwamish River through the food they eat, the water they drink, and sediment they incidentally consume along with their prey (see Figure 4-12). The sandpiper diet was assumed to consist of sediment-dwelling invertebrates (represented by amphipods). Additionally, it was assumed that sandpipers ingest sediment at up to 18 percent of the amount of amphipods they eat, a relatively high consumption of sediment.

Spotted sandpipers were found to have the highest level of risk (moderate to high) in the study area of any of the four wildlife receptors (Table 4-8). Risks to sandpipers were also moderate at the COPC concentrations in prey, food, and sediments at reference sites (WSDOE 1998). Spotted sandpipers appear to be at risk from dietary sources of lead, copper, total PCBs, and zinc. Exposure to doses of these chemicals would appear to be high enough to cause reduced growth and reproduction in these birds. Spotted sandpipers generally are not known to breed in the Puget Sound area, which may help offset these risks, because some of the lead in their diet may have been depurated by the time these animals reach their breeding grounds.

Table 4-8. Summary of Duwamish River Risks to Spotted Sandpipers

	Baseline	Without CSOs	Reference
Is risk present?	Yes	Yes	Yes
What is the magnitude of risk?	Moderate – High[a]	Moderate – High[a]	Moderate
How is the risk harmful?	Reduced growth and reproduction	Reduced growth and reproduction	Reduced growth and reproduction
Where is the risk?	Exposed intertidal mudflats in the Duwamish River	Exposed intertidal mudflats in the Duwamish River	Exposed intertidal mudflats in the Nisqually Delta
What's causing the risk?	Lead, copper, PCBs and zinc from dietary sources accumulated from sediment	Lead, copper, PCBs and zinc from dietary sources accumulated from sediment	Lead, copper, PCBs and zinc from dietary sources accumulated from sediment

[a] Spotted sandpiper risks are identified as moderate to high as several COPCs have average HQs greater than 10 (moderate) and lead HQs are greater than 100 (high risks).

Mean HQs for sandpipers exceeded 1.0 more frequently than for any of the other receptors evaluated (Table 4-9). Mean HQs exceeded 1.0 for copper, lead, zinc and total PCBs (for both the baseline and without CSO scenarios). The overall HQs for copper and zinc are driven by the dietary exposure. The overall HQ for lead is driven mostly by the diet, but sediment ingestion is contributing fairly substantially as well (Appendix B-3).

HQs for copper, lead, and zinc at reference sites were also fairly high, with those for copper and zinc being very similar to those from the study area.

Table 4-9. Summary of Average Spotted Sandpiper Hazard Quotients

	Baseline	Without CSOs	Reference
1,4-Dichlorobenzene	<0.05	<0.05	<0.05
4-Methylphenol	<0.05	<0.05	<0.05
Arsenic	0.2	0.2	0.3
Benzo(a)anthracene	<0.05	<0.05	<0.05
Benzo(a)pyrene	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	<0.05	<0.05	<0.05
Benzo(g,h,i)perylene	<0.05	<0.05	<0.05
Benzo(k)fluoranthene	<0.05	<0.05	<0.05
Bis(2-ethylhexyl)phthalate	2.3	2.3	0.1
Cadmium	0.2	<0.05	0.4
Chrysene	<0.05	<0.05	<0.05
Copper	21.6	20.5	16.1
Dibenzo(a,h)anthracene	<0.05	<0.05	<0.05
Fluoranthene	<0.05	<0.05	<0.05
Indeno(1,2,3-cd)pyrene	<0.05	<0.05	<0.05
Lead	111.6	106.5	17.1
Mercury	0.1	0.1	0.1
Nickel	0.1	<0.05	0.3
Phenanthrene	<0.05	<0.05	<0.05
Pyrene	<0.05	<0.05	<0.05
Total PCBs	2.5	2.5	0.2
TBT	<0.05	<0.05	<0.05
Zinc	1.4	1.3	2.2

Similar or slightly lower risks are predicted for the without CSO scenario than for baseline. All sandpiper HQs (including 95th percentile) for organics other than total PCBs were less than 1.0 under baseline conditions, without CSOs, and for reference sites. As shown in Table 4-10, risks are similar under baseline and without CSO scenarios. For copper and zinc, risks in the Nisqually Delta reference site are similar to risks in the Duwamish Estuary. Lead and PCB risks are higher in the Duwamish Estuary than the Nisqually Delta.

Table 4-10. Spotted Sandpiper Hazard Quotients

Chemical	Mean	90% Prediction Range	
		5th Percentile	95th Percentile
Baseline			
Copper	21.6	16.4	27.5
Lead	111.6	46.0	278.7
Total PCBs	2.5	1.5	3.7
Zinc	1.4	0.5	2.4
Without CSOs			
Copper	20.5	15.4	26.1
Lead	106.5	43.2	274.4
Total PCBs	2.5	1.5	3.7
Zinc	1.3	0.5	2.2
Reference Site (Nisqually Delta) (Dietary Risks Only)			
Copper	16.0	13.9	18.4
Lead	10.2	4.0	28.0
Total PCBs	0.2	0.1	0.4
Zinc	2.1	1.2	3.1

Of the four chemicals of concern, lead posed the greatest risk to spotted sandpipers. Toxicity of lead to birds varies between species and with the form of the metal. Sub-lethal effects on birds include effects on central nervous system function, hematopoiesis (blood formation), growth, and reproduction (Edens et al. 1979; Scheuhammer 1987; Kendall and Scanlon 1981). Young birds are the most susceptible to lead toxicity as organo-lead compounds tend to accumulate in egg yolk and in the developing embryo (Eisler 1988). However, no current observations of individual spotted sandpipers have been made to determine whether these types of effects are currently occurring in the study area.

4.3.2 River Otter

River otters in the study area are at potential risk from exposure to chemicals (see Figure 4-12). Potential risks to river otters from exposure to chemicals are described in Appendix B-3 and are summarized below.

River otters are exposed to chemical stressors present in the Duwamish River through the food they eat, the water they drink, and sediment they consume inadvertently. Living in the study area year-round, these animals feed primarily on small fish (represented by shiner perch), crabs, and mussels. Due to limited information, our results are based on the assumption that otters eat equal proportion of these prey items. It is possible that the overall HQ could change if different dietary fractions were assumed. A detailed analysis of the risks from the individual food items, as well as water and sediment, is presented in Appendix B-3. These results indicate that the river otter's risk estimates are not highly sensitive to the balance of prey items in their diet.

Overall, we found that risks to river otter populations were present in the study area (Table 4-11). In contrast, water, sediment, and prey concentrations from reference sites in the Puget Sound do not present risk to these animals. Lead and arsenic both present low risks to river otter in the study area with the potential for some reduction in reproductive success. For this report, we define low risks to mean that the average dose of each chemical is between 1 and 10 times greater than the safe threshold dose. No other metals and none of the organics present any risks to river otters (Table 4-12). Our analysis of the separate elements of the exposure pathways (food, water, and sediment) indicates that risks to the river otters are derived exclusively from its food (Appendix B-3).

Under baseline conditions, the only metal with an overall mean HQ exceeding 1.0 is lead (HQ = 1.6) (see Table 4-12). The 5^{th} and 95^{th} percentile HQs are 0.7 and 3.8, respectively (Table 4-13). The lead HQs expected with removal of CSOs are only slightly lower (see Table 4-13). These risks are elevated relative to reference concentrations, where the average HQ for lead is 0.2. Only the upper 35^{th} percentile of lead HQs were greater than 1.0, meaning that only 35 percent of the possible exposures to environmental lead would result in risk to river otters (Appendix B-3). The 95^{th} percentile overall HQ for arsenic (both baseline and without CSO) slightly exceeded 1.0 (HQ = 1.1) (Table 4-13). This suggests there is only slightly greater than a 5 percent probability that the arsenic HQ exceeds 1.0. None of the river otter HQs for organics exceeded 1.0 (Table 4-12). The highest mean overall HQ is 0.5 for PCBs.

Table 4-11. Summary of Duwamish River and Elliott Bay Risks to River Otters

	Baseline	Without CSOs	Reference
Is risk present?	Yes	Yes	No
What is the magnitude of risk?	Low[a]	Low	-
How is the risk harmful?	Potential for reduced reproductive success	Potential for reduced reproductive success	-
Where is the risk?	Dispersed throughout the study area.	Dispersed throughout the study area.	-
What's causing the risk?	Lead and arsenic from dietary sources accumulated from sediment sources.	Lead and arsenic from dietary sources accumulated from sediment sources.	-

[a] River otter risks are deemed low as only lead HQs exceed 1.0, with a maximum lead HQ of 3.5.

Table 4-12. Summary of Average River Otter Hazard Quotients

	Baseline	Without CSOs	Reference
1,4-Dichlorobenzene	<0.05	<0.05	<0.05
4-Methylphenol	<0.05	<0.05	<0.05
Arsenic	0.6	0.6	0.3
Benzo(a)anthracene	<0.05	<0.05	<0.05
Benzo(a)pyrene	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	<0.05	<0.05	<0.05
Benzo(g,h,i)perylene	<0.05	<0.05	<0.05
Benzo(k)fluoranthene	<0.05	<0.05	<0.05
Bis(2-ethylhexyl)phthalate	<0.05	<0.05	<0.05
Cadmium	0.2	0.1	0.2
Chrysene	<0.05	<0.05	<0.05
Copper	0.3	0.3	0.4
Dibenzo(a,h)anthracene	<0.05	<0.05	<0.05

Table 4-12. Summary of Average River Otter Hazard Quotients (continued)

	Baseline	Without CSOs	Reference
Fluoranthene	<0.05	<0.05	<0.05
Indeno(1,2,3-cd)pyrene	<0.05	<0.05	<0.05
Lead	1.6	1.5	0.2
Mercury	<0.05	<0.05	<0.05
Nickel	<0.05	<0.05	<0.05
Phenanthrene	<0.05	<0.05	<0.05
Pyrene	<0.05	<0.05	<0.05
Total PCBs	0.5	0.5	0.1
TBT	<0.05	<0.05	<0.05
Zinc	0.1	0.1	<0.05

Table 4-13. Average and 90 Percent Prediction Interval Hazard Quotients for the River Otter Under Baseline and the Without CSO Condition

Chemical	HQ	90% Prediction Interval[a]	
		5^{th} Percentile	95^{th} Percentile
Baseline			
Arsenic	0.6	0.3	1.1
Lead	1.6	0.7	3.8
Without CSOs			
Arsenic	0.6	0.1	1.1
Lead	1.5	0.1	3.5
Reference (Dietary Exposure Only)			
Arsenic	0.2	0.1	0.3
Lead	<0.1	<0.1	0.1

[a] The 90 percent prediction interval represents the range between the 5^{th} percentile and the 95^{th} percentile HQs.

4.3.3 Bald Eagle

Bald eagles are exposed to chemical stressors present in the Duwamish River through the food they eat, the water they drink, and sediment they inadvertently consume (see Figure 4-12, Table 4-14). Representative food for bald eagles consisted of perch and salmon (where data were available). Due to limited information, our results are based on the assumption that eagles are eating equal proportions of each type of food. As with otters, it is possible that the overall HQ could change if their diet varied from this assumption. All HQs presented in Table 4-15 were calculated using equal weighting for chinook and coho, the species of salmon for which we had data. HQs for "combined salmon" (chinook plus coho) as well as chinook and coho individually can be found in Appendix B-3. The combined salmon HQs were used in the calculation of the overall HQ. A detailed analysis of the risks from the individual food items, as well as water and sediment, is presented in Appendix B-3.

Table 4-14. Summary of Duwamish River and Elliott Bay Risks to Bald Eagles

	Baseline	Without CSOs	Reference
Is risk present?	Yes	Yes	No
What is the magnitude of risk?	Low[a]	Low	-
How is the risk harmful?	Potential for delayed egg production	Potential for delayed egg reproduction	-
What's causing the risk?	Dietary lead via sediments	Dietary lead via sediments	-

[a] Risks to bald eagles are considered low as no average HQs are greater than 1.0, and the average maximum lead HQ is only 2.1.

Table 4-15. Summary of Average Bald Eagle Hazard Quotients

	Baseline	Without CSOs	Reference
1,4-Dichlorobenzene	<0.05	<0.05	<0.05
4-Methylphenol	<0.05	<0.05	<0.05
Arsenic	<0.05	<0.05	<0.05
Benzo(a)anthracene	<0.05	<0.05	<0.05
Benzo(a)pyrene	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	<0.05	<0.05	<0.05

	Baseline	Without CSOs	Reference
Benzo(g,h,i)perylene	<0.05	<0.05	<0.05

Table 4-15. Summary of Average Bald Eagle Hazard Quotients (continued)

	Baseline	Without CSO	Reference
Benzo(k)fluoranthene	<0.05	<0.05	<0.05
Bis(2-ethylhexyl)phthalate	0.1	0.1	<0.05
Cadmium	<0.05	<0.05	<0.05
Chrysene	<0.05	<0.05	<0.05
Copper	<0.05	<0.05	<0.05
Dibenzo(a,h)anthracene	<0.05	<0.05	<0.05
Fluoranthene	<0.05	<0.05	<0.05
Indeno(1,2,3-cd)pyrene	<0.05	<0.05	<0.05
Lead	0.9	0.9	0.2
Mercury	0.1	0.1	0.1
Nickel	<0.05	<0.05	<0.05
Phenanthrene	<0.05	<0.05	<0.05
Pyrene	<0.05	<0.05	<0.05
Total PCBs	0.2	0.2	0.1
TBT	<0.05	<0.05	<0.05
Zinc	0.1	0.1	0.1

Overall, our study found that risks to individual bald eagles were present in the study area (see Table 4-14). In contrast, water, sediment, and prey concentrations from other sites in the Puget Sound posed no risks to these animals. Lead posed low risks to bald eagle in the study area, with the potential for some reduction in reproductive success. No other metals, as well as none of the organics posed any risks to bald eagles. Under both baseline conditions and the without CSO scenario, no mean HQs are greater than 1.0 (see Table 4-15).

The 95th percentile HQ for lead exceeds 1.0 (HQ = 2.0), with the driving exposure pathway being sediment ingestion. All mean bald eagle HQs were less than 1.0 for all conditions and sites evaluated (Table 4-16). Finally, removing the CSO contribution did not materially affect the risks from lead to eagles.

In considering the eagle, it is important to note that risks to bald eagles resulted from only 25 percent of the possible exposure combinations to environmental lead (Appendix B-3). For example, this would mean that only 25 out of every 100 times bald eagles use the study area would result in exposure to lead doses that could result in an adverse effect. Observations that mated pairs of bald eagles have successfully fledged young in the study area further supports a conclusion that bald eagle risks are low in the study area. We expect CSO removal to have little impact on the success of these birds because the source of lead is existing sediments.

Table 4-16. Average and 90 Percent Prediction Interval Hazard Quotients for the Bald Eagle Under Baseline and the Without CSO Condition

Chemical	HQ	90% Prediction Range	
		5th Percentile	95th Percentile
Baseline			
Lead	0.9	0.4	2.0
Without CSOs			
Lead	0.9	0.4	2.1
Reference (Dietary Exposure Only)			
Lead	0.1	<0.1	0.2

4.3.4 Great Blue Heron

As with the other avian receptors, great blue herons were exposed to chemical stressors from ingestion of small fish (shiner perch), sediments, and water. Overall, our study found that risks to great blue heron populations were present in the study area (Table 4-17). In contrast, water, sediment, and prey concentrations from reference sites in the Puget Sound posed no risks to these animals. Lead posed low risks to great blue herons in the study area, with the potential for some reduction in reproductive success (Table 4-18). No other metals, as well as none of the organics, posed any risks to great blue herons.

Under both baseline conditions and the without CSO scenario, no mean HQs are greater than 1.0 (Table 4-19). The 95th percentile HQ for lead exceeds 1.0 (HQ = 1.8), with the driving exposure pathway being sediment ingestion. All great blue heron HQs were less than 1.0 for all conditions and sites evaluated. Finally, removing the CSO contribution did not materially affect the risks from lead to eagles.

Table 4-17. Summary of Duwamish River and Elliott Bay Risks to Great Blue Herons

	Baseline	Without CSOs	Reference
Is risk present?	Yes	Yes	No
What is the magnitude of risk?	Low[a]	Low	-
How is the risk harmful?	Potential for delayed egg production	Potential for delayed egg reproduction	-
What's causing the risk?	Dietary lead via sediments	Dietary lead via sediments	-

[a] Risks to great blue herons are deemed low as all average HQs are less than 1.0, and the maximum lead HQ is only 1.8.

Table 4-18. Summary of Average Great Blue Heron Hazard Quotients

	Baseline	Without CSOs	Reference
1,4-Dichlorobenzene	<0.05	<0.05	<0.05
4-Methylphenol	<0.05	<0.05	<0.05
Arsenic	<0.05	<0.05	<0.05
Benzo(a)anthracene	<0.05	<0.05	<0.05
Benzo(a)pyrene	<0.05	<0.05	<0.05
Benzo(b)fluoranthene	<0.05	<0.05	<0.05
Benzo(g,h,i)perylene	<0.05	<0.05	<0.05
Benzo(k)fluoranthene	<0.05	<0.05	<0.05
Bis(2-ethylhexyl)phthalate	<0.05	<0.05	<0.05
Cadmium	<0.05	<0.05	<0.05
Chrysene	<0.05	<0.05	<0.05
Copper	<0.05	<0.05	<0.05
Dibenzo(a,h)anthracene	<0.05	<0.05	<0.05
Fluoranthene	<0.05	<0.05	<0.05

Table 4-18. Summary of Average Great Blue Heron Hazard Quotients (continued)

	Baseline	Without CSOs	Reference
Indeno(1,2,3-cd)pyrene	<0.05	<0.05	<0.05
Lead	0.9	0.9	0.2
Mercury	<0.05	<0.05	<0.05
Nickel	<0.05	<0.05	<0.05
Phenanthrene	<0.05	<0.05	<0.05
Pyrene	<0.05	<0.05	<0.05
Total PCBs	0.2	0.2	<0.05
TBT	<0.05	<0.05	<0.05
Zinc	0.1	<0.05	0.1

Table 4-19. Average and 90 Percent Prediction Interval Hazard Quotients for the Great Blue Heron Under Baseline and the Without CSO Condition

Chemical	HQ	90% Prediction Range	
		5th Percentile	95th Percentile
Baseline Conditions			
Lead	0.9	0.5	1.8
Complete Year, Without Conditions			
Lead	0.9	0.5	1.7
Reference			
Lead	0.1	<0.1	0.1

In considering the heron, as was the case with bald eagles, it is important to note that risks to great blue herons resulted from only 25 percent of the possible exposure combinations to environmental lead (Appendix B-3). As for bald eagles, only 25 out of every 100 times great blue herons use the study area would result in exposures to lead doses that could result in an adverse effect. Combined with the observation that successful rookery reproduction occurs in the study area further supports a conclusion that great blue heron risks are low in the study area. Again, we expect that CSO removal to have little impact on the success of these birds because the primary source of lead exposure is existing sediments.

4.4 Risks to People

Results of the evaluations of risk to people are discussed in this section. By understanding the nature and magnitude of the health risks posed with and without CSOs, King County will be able to better understand its options for managing CSO discharges in the future. As with aquatic life and wildlife, risks to people are evaluated in the Duwamish River and Elliott Bay for two scenarios: baseline conditions, which include CSO discharge, and conditions in the absence of CSO discharge. In addition to these scenarios, risks were also examined at a reference site consistent with the aquatic life and wildlife risk evaluations. The purpose in examining risks at the reference location is to answer the question "how do risks to people exposed in the Duwamish River and Elliott Bay compare with similar exposures at a location without CSO impacts." Figure 4-14 shows the locations where exposures of people are evaluated in the Duwamish River and Elliott Bay.

Risks to people were evaluated by first gaining an understanding of the way in which people can be exposed to chemicals and pathogens in the Duwamish River and Elliott Bay. This was done as part of the problem formulation report prepared by King County (attached as Appendix A of this report). A simple "model" of how people using the study area can come into contact with the chemical and microbiological (pathogen) COPCs was developed and is depicted in Figure 4-15 and Figure 4-16. As shown, chemicals and pathogens enter the Duwamish River and Elliott Bay primarily through storm water runoff and CSO discharge. These contaminants then cycle between the sediment, surface water and biological organisms, which are the "media" through which people become exposed.

Direct exposures to people from sediment and surface water are identified for several types of activities (swimming, scuba, etc.), exposure pathways (ingestion or skin contact), and study area locations, as shown in Table 4-20. The activities used as a basis for quantifying direct exposures are known to occur in the study area. Exposures to both children and adults are evaluated, though children are evaluated only for a swimming scenario and not for scuba, windsurfing, or net fisher scenarios. The evaluation of skin contact with and incidental ingestion of sediment was not conducted for scuba divers as it was for others, for two reasons. First, direct contact with bottom sediments (skin contact, incidental ingestion) is probably very limited due to the general use of wet or dry suits and gloves; and second, there is a lack of sustained sediment contact with skin during active scuba activities which reduces (eliminates) chemical absorption through the skin. Appendix B-2 presents a detailed discussion of how direct exposures were estimated and the assumptions regarding exposure that were used.

Figure 4-14. Locations Where Exposures of People are Evaluated in the Duwamish River and Elliott Bay

Figure 4-14, page 2 (11x17)

Figure 4-15. Conceptual Model for Human Exposure to Chemicals in the Duwamish River and Elliott Bay

Figure 4-15, page 2 (11x17)

Figure 4-16. Conceptual Model for Human Exposure to Pathogens in the Duwamish River and Elliott Bay

Figure 4-16, page 2 (11x17)

Table 4-20. Direct Exposure Pathways Evaluated in the Human Health Risk Assessment

Exposure Media	Exposure Pathways	Activity Group	Location
Water	Incidental Ingestion and Skin Exposures	Swimming	Duwamish Park in Duwamish River Duwamish Head in Elliott Bay
		Scuba Diving	Seacrest Park
		Windsurfing/Sailboarding	Elliott Bay
		Netfishing	Duwamish River
Sediment	Incidental Ingestion and Skin Exposure	Swimming	Duwamish Park in Duwamish River Duwamish Head in Elliott Bay
		Netfishing	Duwamish River

The seafood consumption pathway is another exposure pathway evaluated for adults and children using the study area. People eat a variety of different types of aquatic organisms from the Duwamish River and Elliott Bay; each with a different potential-as a result of ecological and physiological differences-for absorbing and concentrating chemicals and pathogens. King County conducted a site-specific survey in 1997 to gain a more specific understanding of the use of this resource in the study area. Approximately 1,183 different individuals were interviewed, which provided information on the ethnic makeup of people catching seafood and their collection frequencies and consumption patterns.

Appendix B-2 presents a summary of the methods and results of the Elliott Bay and Duwamish River Seafood Consumption Survey. Additionally, we prepared an issue paper for the Stakeholder Committee on use of the study area by people (Issue Paper No. 3) which is included with the full set of issue papers in Appendix C of this report. The King County survey data are used in the human health risk assessment for establishing the frequency of seafood consumption from the study area. Because cooking methods and tissue consumption preferences can influence tissue chemical concentration, several types of seafood tissues (cooked vs. raw vs. fillets vs. other parts) were evaluated in the human health risk assessment. The types of seafood evaluated are summarized in Table 4-21.

Table 4-21. Aquatic Species used in Evaluation of Human Seafood Consumption Risks

Region	Tissue Description
Duwamish River	Raw and cooked sole fillets
	Whole-body sole
	Raw whole body perch
	Raw chinook and coho salmon fillets
	Raw and cooked Dungeness crab meat
	Raw crab (*Hepatopancreas)*
	Raw mussels
Elliott Bay	Raw and cooked sole fillets
	Whole-body sole
	Raw rockfish fillets
	Raw whole body perch
	Raw and cooked Dungeness crab meat
	Raw and cooked crab (*Hepatopancreas*)
	Raw mussels
	Raw prawns
	Raw squid
Reference locations	Raw and cooked sole fillets
	Whole-body sole
	Raw rockfish fillets
	Raw whole body perch
	Raw chinook and coho salmon fillets
	Raw and cooked Dungeness crab meat
	Raw and cooked crab (*Hepatopancreas*)
	Raw mussels
	Raw prawns

Health risks to people using the study area are quantified for chemicals for the exposures discussed above. The risk assessment principles and generic guidance developed by U.S. EPA (1989; 1992) are used, with site-specific data, to quantify chemical intakes. Because exposures can vary across people and activities in the study area,[25] the human health risk assessment quantified child and/or adult chemical intakes as low, moderate or high using different exposure values. Table 4-22 illustrates the differences in the low, moderate, and high values for two exposure parameters: exposure frequency and exposure duration. Appendix B-2, presents a detailed discussion on the methods used to characterize chemical exposures to people using the study area, including the basis for all exposure values used, the computational approach, and important assumptions and uncertainties.

Chemical risks to human health are quantified by comparing the predicted intake from the study area with a chemical intake (termed toxicity value) that is considered "safe" (i.e., associated with an acceptable level of risk). These toxicity values were developed by the U.S. EPA. Appendix B-2 discusses the basis for the toxicity values used in assessing chemical risk, their uncertainties, and contains concise profiles summarizing the types of toxic effects that are associated with exposure to chemicals of concern in the WQA. There are a number of issues that underlie the toxicity values used in the WQA, and these are also further discussed in an issue paper developed for the Stakeholder Committee on human health toxicology (Issue Paper No. 8, found in Appendix C of this report).

Based on the exposure and toxicity information discussed above, health risks to people from chemical exposures are estimated for two different types of endpoints: the development of cancer, and the occurrence of other health effects that are not related to cancer.[26] Appendix B-2 presents a concise description of the methods used to quantify the health risks to people for both types of endpoints.

Human exposures and risks from pathogens were assessed using two methods. In the first method, fecal coliform concentrations in the river and bay were used as an indicator of the potential for human exposures. In the second method, exposures and risks from viruses (rotavirus) and protozoa (giardia) in CSO discharges were quantified. Appendix B-2 presents a detailed discussion of the methods and assumptions used to estimate health risks from exposures to pathogens, as well as the uncertainties associated with these predicted health risks.

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[25] Predicted exposures and risks to an individual can also vary based on other risk factors, which are not evaluated in this study. Specifically, the risks predicted to people in this assessment are above and beyond any chemical or pathogen exposures to surface water or sediment from locations outside of the study area, or from seafood taken outside the study area. We have included exposure scenarios that assume high levels of exposure over long periods of time, so it is unlikely that that our results underestimate the combined risks from water, sediment and seafood exposures from all locations.

Table 4-22. Low, Medium and High Exposure Durations and Frequencies Used in Assessing Human Exposures

Parameter	Value		Units	Reference
	Adult	Child		
Low Exposure Conditions				
Seafood Consumption Frequency	8	8	meals/year	King County (1997b)
Swimming Exposure Frequency	2	2	days/year	Best Professional Judgement
Windsurfing and SCUBA Diving Exposure Frequency	2	0	days/year	Best Professional Judgement
Net Fishing Exposure Frequency	2	0	days/year	Best Professional Judgement
Exposure Duration	9	6	years	Average U.S. residency time.
Medium Exposure Conditions				
Seafood Consumption Frequency	24	24	meals/year	Best Professional Judgment
Swimming Exposure Frequency	12	12	days/year	Based on an average monthly swimming frequency of once per month.
Windsurfing and SCUBA Diving Exposure Frequency	12	0	days/year	Based on an average monthly windsurfing and scuba diving frequency of once per month.
Net Fishing Exposure Frequency	24	0	days/year	Best Professional Judgment
Exposure Duration	33	6	years	95th percentile U.S. residency time.
High Exposure Conditions				
Seafood Consumption Frequency	365	365	meals/year	King County (1997b)
Swimming Exposure Frequency	24	24	days/year	Best Professional Judgement
Windsurfing and SCUBA diving	24	0	days/year	Best Professional

[26] These vary based on the chemical evaluated. Appendix B-2 discusses the non-cancer endpoints specific to the chemicals evaluated in the WQA. A more general discussion of the different types of non-cancer health effects is provided in Issue Paper No. 8, found in Volume 3 of this report.

exposure Frequency				Judgement
Net Fishing Exposure Frequency	90	0	days/year	Best Professional Judgement
Exposure Duration	75	6	years	Lifespan estimate

4.4.1 Risks to People from Direct Exposures to Sediment and Surface Water

A discussion of the health risks to people from activities that bring them in direct contact with sediment and surface water follows. Results are discussed by type of toxic effect, beginning with non-cancer risks from exposure to chemicals, followed by cancer risks and risks from exposure to pathogens.

Table 4-23 through Table 4-26 summarize the results for each of these endpoints for different recreational activities in the study area (swimming, net fishing, SCUBA, wind surfing). Health risks are compared between baseline and without CSO conditions, with comparative risks from exposure to sediments also presented for reference locations. Sediment reference data are from Port Susan, Port Madison, Carr Inlet, and Sequim Bay (WSDOE 1998). No reference data for surface water were available. Detailed analysis and discussion of the direct exposure chemical risks for cancer and non-cancer endpoints is provided in Appendix B-2, as is a further discussion of the infection potential to people from direct contact with pathogens.

Non-Cancer Risks From Direct Exposure to Chemicals. No non-cancer health risks from exposure to chemicals are predicted from any direct exposure scenario for baseline or without CSO conditions, or at the reference locations. Specifically, potential health risks from all of the chemicals evaluated (metals, PAHs, PCBs, other organics) were below their “safe” doses under all of the conditions (with-, without CSO) and activities (swimming, SCUBA, net fishing, wind surfing) evaluated. Appendix B-2 provides a detailed presentation of the non-cancer risk values (i.e., all below safe doses) for direct exposure pathways to sediment and surface water.

Cancer Risks From Direct Exposure to Chemicals. The analysis indicates that there is approximately a 1 in 100,000 chance of getting cancer from skin exposure to inorganic arsenic and PCBs in sediment and water for highly exposed adults that net fish. These risks are specific to people that net fish in the Duwamish River at a frequency of 90 days per year or greater (over a lifetime), and for highly exposed children aged one to six who swim at Duwamish Park along the Duwamish River at a frequency of 24 times per year or greater (over a six year period). Figure 4-17 and Figure 4-18 summarize the range of predicted cancer risk for arsenic and PCBs (respectively) for these two groups (Appendix B-2 provides an in-depth presentation of these results). In general, cancer risks greater than one chance in a million are reported in human health risk assessments, because one chance in a million is the low end of the thresholds used by federal and state regulatory

Table 4-23. Summary of Risks to Swimmers Directly Exposed to Chemicals and Pathogens in Sediments and Waters of the Duwamish River and Elliott Bay

	Baseline	Without CSOs	Reference Data (WSDOE 1998)
Is risk present?	Yes	Yes	Yes
Who is at risk?	Risks from chemicals and pathogens are predicted for children aged 1 to 6 years that swim in the Duwamish River and Elliott Bay. Risks are predicted for those that swim at a frequency of 24 days per year or greater over this six year age period.	Similar to baseline.	Children aged 1 to 6 years that swim greater than 24 days per year over this 6-year age span are predicted to experience elevated cancer risks from exposure to sediment. No pathogen or surface water chemistry data are available.
What is causing the risk?	These risks are primarily associated with absorption of inorganic arsenic following skin contact with sediment. Risks are also associated with exposure to pathogens in the surface water.	Similar to baseline.	Chemical risks are associated with skin contact with arsenic in sediment. No pathogen or surface water chemistry data are available.
What is the magnitude of the risk? [a]	The lifetime probability of contracting cancer to a child aged 1 to 6 who swims 24 times per year for six years is predicted to be about 1 in 100,000. Health risks for non-cancer toxicity endpoints are not predicted. Fecal coliform water quality standards (used by the State of Washington as an indicator of pathogen risk) are frequently exceeded.	Similar to baseline, though fecal coliform standards along the shoreline of Elliott Bay are exceeded less frequently for fecal coliforms.	The probability of contracting cancer is predicted to be about 7 in 1,000,000 from skin contact with sediment. No pathogen or surface water chemistry data are available.
How is the risk harmful?	Inorganic arsenic causes skin cancer in exposed humans. PCBs cause liver cancer in exposed laboratory animals. Pathogen exposure can cause a wide range of illnesses.	Similar to baseline.	See baseline.
Location of risk?	Children may swim in the study area at Duwamish Head in Elliott Bay and in the Duwamish River at Duwamish Park.	Similar to baseline.	Risk represents average of several reference locations in Puget Sound.

[a] The benchmark "acceptable" probability of contracting cancer used by the State of Washington and the U.S. EPA is one in 1,000,000. For non-cancer health effects the ratio of the predicted dose to the "safe" dose cannot exceed a value of one.

Table 4-24. Summary of Risks to Net Fishers Directly Exposed to Chemicals and Pathogens in Sediments and Waters of the Duwamish River and Elliott Bay

	Baseline	Without CSOs	Reference Data (WSDOE 1998)
Is risk present?	Yes	Yes	Yes
Who is at risk?	Risks from chemicals and pathogens are predicted for people net fishing along the Duwamish River at a frequency of 90 days per year or greater over a 75-year lifetime.	Similar to baseline.	People that net fish at a frequency of 90 days per year or greater over a 75-year lifetime are predicted to have elevated cancer risks. No pathogen or surface water chemistry data are available.
What is causing the risk?	These risks are primarily associated with absorption of inorganic arsenic and PCBs following skin contact with sediment. Risks are also associated with exposure to pathogens in the surface water.	Similar to baseline.	Chemical risks are associated with skin contact with inorganic arsenic in sediment. No pathogen data or surface water chemistry data are available.
What is the magnitude of the risk? [a]	The lifetime probability of contracting cancer from net fishing 90 days per year for a 75-year lifetime is predicted to be about 2 in 100,000. Health risks for non-cancer toxicity endpoints are not predicted. Fecal coliform water quality standards (used by the State of Washington as an indicator of pathogen risk) are frequently exceeded.	Similar to baseline.	The lifetime probability of contracting cancer from net fishing for 90 days per year for a 75-year lifetime is predicted to be about 8 in 1,000,000. No pathogen or surface water chemistry data are available.
How is the risk harmful?	Inorganic arsenic causes skin cancer in exposed humans. PCBs cause liver cancer in exposed laboratory animals. Pathogen exposure can cause a wide range of illnesses.	Similar to baseline.	See baseline.
Location of risk?	Duwamish river (chemicals, pathogens).	Similar to Baseline.	Risk represents average of several reference sediment locations in Puget Sound

[a] The benchmark "acceptable" probability of contracting cancer used by the State of Washington and the U.S. EPA is one in 1,000,000. For non-cancer health effects the ratio of the predicted dose to the "safe" dose cannot exceed a value of one.

Table 4-25. Summary of Risks to SCUBA Divers Directly Exposed to Chemicals and Pathogens in Sediments and Waters of the Duwamish River and Elliott Bay

	Baseline	Without CSOs	Reference Data (WSDOE 1998)
Is risk present?	Yes	Yes	No
Who is at risk?	Risks from exposure to pathogens are predicted for SCUBA divers at Seacrest Park. No health risks from direct chemical exposures are predicted, even at the highest frequency of SCUBA diving evaluated (24 days per year over a 75-year lifetime).	Similar to baseline.	No health risks from chemicals in sediments are predicted for SCUBA divers at these locations assuming similar exposure conditions as baseline. No pathogen or surface water chemistry data are available.
What is causing the risk?	Risks are associated with exposure to pathogens in the surface water.	Similar to baseline.	No risks from sediment are predicted. No pathogen or surface water chemistry data are available.
What is the magnitude of the risk?[a]	Fecal coliform water quality standards (used by the State of Washington as an indicator of pathogen risk) are frequently exceeded.	Similar to baseline, though standards along the shoreline of Elliott Bay are exceeded less frequently for fecal coliforms.	No risks from sediment are predicted. No pathogen or surface water chemistry data are available.
How is the risk harmful?	Pathogen exposure can cause a wide range of illnesses.	Similar to baseline.	No risks from sediment are predicted. No pathogen or chemical surface water data are available.
Location of risk?	Seacrest Park.	Similar to baseline.	No risks from sediment are predicted. No pathogen or surface water chemical data are available.

[a] The benchmark “acceptable” probability of contracting cancer used by the State of Washington and the U.S. EPA is one in 1,000,000. For non-cancer health effects the ratio of the predicted dose to the “safe” dose cannot exceed a value of one.

Table 4-26. Summary of Risks to Wind Surfers Directly Exposed to Chemicals and Pathogens in Sediments and Waters of the Duwamish River and Elliott Bay

	Baseline	Without CSOs	Reference Data (WSDOE 1998)
Is risk present?	Yes	Yes	No
Who is at risk?	Risks from exposure to pathogens are predicted for wind surfers in Elliott Bay. No health risks from chemicals are predicted, even at the highest frequency of wind surfing evaluated (24 days per year over a 75-year lifetime exposure).	Similar to baseline.	No health risks to wind surfers from chemicals are predicted at these locations assuming the same exposures as baseline conditions. No pathogen or surface water chemistry data are available.
What is causing the risk?	Risks are associated with exposure to pathogens in the surface water.	Similar to baseline.	No risks from sediment are predicted. No pathogen or surface water chemistry data are available.
What is the magnitude of the risk?[a]	Fecal coliform water quality standards (used by the State of Washington as an indicator of pathogen risk) are sometimes exceeded.	Similar to baseline, though standards along the shoreline of Elliott Bay are exceeded less frequently for fecal coliforms.	No sediment risks are predicted. No pathogen or surface water chemistry data are available.
How is the risk harmful?	Pathogen exposure can cause a wide range of illnesses.	Similar to baseline.	No sediment risks are predicted. No pathogen or surface water chemistry data are available.
Location of risk?	Elliott Bay.	Similar to baseline.	No sediment risks are predicted. No pathogen or surface water chemistry data are available.

[a] The benchmark “acceptable” probability of contracting cancer used by the State of Washington and the U.S. EPA is one in 1,000,000. For non-cancer health effects the ratio of the predicted dose to the “safe” dose cannot exceed a value of one.

Figure 4-17. Arsenic Cancer Risks to Adult and Child (Age 1 to 6) from Swimming and Net Fishing

Figure 4-17 pg 2

Figure 4-18. PCB Cancer Risks to Adult and Child (Age 1 to 6) from Swimming and Net Fishing

Figure 4-18 pg.

agencies for determining whether a predicted cancer risk to the general population is "acceptable."[27]

As shown in Figure 4-17 and Figure 4-18, estimated direct pathway cancer risks for these two groups are predicted to be above 1 in 1,000,000 only for those exposed at the very highest of the three exposure levels (low, medium, high) evaluated in the WQA. Therefore, the risks estimated do not represent the risks likely to be encountered by most people engaging in these activities in the study area. Of importance is that cancer risks predicted for these exposure scenarios are not spatially uniform across the study area, but instead limited to specific sites identified in Table 4-20 (refer to Figure 4-14 to locate these sites).

Figure 4-17 and Figure 4-18 also illustrate how cancer risks compare between baseline and without CSO conditions for arsenic and PCBs. Notably, the risks estimated from direct exposure pathways do not change between baseline and without CSO conditions**.** The lack of change in the predicted cancer risks between baseline and without CSO conditions indicates that the CSOs do not contribute to human health risks from direct exposure pathways in the study area.

Inorganic arsenic, one of the two key chemicals contributing to the observed cancer risks to highly exposed net fishers and children who swim, is a known human carcinogen. This is known from studies on the occurrence of skin cancer in human populations exposed to inorganic arsenic in their drinking water. As discussed in Issue Paper No. 8 (found in Appendix C of this report), cancer risks predicted using the U.S. EPA cancer slope factor for arsenic may over-predict cancer risk, because new information on how arsenic is believed to cause cancer currently is not incorporated in U.S. EPA's dose-response assessment. The new information suggests there may be a "safe" dose for arsenic, in contradiction to U.S. EPA's current practice of assuming exposure to any cancer-causing substance is always associated with some chance of risk. How much we may have over-predicted cancer risk from direct contact with inorganic arsenic in sediments (by using the U.S. EPA slope factor) is unknown.

Cancer risks of a similar magnitude are also predicted for net fishers from exposure to inorganic arsenic in reference sediments (WSDOE 1998). It is well understood that naturally occurring levels of arsenic in the Puget Sound area can pose cancer risk in the absence of anthropogenic contributions (e.g., CSOs) (assuming U.S. EPA's slope factor is correct). The cancer risks predicted for the reference location and the Duwamish River and Elliott Bay very likely reflect naturally occurring arsenic levels.

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[27] For example, in the State of Washington, the Model Toxics Control Act (Chapter 173-340 WAC) considers cancer risks of one in 100,000 (industrial exposures) to 1 in 1,000,000 (general population) depending on the type of exposed population. Federal agencies such as the EPA consider a broader range of cancer risks as "acceptable", such as under the 1986 amendments to the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, or "Superfund"). Under the enacting regulations for this legislation (referred to as the National Oil and Hazardous Waste Substances Pollution Contingency Plan; 55 Federal Register No. 46, 1990), cancer risks maybe considered acceptable if they fall within the range of one in 10,000 to 1 in 1,000,000.

Total PCBs, the other key chemical of concern, is classified as a probable human carcinogen though there is some limited evidence of carcinogenic activity in humans. The PCB cancer risks we have predicted for people in frequent direct contact with Duwamish River sediments over extended periods of time, are based on a slope factor derived from data on liver cancer in PCB-exposed laboratory rats.

As a way of providing additional context on the risks posed by swimming and net fishing in the study area for those that may engage in these activities, Table 4-27 summarizes an analysis of the number of swimming or net fishing events it would take to exceed the allowable cancer risk benchmark of one in 1,000,000 (the number of events for SCUBA and wind surfing are also shown) for baseline conditions. For arsenic cancer risk potential to be below the 1 in 1,000,000 acceptable cancer risk level, an adult can swim up to 58 times in a year at the Duwamish Head near Elliott Bay. The number of swimming events is the same for baseline and without CSO conditions. Additionally, the number of swimming events that can occur for an adult is higher for Duwamish Park (100 swimming events). Additional discussion on the number of events for direct exposure that may result in risks above acceptable levels is provided in Appendix B-2.

Table 4-27. Number of Annual Exposure Events Required to Achieve Lifetime Carcinogenic Risk of 1 in 1,000,000—Direct Exposure Pathways

	Arsenic	PCBs	All other Chemicals Evaluated
Child age 1 to 6			
Swimming D.P.	21	92	> 1,000
Swimming D.H	12	51	> 1,000
Child age 7 to 12			
Swimming D.P.	31	132	> 1,000
Swimming D.H	18	73	> 1,000
Child age 13 to 18			
Swimming D.P.	39	158	> 1,000
Swimming D.H	22	88	> 1,000
Adult			
Swimming D.P.	150	164	> 1,000
Swimming D.H	87	192	> 1,000
Netfishing	65	126	> 1,000
SCUBA	450	407	> 1,000
Windsurfing	484	164	> 1,000

D.P. = Duwamish Park

D.H. = Duwamish Head

Risks From Direct Exposure to Pathogens. Potential risks from pathogens were identified using two methods. First, fecal coliform concentrations in water were modeled and compared to the Washington State water quality standards to indicate the potential for risks from human pathogens in surface water. Second, a quantitative assessment of the risk of infection from viruses (rotavirus) and protozoa (*Giardia*) associated with CSOs was conducted. The methods and results of the human health pathogen risk assessment are presented in Appendix B-2.

Fecal Coliforms. The analysis of fecal coliform concentrations indicates that there is risk of exposure to pathogens from direct exposure to the waters of the Duwamish River and Elliott Bay under baseline and without CSO conditions. Fecal coliform concentrations in surface water were used as an indicator of the presence of fecal contamination and an increased likelihood of infection by human pathogens. It is acknowledged that fecal coliforms may originate from many non-human sources (see Issue Paper number 4, Appendix C) and hence may not accurately predict concentrations of pathogenic organisms. However, we assumed that fecal coliform concentrations may be used as a general indicator of water quality, and hence as a general indicator of the likelihood of exposure to pathogenic organisms.

Fecal coliform concentrations were assessed using a variety of methods. First, geometric mean and 90^{th} percentile fecal coliform concentrations under baseline and without CSO conditions were compared to the state water quality standards on a monthly basis. Each model cell's compliance with state standards for any given month was assumed if the cell's monthly geometric mean and 90^{th} percentile concentrations were both below the appropriate standards. Second, the percent of time during the year that fecal coliform concentrations under baseline and without CSO conditions exceed various numerical standards were determined. Finally, peak concentrations at specific locations were assessed to estimate the magnitude of any potential risks.

The frequencies that modeled fecal coliform concentrations in the surface water layer exceed the state standards are presented in Figure 4-19 and Figure 4-20 for baseline conditions and without CSO conditions, respectively. As shown, the geometric mean and/or the 90^{th} percentile fecal coliform concentrations in the surface layers for most of the Duwamish River are above the state standards for over nine months of the year, both baseline and without CSO discharges. Figure 4-19 and Figure 4-20 also show that the geometric mean and 90^{th} percentile fecal coliform concentrations in the surface layer along the Elliott Bay shoreline frequently exceed the state standards under baseline and without CSO conditions. The exception to this is along the Elliott Bay shoreline north and West of the Denny Way CSO, where standards are exceeded less frequently under without CSO conditions than under baseline conditions. State standards are infrequently exceeded in the middle of the bay under baseline and without CSO conditions. In general, more model cells were predicted to exceed state standards during wet months than dry months.

Figure 4-19. Number of Months per Year that Surface Cells Exceed State Fecal Coliform Standards, Baseline Conditions

Figure 4-19, page 2 (11x17)

Figure 4-20. Number of Months per Year that Surface Cells Exceed State Fecal Coliform Standards

Figure 4-20, page 2 (11x17)

These comparisons of monthly fecal coliform concentrations to state standards indicate frequent potential risks of infection from direct contact with surface water from the Duwamish River and the shoreline of Elliott Bay under baseline and without CSO conditions. North and west of the Denny Way CSO, fecal coliform concentrations indicate a substantial decrease in risk. These results also indicate that fecal coliforms from other sources are of such a magnitude that the complete removal of CSO discharges would not allow for the Duwamish River or the majority of the Elliott Bay shoreline to frequently meet the fecal coliform standards, although the other sources of fecal coliforms and the actual concentrations of human pathogen organisms remains uncertain.

Fecal coliform concentrations in surface waters were further investigated to identify the fraction contributed by CSOs, and whether the CSO contribution, without considering any other sources, would result in an exceedance of the state standards (Figure 4-21). As shown, only along the Elliott Bay shoreline north and west of the Denny Way CSO are monthly geometric mean and 90th percentile fecal coliform concentrations attributable to CSO discharges predicted to frequently exceed standards. These observations support the conclusion that sources other than CSOs contribute substantially to the fecal coliform concentrations in the Duwamish River and along the Elliott Bay shoreline. The potential for risks under both baseline and without CSO conditions is also obtained from the observation that fecal coliform concentrations in the Duwamish River exceed 400 organisms per 100 ml between 10 and 25 percent of the year both under baseline and without CSO conditions (Appendix B-2).

Worst-case estimates of risk were assessed by reviewing peak fecal coliform concentrations (Appendix B-2). Peak fecal coliform concentrations in the Duwamish River during January (a month with many CSO discharges) were found to frequently exceed 1,000 organisms per 100 ml both under baseline and without CSO conditions (Appendix B-2). Peak concentrations in Elliott Bay in January were similar under baseline and without CSO conditions along the West Seattle shoreline (greater than 1,000 organisms per 100 ml), the Seattle waterfront (greater than 1,000 organisms per 100 ml) and the middle of the bay (100 to 300 organisms per 100 ml). Peak January concentrations near the Denny Way CSO were substantially higher under baseline conditions (nearly 40,000 organisms per 100 ml) than under without CSO conditions (100 to 200 organisms per 100 ml). These results indicate that there are periods when fecal coliform concentrations indicate the potential for substantial risk.

Figure 4-21. Number of Months per Year that Surface Cells Exceed State Fecal Coliform Standards, CSO Contribution Only

Figure 4-21, page 2 (11x17)

Viruses and Protozoa. We modeled the risks of infection from incidental ingestion of 50 ml of surface water containing viruses and protozoa that were presumed to have originated from CSO discharges. These exposures may occur while engaging in many direct exposure activities, such as swimming, net fishing, SCUBA diving, or windsurfing, among others. Risks of infection were modeled for pathogens presumed to originate from CSO discharges only since appropriate pathogen data from surface waters were not available. Therefore, the estimated risks are equal to the increase in overall risks that are attributable to CSO discharges. The estimated risks may also be interpreted as the amount of risk reduction that would occur upon CSO removal.

Risks of infection were calculated for viruses (where rotavirus was assumed to be an appropriate surrogate) and protozoa (where *Giardia* was assumed to be an appropriate surrogate). First, the risks of infection were calculated for every surface cell, and then compared to various risk levels. Second, discharges from Denny Way CSO (in Myrtle Edwards Park) were examined in greater detail to assess the risks during discharges and at several time intervals after discharges have ended.

No guidelines are available that state acceptable risk levels in surface waters for viruses and *Giardia*. A 1 in 100-risk level is approximately equal to the level the U.S. EPA used to recommend ambient water quality standards for enterococci. A 1 in 10,000-risk level is the acceptable annual risk level for *Giardia* in drinking water. A 1 in 1,000-risk level was used as an intermediate risk level between the proposed risk level for enterococci in surface water and for *Giardia* in drinking water. For comparison purposes, epidemic proportions are normally associated with an incidence of disease of 1 in 10 or greater.

Figure 4-22 and Figure 4-23 shows the percent of time that the risk of infection (based on incidental ingestion of 50 ml of water) exceeds 1 in 1,000 for viruses and *Giardia*, respectively. As shown, the risk of infection from viruses and *Giardia* in CSO discharges is predicted to exceed 1 in 1,000 less than 5 percent of the time throughout the Duwamish River and along the Elliott Bay shoreline. Risks never exceed 1 in 1,000 in the middle of the bay. Similarly, a 1 in 100 risk is exceeded less than 1 percent of the time in the lower Duwamish River and in Elliott Bay near the Denny Way CSO, and is never exceeded elsewhere in the study area (Appendix B-2). The 1 in 10,000 risk level is exceeded more frequently, up to 25 percent of the time in the lower Duwamish River and along the Elliott Bay shoreline, and zero to 10 percent of the time elsewhere in the study area (Appendix B-2).

These results indicate that there would be some risk reduction associated with removal of CSOs. While the risks of infection from viruses and *Giardia* attributable to CSO discharges are frequently less than 1 in 10,000 (the most stringent available acceptable risk level for pathogens), the risks occasionally exceed 1 in 1,000 and even 1 in 100. The highest risk levels are predicted to occur during the CSO discharges and immediately after CSOs stop discharging (Appendix B-2). During discharge, the giardiasis risks would be less than 1.4/1,000 90 percent of the time and less than 3.5/1,000 99 percent of the time. During discharge, the virus risks were estimated at less than 8.5/10,000 90 percent of the time and 2.2/1,000 99 percent of the time. Within 6 to 24 hours after discharge, the risks were reduced by 10 fold.

NEW FIGURE

Figure 4-22. Percent of Time that the Risk of Infection from Viruses in CSO Discharges Exceed 1 in 1,000 Based on Ingestion of 50 ml Surface Layer Water

Figure 4-22, page 2 (11x17)

NEW FIGURE

Figure 4-23. Percent of Time that the Risk of Infection from *Giardia* in CSO Discharges Exceed 1 in 1,000 Based on Ingestion of 50 ml Surface Layer Water

Figure 4-23, page 2 (11x17)

4.4.2 Risks to People Who Eat Seafood from the Duwamish River and Elliott Bay

This section discusses the health risks to people from eating Duwamish River and Elliott Bay seafood. As with the direct exposure risks summarized above, results are discussed by type of toxic effect, beginning with non-cancer risks from exposure to chemicals, followed by cancer risks and ending with risks from exposure to pathogens.

Table 4-28 summarizes the results for each of these endpoints. Health risks are compared between baseline and without CSO conditions, with comparative risks also presented for reference locations (Port Susan and Hood Canal). Detailed analyses and discussions of the chemical risks (cancer and non-cancer) from eating seafood, and the infection potential to people from eating seafood containing pathogens is provided in Appendix B-2.

Table 4-28. Summary of Risks to People who Eat Seafood from the Duwamish River and Elliott Bay

	Baseline	Without CSOs	Reference Locations
Is risk present?	Yes	Yes	Yes
Who is at risk?	Risks are predicted for all people who eat fish, shellfish or other seafood (squid).	Similar to baseline.	Similar to baseline
What is causing the risks?	Primarily arsenic and PCBs, though other chemicals also contribute to a lesser degree. Risks from exposure to methyl mercury were predicted for some tissues. Other chemicals contribute a lesser degree of risk. Risk may also exist from pathogens in seafood.	Chemical risks similar to baseline, pathogen risks probably lower.	Chemical risks similar to baseline.

Table 4-28. Summary of Risks to People who Eat Seafood from the Duwamish River and Elliott Bay (continued)

	Baseline	Without CSO	Reference Locations
What is the magnitude of the risk?[a]	Adults and children that consume seafood at "moderate" exposure levels (24 times per year) for 33 years (adults) or 6 years (children) are predicted to have cancer risks ranging up to 2 in 10,000, depending on the seafood eaten. Chemical intakes at these exposure levels exceed "safe" intakes for inorganic arsenic and PCB non-cancer health effects by up to 9 times, depending on the type of seafood eaten. PCB exceedances of non-cancer safe doses were higher than for arsenic. Children had the highest exceedance of a safe dose. Adults who eat seafood from the Duwamish River and Elliott Bay every day over a 75-year lifetime are predicted to have cancer risks about 80 times higher than moderate seafood consumers. Children aged 1 to 6 years who eat Duwamish River and Elliott Bay seafood everyday over a 6-year period are predicted to have non-cancer risks 34 times higher than moderately exposed children.	Similar to baseline	Risks from inorganic arsenic in consumed seafood are similar to Duwamish River and Elliott Bay risks. Risks from PCBs in seafood vary dependent on seafood type. Risks are 5 to 60 times lower than those in the Duwamish River and 3 to 10 times lower than those in Elliott Bay.
How is the risk harmful?	Inorganic arsenic causes skin cancer and other changes to the skin in exposed people. PCBs cause cancer, reproductive and neurologic effects, and decreased immune response in exposed laboratory animals. Pathogen exposure can cause a wider range of illnesses.	See baseline	See baseline
Location of Risk?	Elliott Bay and the Duwamish River	See baseline	Risks are predicted from seafood concentrations averaged over all of the reference locations

[a] The benchmark "acceptable" probability of contracting cancer used by the State of Washington and the U.S. EPA is one in 1,000,000. For non-cancer health effects the ratio of the predicted dose to the "safe" dose cannot exceed a value of one.

Non-Cancer Health Risks Posed by Eating Seafood. The Duwamish River and Elliott Bay seafood survey indicates that people do catch and eat seafood from the study area, though few do it at a high frequency. Specifically, 1.5 percent of the 452 people interviewed who stated that they eat seafood from the study area indicated that they consume seafood at the high rate of 365 days per year. These people were used in this risk assessment to characterize “highly exposed” consumers. Twenty-five percent of the 452 people reported catching and eating seafood at least 24 days per year or more, which is the exposure frequency we used to represent “moderately exposed” people. Fifty percent of the 452 people reported eating seafood less than eight days per year, which is the exposure frequency used to represent “low exposed” people. The complete report on the fishing survey is found in Appendix B-2.

As indicated in Table 4-28, a variety of health effects are predicted for adults and children consuming fish, shellfish, and other seafood daily from the Duwamish River or Elliott Bay. Across all types of seafood evaluated (fish, shellfish and other species, for example squid), the chemicals contributing chiefly to the predicted non-cancer health risks are inorganic arsenic and PCBs.

Chemicals other than inorganic arsenic and PCBs that are identified as posing non-cancer health risks from eating Duwamish River and Elliott Bay seafood every day (high exposure scenario) are shown in Table 4-29. These chemicals include TBT (immunosuppression effects have been observed in laboratory animals), mercury (neurological effects have been observed in the offspring of maternally exposed women, and in exposed young children), and a number of other metals exhibiting a variety of health effects in exposed laboratory animals. In general though, the magnitude of the predicted health risks from these chemicals is much lower than the risks posed by arsenic and PCBs. The highest HQs under the high exposure scenario for arsenic and PCBs were 99 and 663, respectively in the Duwamish River, 88 and 176 in Elliott Bay, and 99 and 46 at the reference sites. In contrast, HQs were less than 20 for all other chemicals in the Duwamish River and Elliott Bay, and less than 25 at the reference sites. Appendix B-2 contains a detailed presentation and discussion of the non-cancer health risks predicted for each of the chemicals shown in Table 4-29.

The highest exceedances of a “safe” dose for non-cancer health effects are predicted for highly exposed children (ages one to six years) that eat seafood 365 days per year over a six year period from the Duwamish River and Elliott Bay. As mentioned above, less than 2 percent of the people who consume seafood from the river or bay do so at this frequency, and thus these risks are not representative of the risks posed to the majority of people who eat seafood from the Duwamish River and Elliott Bay. Non-cancer risks were also predicted for highly exposed children aged 7 to 12 and 13 to 18, for highly exposed adults, as well as for moderately exposed (24 meals per year) adults and children.

Non-cancer health risks were also predicted from arsenic and PCBs for people who eat seafood from the Duwamish River or Elliott Bay at medium exposure levels (24 meals per year). Maximum HQs for arsenic and PCBs were 3 and 19 respectively in the

Duwamish River, three and nine in Elliott Bay, and three and one at the reference sites. No other chemicals besides arsenic and PCBs had HQs greater than one under the

Table 4-29. Chemicals with Seafood Consumption Hazard Quotients Greater than One Under High Exposure Assumptions

Substance	Tissue Type	Location
PCBs		
Aroclor 1254	All	Duwamish, Elliott Bay and reference
Organometallic		
TBT	Cooked and raw crab, raw perch and rockfish, mussels, prawns and squid, cooked crab hepatopancreas	Duwamish, Elliott Bay and reference (perch only)
Metals		
Arsenic	All	Duwamish, Elliott Bay and reference
Cadmium	Cooked and raw crab, crab hepatopancreas cooked and raw, mussels and squid	Duwamish, Elliott Bay and reference
Copper	Squid	Elliott Bay
Lead	Mussels, raw crab	Elliott Bay and Duwamish
Mercury	Whole body sole, cooked and raw sole, perch, prawn, squid, cooked and uncooked crab, raw rockfish and salmon	Elliott Bay, Duwamish, reference
Zinc	Mussels, cooked and raw crab	Duwamish, Elliott Bay and reference

medium exposure scenario (24 meals per year). Only PCBs had HQs greater than one (maximum HQ=4) under the low exposure scenario (eight meals per year).

Health effects associated with PCBs include neurological impairment and decreased immune function, while for inorganic arsenic the primary risk is for changes to the skin (Blackfoot disease; U.S. EPA 1998). Figure 4-24 and Figure 4-25 illustrate the HQs for these types of non-cancer health effects based on the predicted intakes of arsenic and PCBs (respectively) from seafood. A HQ is the ratio of an exposure level to the maximum “safe” dose. A HQ of one indicates the predicted intake is equal to the maximum “safe” dose, and is often used by regulatory agencies for deciding whether

Figure 4-24. Arsenic Non-Cancer Hazard Quotients for Adult and Child (Age 1 to 6) Seafood Consumers

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Figure 4-25. PCB Non-Cancer Hazard Quotients for Adult and Child (Age 1 to 6) Seafood Consumers

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risks are "acceptable.[28]" HQs for the arsenic and PCB health effects described above are predicted to be higher for children (1 to 6 years) than for adults because young children eat more per unit of body weight than do adults. Non-cancer health risks to children aged 7 to 12 and 13 to 18 for eating seafood from the Duwamish River and Elliott Bay are intermediate to the risks predicted for adults and children aged one to six (Appendix B-2). The similarity of the predicted health risks between the baseline and without CSO conditions indicates that the CSOs do not contribute significantly to the non-cancer health risks predicted from eating Duwamish River and Elliott Bay seafood.

Some of the higher risks for inorganic arsenic are associated with the consumption of sole fillet and crab from both the Duwamish River and Elliott Bay (see Appendix B-2), though many seafood types were associated with inorganic arsenic risks. The greatest percentage of arsenic found in seafood (approximately 90 percent) occurs as an organic form (termed "fish arsenic") that is known to be non-toxic (ATSDR 1991; Edmonds and Francesconi 1977; Neff 1997; Parametrix 1993, 1995). Accordingly, the exposure assessment evaluated chemical intakes based on only the inorganic form of arsenic, which was conservatively assumed to be 15 percent of the total arsenic concentration measured in tissue samples. Inorganic arsenic does occur naturally in the soils, water, and sediments in the Puget Sound area and generally is predicted to pose health risks at natural reference concentrations. The similarity of the inorganic arsenic risks from seafood consumption under baseline and without CSO conditions is a reflection of the fact that CSOs are not a significant source of arsenic in the Duwamish River and Elliott Bay. Notable also is the similar level of exceedance of the safe dose for inorganic arsenic in the Puget Sound reference locations and the Duwamish Estuary, indicating the importance of natural sources of inorganic arsenic in Puget Sound.

To help put the predicted PCB risks in perspective, we note that PCB concentrations in all of the fish tissues collected from the Duwamish River and Elliott Bay were below the FDA tolerance level for total PCBs. The FDA has set a tolerance level of 2 mg/kg for total PCBs in edible fish tissues. The tolerance level is a concentration that FDA has determined to be unavoidable in commercial fish, and adequately protective of public health, without causing undue disruptions in the food supply to American consumers (Federal Register 49(100): 21514, May 22, 1984). The FDA tolerance level indicates that PCB contamination in fish is a widespread problem, rather than a problem unique to the Duwamish River and Elliott Bay. For comparison, the 95th upper confidence limit (UCL) of the mean total PCB concentrations estimated from the Duwamish River ranged from 0.024 mg/kg in salmon to 1.2 mg/kg in whole body English sole. Elliott Bay estimated mean total PCB tissue concentrations ranged from 0.031 mg/kg in whole squid to 0.96 mg/kg in raw crab hepatopancreas, and at reference locations the estimated means ranged from 0.018 in whole body sole to 0.17 mg/kg in cooked crab hepatopancreas.

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[28] A hazard quotient value of one for example, is considered as the benchmark for predicting adverse effects by the EPA in their Superfund risk assessment guidance, as well as by the State of Washington in establishing risk-based cleanup levels under the Model Toxics Control Act (Chapter 173-340 WAC).

As described in Appendix B-2, about 10 percent of the observed people who consume fish from the Duwamish River and Elliott Bay eat parts other than the fillet and skin. Table 4-29 summarizes the chemicals and types of seafood (including cooked versus uncooked for some tissue types) predicted to pose non-cancer health risks. The non-cancer health risks from chemicals in uncooked seafood change minimally when the seafood is cooked, suggesting that the cooking methods evaluated do not alter chemical content appreciably.

To provide additional context on the risks posed by consuming seafood in the study area, Table 4-30 summarizes an analysis of the number of seafood meals a one to six-year-old child would need to consume from the study area per year to exceed the allowable non-cancer risk benchmark of one for baseline conditions. The number of meals that can be "safely" consumed varies by type of seafood and location. As indicated in Table 4-30, this number is typically lower in the Duwamish River than in Elliott Bay. For the non-cancer risk potential to be below an allowable benchmark of one, a one to six-year-old child can consume at the fewest, one meal of whole body sole containing PCBs from the Duwamish River. The number of meals that can be consumed in the study area increases slightly to markedly (e.g., 44 meals of salmon from the Duwamish River) for other types of seafood containing PCBs. Additional discussion on the number of seafood meals that can be consumed to remain below the "safe" dose for arsenic and PCBs is provided in Appendix B-2.

Cancer Health Risks Posed by Eating Seafood. Arsenic and PCBs contribute the majority of the predicted cancer risks from eating Duwamish River and Elliott Bay seafood. The predicted cancer risks are as high as two in 100 for adults eating Duwamish River and Elliott Bay seafood every day over a 75-year lifetime. Based on the frequencies of actual seafood consumption determined from the survey, about 1.5 percent of the observed people who eat seafood from the study area do so every day of the year (see also Appendix B-2 and Issue Paper No. 3, Appendix C). Therefore, predicted cancer risks for people consuming at this frequency are not representative of the risks to most people who eat seafood from the Duwamish River and Elliott Bay. The highest predicted cancer risk for people who eat seafood on average twice a month over a 33-year period (our "moderate exposure" scenario, corresponding to the 75^{th} percentile of the fishing survey respondents who eat seafood from the study area) is two in 10,000.

As a point of reference, we again note that one chance in a million is the low end of the thresholds used by federal and state regulatory agencies for determining whether a predicted cancer risk to the general population is "acceptable." However, in the case of PCBs in fish tissue, a one in a million chance of cancer from eating fish is considered by the U.S. Food and Drug Administration (FDA) to be an unachievable risk level. Nonetheless, cancer risks from PCBs in seafood from our Puget Sound reference locations were 10 to 30 times lower than cancer risks predicted from PCBs in Duwamish River and Elliott Bay seafood.

Table 4-30. Number of Meals a One to Six Year-Old Child Must Eat per Year to Reach HQ = 1 Under Baseline Conditions[a]

COPC	Sole	Sole – Whole Body	Rockfish	Perch - Whole Body	Salmon	Crab Hepatopancreas	Crab	Mussel	Prawn	Squid	Cooked Sole	Cooked Crab	Cooked Crab Hepatopancreas
Duwamish River													
Arsenic	14	24	N/AP	136	225	74	8	232	N/AP	N/AP	10	24	N/AP
PCBs	5	1	N/AP	3	44	3	7	42	N/AP	N/AP	3	12	N/AP
Elliott Bay													
Arsenic	25	30	169	183	N/AP	65	11	180	9	39	19	12	95
PCBs	97	11	22	8	N/AP	4	10	ND	ND	47	20	28	5
Reference Site													
Arsenic	17	25	83	193	27	215	52	249	8	N/AP	12	28	44
PCBs	ND	79	ND	18	51	35	ND	ND	ND	N/AP	73	85	20

[a] Adults must eat about twice as many meals per year as one to six year-old children to reach the same HQ.

N/AP = Not applicable-seafood not collected and analyzed from this location

ND = Not detected

Figure 4-26 and Figure 4-27 illustrate the range of predicted cancer risks to adults and children age one to six at the moderate (24 meals per year) and high (365 meals per year) rates of seafood consumption for arsenic and PCBs, respectively. The range of predicted cancer risks is shown for both baseline and without CSO conditions, as well as for reference locations. As shown, the predicted cancer risks between baseline and without CSO conditions are very similar, suggesting that the CSOs do not contribute significantly to the cancer risks predicted from seafood consumption in Elliott Bay or the Duwamish River. PCB cancer risks are the same under baseline and without CSO conditions because CSOs are not a significant source of PCBs (i.e., PCBs are not detected in CSOs).

Figure 4-26 and Figure 4-27 illustrate that cancer risks are higher for adults than children aged one to six because their risks are based on eating seafood over a greater portion of their lifespan than are the cancer risk estimates for children. Cancer risks for children aged 7 to 12 and 13 to 18 are lower than the cancer risks for children aged one to six

Figure 4-26. Arsenic Cancer Risks to Adult and Child (Ages 1 to 6) Seafood Consumers

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Figure 4-27. PCB Cancer Risks to Adult and Child (Age 1 to 6) Seafood Consumers

Pg. 2 of Figure 4-27

(Appendix B-2). Inorganic arsenic cancer risks from eating seafood are similar at the reference site and within the study area. The cancer risks for PCBs tended to be about 10 to 30 times higher in the study area than at the reference locations, suggesting a source of PCBs in the study area is contributing to the predicted PCB risks from eating Duwamish River and Elliott Bay seafood.

Highest arsenic cancer risks are predicted from eating sole fillet and crab (Appendix B-2). Cancers predicted from seafood consumption in this study are based on the results of studies of the occurrence of skin cancer in human populations exposed to inorganic arsenic in their drinking water. Adjustments made in exposure analysis to account for the small percentage of arsenic in tissue present as inorganic arsenic still suggests a potential for cancer risks to seafood consumers. However, as we said in our discussion of arsenic risks from direct contact with sediment, (and in Issue Paper No. 8, Appendix C), the arsenic cancer risks we have predicted may over-estimate the actual chance of contracting cancer. Recent information on how arsenic causes cancer currently is not incorporated in the U.S. EPA dose-response assessment used to derive the arsenic cancer slope factor. Therefore, it is possible that some exposure to arsenic is not associated with any cancer risk; though the current U.S. EPA slope factor is based on the assumption that any exposure poses some degree of cancer risk. How much we may have over-predicted cancer risks for arsenic through seafood consumption is unknown.

Some of the highest cancer risks predicted for PCBs are associated with eating whole body sole, though risks from PCBs are associated with all other tissues as well. As we noted when we discussed PCB cancer risks from direct contact with sediment, our PCB cancer risk estimates are based on data from studies where liver cancer was observed in exposed laboratory rats. The occurrence of cancer in laboratory animals does not conclusively indicate that this type of cancer will occur in people consuming seafood from the Duwamish River and Elliott Bay, although U.S. EPA has classified PCBs as probable human carcinogens based on the available laboratory animal data.

Table 4-31 summarizes the other chemicals that contribute to the predicted cancer risks to seafood consumers under the high exposure scenario (365 meals per year). As shown, high molecular weight PAHs also contribute cancer risks greater than one in 1,000,000 for some tissue types, but to a much smaller degree than risks posed by arsenic and PCBs (Appendix B-2). The chemicals other than arsenic and PCBs that were predicted to pose risks greater than one in 1,000,000 under the high exposure scenario typically did so for only a few tissue types. These chemicals generally were not detected in other tissue types (Appendix B-2). When these chemicals were detected, risks ranged from one in 1,000,000 to one in 1,000.

To provide additional context on the risks posed by consuming seafood in the study area, Table 4-32 summarizes an analysis of the number of seafood meals an adult would need to consume from the study area each year for 33 years to exceed the allowable cancer risk benchmark of one in 1,000,000. The number of meals that can be "safely" consumed varies by type of seafood and location. This number is typically very low across all seafood types (in some cases less than one full seafood meal per year) and is the same for CSO and without CSO conditions. The lowest number of meals for PCBs is associated

Table 4-31. Chemicals Predicted to Pose Cancer Risks Greater than One in 1,000,000 Under High Exposure Assumptions (365 Meals per Year)

Substance	Tissue Type	Location
PCBs		
Aroclor 1254	All	Duwamish River, Elliott Bay, and reference
Aroclor 1260	Salmon, raw and cooked sole, whole body sole, raw and cooked crab, raw and cooked crab hepatopancreas prawns and perch	Duwamish River, Elliott Bay, and reference
PAHs		
Benzo(a)anthracene	Mussels, raw crab	Duwamish River, Elliott Bay
Benzo(a)pyrene	Perch, raw crab	Elliott Bay
Benzo(b)fluoranthene	Mussels	Duwamish River
Chrysene	Mussels, raw crab	Duwamish River, Elliott Bay
Metals		
Arsenic	All	Duwamish River, Elliott Bay, and reference
Other		
Bis(2-ethylhexyl) phthalate	Salmon, mussels, prawns, squid	Duwamish River, Elliott Bay, and reference

Table 4-32. Number of Meals An adult Must Eat Pear Year for 33 Years to Achieve Lifetime Excess Cancer Risk of One in 1,000,000

	Raw Sole Fillet	Whole Body Sole	Perch	Salmon	Crab Hepatopancreas	Raw Crab	Mussel	Cooked Sole	Cooked Crab	Cooked Crab Hepatopancreas	Rockfish	Prawn	Squid
Duwamish River													
Arsenic	0.2	0.3	1.6	2.6	1	0.1	2.7	0.1	0.3	N/AP	N/AP	N/AP	N/AP
PCBs	0.7	0.2	0.4	3.2	0.5	0.9	5.5	0.4	1.6	N/AP	N/AP	N/AP	N/AP
Other	ND	ND	ND	36.7	ND	ND	22.3	ND	ND	N/AP	N/AP	N/AP	N/AP
Elliott Bay													
Arsenic	0.3	0.3	2.1	N/AP	0.9	0.1	2.1	0.2	0.1	1.3	2.0	0.1	0.5
PCBs	12.6	1.0	1.0	N/AP	0.5	1.3	ND	2.7	3.7	0.8	1.5	13.6	6.2
Other	ND	ND	1.1	N/AP	ND	1.4	16.6	ND	ND	ND	ND	513.9	232.7
Reference													
Arsenic	0.2	0.3	2.2	0.7	2.9	0.6	2.7	0.1	0.3	0.6	1.0	0.1	N/AP
PCBs	ND	10.4	2.3	10.2	5.4	ND	ND	9.6	11.2	3.1	ND	ND	N/AP
Other	ND	N/AP	ND	329	ND	ND	ND	ND	ND	ND	ND	526	N/AP

ND – Chemical not detected in this seafood.

N/AP – Not Applicable, seafood not collected and analyzed from this location.

with seafood caught and consumed from the Duwamish River. For arsenic, the low number of meals (again, generally less than one meal) that can be consumed is similar between the study area and the reference locations; indicating the importance of naturally occurring arsenic in Puget Sound. Additional discussion on the number of seafood meals that can be consumed to remain below the benchmark cancer risk level for arsenic and PCBs is provided in Appendix B-2. Because similar cancer risks are predicted for the without CSO scenario as under baseline conditions, similar numbers of meals per year are required under the without CSO scenario to achieve a 1 in a 1,000,000 cancer risk.

Pathogen Risks Posed by Eating Seafood. The analysis of fecal coliform concentrations indicates that there is an increased risk of exposure to pathogens from consumption of shellfish from the Duwamish River and Elliott Bay. The fecal coliform water quality standards for Elliott Bay (geometric mean of 14 colonies per 100 ml and a concentration not to be exceeded by more than 10 percent of the samples of 43 colonies per 100 ml) were designed to be protective of shellfish harvesting from marine waters. As shown in Figures 4-19, 4-20 and 4-21 and described in Appendix B-2, fecal coliform concentrations in the river and bay frequently exceed these standards. Fecal coliform concentrations in the bay are predicted to exceed the standards less frequently under without CSO conditions than baseline conditions, especially north and west of the Denny Way CSO. These results indicate the potential for a reduction, although not an elimination of health risks from the consumption of shellfish from Elliott Bay with CSO removal.

Quantitative risk estimates based on exposures to viruses and *Giardia* in shellfish were not calculated because of limited exposure data on virus concentrations in shellfish.

5. UNCERTAINTY

5.1 Background

The project team believes that the findings of the CSO Water Quality Assessment are sound. However, not only in this study but whenever people assess environmental quality, questions and concerns about uncertainty arise. Environmental systems are complex, varied and ever changing, so environmental quality assessments are inherently uncertain but nonetheless necessary. These assessments influence decisions about environmental and economic values people care about and want to protect. As such, they want assurance of the assessments' reliability.

How best to report and assess uncertainties in environmental quality assessments is a very complicated question. Ignoring uncertainties can lead to bad decisions, but so can considering them. The pitfalls of uncertainty analysis are difficult to explain. Two of the best attempts to date are books published almost a decade ago. One is a Resources for the Future publication by Adam Finkel, entitled *Confronting Uncertainty in Risk Management: A Guide for Decision Makers* (Finkel 1990). The other is a book by Granger Morgan, Max Henrion and Mitchell Small, three professors from Carnegie Mellon University's Department of Engineering and Public Policy, entitled *Uncertainty: A Guide to Dealing with Uncertainty in Quantitative Risk and Policy Analysis* (Morgan et al. 1990). Both advocate uncertainty analysis, but warn against falling into the trap of "paralysis by analysis." A classic paper on right and wrong ways for dealing with uncertainty in making risk management decisions is "Witches, Floods and Wonder Drugs: Historical Perspectives on Risk Management" by Bill Clark (Clark 1979). Dr. Clark has a varied background that gives him a broad and interesting perspective on ecological risks. He has worked at Harvard's Kennedy School of Government; the International Institute for Applied Systems Analysis, and University of British Columbia's Institute of Resource Ecology. A compilation of classic papers on making risk management decisions under uncertainty can be found in the Resources for the Future book *Readings in Risk* (Glickman and Gough 1990). Finally, a more recent and somewhat more technical treatment of the topic can be found in the Society of Environmental Toxicology and Chemistry publication *Uncertainty Analysis in Ecological Risk Assessment* (Warren-Hicks and Moore 1998).

The proper place to begin discussing uncertainty as it relates to ecological risk assessment is by defining the term uncertainty. Uncertainty encompasses at least seven different phenomena. They are:

- *Incomplete information,* i.e., missing data.
- *Natural variability,* i.e., conditions that change over time, vary among individuals, or change with location.

- *Model structural uncertainty*, i.e., uncertainties about the correct way to describe something (like the fate of a chemical in the environment) in a model, or approximation errors, due to the fact that models are just models, not perfect representations of the real world.

- *Missing variables*, i.e., things not considered simply because we do not know about them, or enough about them, to include them in the analysis. An example of this, raised by one of the Stakeholder Committee members, is the newly emerging body of peer-reviewed and published data on the effects of estrogenic chemicals in sewage treatment plant effluent on male fish, particularly roach fish.

- *Lack of understanding*, i.e., inability to fully understand available data and models.

- *Disagreement*, i.e., legitimate differences of opinion about priorities or values that in turn affect the system being assessed or the questions we are trying to answer about it.

- *Ambiguity*, i.e., sloppiness or imprecision in defining objectives, variables, assumptions, or decision criteria.

These are just working definitions assembled for explaining the complexity of uncertainty. They are not necessarily definitive or comprehensive. Hopefully, they provide the reader with some insight and perspective on the complicated concept of uncertainty as it pertains to the WQA. Failure to distinguish among the different types of uncertainty is a major impediment to dealing with it. Even if one can tell apart the different types of uncertainty, each is difficult to understand. Lumping them just adds to the challenge.

Understanding how uncertainty "propagates," i.e., how uncertainty about one thing relates to uncertainty about something else, is another problem we face whenever we assess environmental quality. For example, how does uncertainty about the timing or magnitude of a CSO discharge affect uncertainty about the health risks to a person who swims in the Duwamish River on warm, sunny days? How does uncertainty about "other sources" affect uncertainty about the relative risks from CSOs? How does uncertainty about Puget Sound and Elliott Bay currents and tides affect uncertainty about sediment resuspension and deposition? How does uncertainty about the representativeness of laboratory data on chicken egg hatchability affect uncertainty about PCB risks to great blue herons? How does uncertainty about what outmigrating salmon eat affect uncertainty about their risks? How does uncertainty about the bioavailability of chemicals in the outmigrating salmon's prey affect uncertainty about the salmon's risks? How does uncertainty about where spotted sandpipers nest affect uncertainty about chemical concentrations in their eggs?

The questions one could ask about uncertainty in any environmental quality assessment are virtually endless. Therefore, a reductionist approach – i.e., assessing each source of uncertainty and its consequences – is infeasible. Instead, we must start with the conclusions of the assessment, and work backward to identify factors that could significantly change those conclusions. This "top-down" approach to uncertainty analysis focuses on identifying sources of uncertainty that are important, in the sense of affecting the reliability of the assessment's key findings.

The remainder of this section follows a top-down approach to uncertainty analysis. As such, it addresses each of the key findings of the WQA in turn. For each of the key findings, we attempt to assess the importance of the seven types of uncertainty described above. Some types of uncertainty are more amenable to analysis than others. It is difficult to assess the importance of uncertainty due to missing variables, because in general we do not know what the missing variables are. An example of a missing variable might be a chemical whose toxicity has not been discovered or scientifically verified, for example, or an undiscovered process affecting a chemical's fate in the environment. Lack of understanding is another type of uncertainty that is difficult to assess, because it is different for every person, depending on their reference and familiarity with the specific analysis, the data used, general risk assessment methods, environmental toxicology and chemistry, estuarine ecology, mathematical modeling techniques, etc. With these caveats, we will attempt to describe the uncertainties in the key findings of the WQA, and identify their sources. Next, we evaluate the uncertainty associated with each of the WQA's key findings in turn. We then close this section with a statement about the potential uncertainties associated with using the tools and data developed in this WQA for future investigations.

5.2 Uncertainty in Key Findings

5.2.1 Overall Finding

We found clear evidence of potential risks to aquatic life, wildlife, and people, under both baseline and without CSO conditions.

This is the overall conclusion of the WQA, and we are confident of its reliability. We discuss the reasons why in Sections 5.2.2 (Aquatic Life), 5.2.3 (Wildlife) and 5.2.4 (People).

5.2.2 Aquatic Life

The WQA found minimal risks to aquatic life from chemicals in the water column, no apparent risks to juvenile salmon from direct exposure to chemicals in the water, and no apparent risks to salmon smolt from consuming amphipods in the Duwamish Estuary.

This conclusion is based on the fact that all observed and predicted water column exposure concentrations fell below water quality criteria, below the estimated fifth percentile of the distribution of TRVs in the aquatic community, and below the TRVs for salmonids. Issue Paper #6, *Aquatic Life and Wildlife Toxicology* (Appendix C), and the aquatic ecological risk assessment appendix describe the details of the methods and assumptions used to derive aquatic TRVs. The exposure estimates used in the risk assessment are monthly maximum acute and chronic values. While exposure estimates for individual locations and times contain uncertainties, the fact that exposure estimates were consistently below levels of concern throughout the study area, throughout the simulated year, indicates that water column exposure concentrations fall below levels posing potential risk.

The greatest uncertainty about risks to aquatic life from chemicals in the water column has to do with endpoints not evaluated in the WQA, due to lack of information or understanding. For example, data recently published by the National Marine Fisheries Service (Arkoosh et al. 1998) show immunosuppression in salmon smolt from the Duwamish Estuary relative to Nisqually Estuary smolt. However, the cause of the observed immunosuppression has not been determined, so it cannot at this time be causally linked to any particular stressor or stressors, nor has it been linked to a population-level effect. Therefore, while the new immunosuppression data create uncertainty about sufficiency of the existing toxicological database, which indicates minimal risk to aquatic life from chemicals in the water column, they do not specifically point to chemicals as the cause of the observed immunosuppression. Replication of the results, demonstration of a population-level effect, and identification of physical, biological, and chemical stressors contributing to the immunosuppression are needed before we can move from a conclusion of uncertainty to a conclusion of risk.

The WQA found potential risks to the benthic community from chemicals in the sediments, and localized areas of risk from sedimentation and scouring.

Our benthic community survey of transects from the Duwamish/Diagonal CSO/storm drain and Kellogg Island demonstrated reduced benthic diversity, and increased abundance of organic enrichment-tolerant taxa near the CSO. Duwamish River sediment data have identified PCB concentrations above Washington State sediment management standards. Data from near Harbor Island indicate TBT sediment concentrations high enough to potentially pose risks near Harbor Island. TBT concentrations are attributable primarily to historic shipping activities, so are unaffected by the presence or absence of CSOs. We consider this clear evidence of potential risks to the benthic community under both baseline and without CSO conditions.

Eliminating CSO discharges could increase benthic diversity in the CSO footprint, although the effects of other nearby discharges (i.e., storm drains) could at least partially offset the nearfield benefits of removing CSOs.

It is clear that CSOs cause organic enrichment in depositional areas near the CSO pipe (the footprint). In addition, the solids in CSOs contain chemicals (specifically 1,4-dichlorobenzene and bis(2-ethylhexl)phthalate, but potentially others) at concentrations that exceed Washington State sediment management standards, and are elevated relative to surrounding sediments. Removing CSOs would over time eliminate CSO footprints. However in some cases there are storm water discharges at or near the CSO discharge point that also are likely contributing to the footprint. These discharges would continue if

CSOs were removed leaving a storm drain footprint. Therefore, it is uncertain how effective CSO control will be at increasing benthic community diversity in the footprint areas.

5.2.3 Wildlife

The WQA found relatively high risks to spotted sandpipers from lead in their food, and lower risks to bald eagles, great blue herons and river otters. The WQA found no discernible differences in risks to wildlife under baseline and without CSO conditions.

We collected prey items for our wildlife receptors (bald eagle, great blue heron, river otter and spotted sandpiper) and measured chemical concentrations in the prey. We used data and exposure models from the scientific literature, as described in the U.S. EPA's *Wildlife Exposure Factors Handbook*, to estimate how much chemical exposure these wildlife receptors would receive from their prey, and compared these estimates to toxicity reference values (TRVs) derived from the scientific literature (Appendix B-3). An issue paper (Issue Paper #6) on aquatic life and wildlife toxicology, and uncertainties associated with TRVs, was developed, shared and discussed with our stakeholder and peer review committees during the analysis phase of the WQA (Appendix C). The TRVs incorporate uncertainty factors to prevent overestimation bias, for example due to interspecies variability and potentially more sensitive endpoints than those tested (Appendix B-3).

The wildlife risk assessment found that lead in amphipods eaten by spotted sandpipers could cause exposures hundreds of times higher than the sandpiper's lead TRV. The range of uncertainty in the spotted sandpiper's lead HQ was 24 to 481, with a sample mean of 112. These HQs are about ten times higher than those calculated for the reference sites. This uncertainty distribution accounts for uncertainty in the average concentration in the spotted sandpiper's diet and uncertainty about average body weight and food ingestion rate. Details of how uncertainties were treated in the exposure and effects characterizations are presented in the wildlife risk assessment appendix. However, it is worth pointing out that not all sources of uncertainty are accounted for in the analysis. Most notably, there is a model structural uncertainty that is not accounted for. Specifically, the lead TRV is based on reproductive effects, but spotted sandpipers generally are thought not to breed in the Duwamish Estuary or Puget Sound. Our exposure model does not take into account lead depuration that may occur between exposure in the Duwamish Estuary, and nesting elsewhere. As such they contain an unquantified overestimation bias. Nonetheless, the range of spotted sandpiper lead HQs is sufficiently high to clearly indicate potential risks to wildlife in the Duwamish Estuary. Lead risk estimates are the same for baseline and without CSOs, because the source of the lead is historically contaminated sediments near Kellogg Island.

The same sources of uncertainty were evaluated for the other three wildlife receptors as for the sandpiper. These include uncertainty about exposure concentrations, uncertainty about body weight and food ingestion rate, and uncertainty about the TRV. These uncertainties were treated probabilistically. Uncertainty about dietary composition was also evaluated through sensitivity analysis. Specifically, we estimated risk separately for each prey species collected (i.e., assuming each prey species in turn comprised 100 percent of the receptor's diet). This allowed us to see how variability in prey species body burdens affected wildlife risk estimates. Final risk estimates were computed using an overall average prey concentration for each chemical of potential concern.

There is an additional source of uncertainty in the bald eagle risk estimates, due to the fact that we used fish tissue concentrations to estimate dietary exposure to COPCs. As we note in the Appendix B-3, in the section *Sources of Environmental Concentration Data*, bald eagles are opportunistic feeders whose diet may be comprised of a variety of species, not all of which were sampled in the Duwamish Estuary. We based our bald eagle exposure estimates on shiner perch and (adult) salmon data. We did not have waterfowl tissue data, though waterfowl may be part of the bald eagle's diet. If waterfowl tissue concentrations are higher than shiner perch and salmon tissue concentrations, our use of the fish data to estimate the bald eagle's exposure would introduce an underestimation bias. Conversely, if waterfowl tissue concentrations are lower than the shiner perch and salmon tissue concentrations, our exposure estimates are biased to overestimate the bald eagle's risk.

We did estimate HQs greater than one for the bald eagle, great blue heron, and river otter, specifically for lead (for all three receptors) and also arsenic for the river otter. The probability of the arsenic HQ exceeding one for the river otter was less than 10 percent, with an estimated minimum of 0.2 and maximum of 2.5. The results were the same for baseline and without CSOs. The lead HQs for river otter ranged from about 0.5 to 6, with about a two-thirds probability of exceeding one. The lead HQs for the great blue heron ranged from about 0.4 to 4 during fledgling season, with about a 25 percent probability of exceeding one. The lead HQs for the bald eagle ranged from about 0.3 to 3, and also had about a 25 percent probability of exceeding one. These risk estimates do not contain any intentional biases, other than safety factors on the TRVs for inter-and intra-species variability and the possibility of a more sensitive endpoint than measured (decreased litter size for arsenic and reproductive endpoints for lead). Removing these safety factors would reduce the maximum HQs below one, indicating that the presence or absence of risk to the eagle, heron and otter is uncertain.

Uncertainty about the conclusion that removing CSOs would have no discernable effect on risks to wildlife is low. We have a reasonably good understanding that sources other than baseline CSO discharges are principally responsible for the arsenic and lead to which wildlife are exposed. Therefore, removing CSOs has little effect on risks.

5.2.4 People

The WQA found relatively high health risks from arsenic and PCBs to people that eat seafood every day. PCB risks are higher in the Duwamish Estuary than in Puget Sound, and arsenic risks are the same in the Duwamish Estuary and Puget Sound. No differences were discerned in risks to people from eating seafood under baseline and without CSO conditions.

Our exposure estimates were based on seafood tissue concentration data and fishing survey results, so we consider them reliable. The reference doses and slope factors are U.S. EPA values. Uncertainty about the accuracy of these toxicity reference values is probably the greatest source of uncertainty in these risk estimates.

We caught fish and other forms of seafood from the Duwamish Estuary that people eat, and we measured chemical concentrations of concern in these samples. We conducted a survey that shows a small number of people catch and eat seafood from the Duwamish Estuary every day. We used standard U.S. EPA methods to estimate how much chemical exposure these people would receive from the seafood they catch and eat, and compared these estimates to U.S. EPA reference doses for non-cancer effects, and slope factors for cancer (Appendix B-2). An issue paper (Issue Paper #7) on human health toxicology and uncertainties associated with reference values was developed, shared and discussed with our stakeholder and peer review committees during the analysis phase of the WQA (Appendix C). Exposure estimates derived from our measured seafood samples exceeded reference doses, and cancer risks were on the order of one in one thousand (Appendix B-2). We consider this clear evidence of potential risks to people under baseline conditions.

The risk assessment found that the two chemicals of greatest concern from a human health perspective are PCBs and arsenic. We cannot rule out CSOs as a source of PCBs and arsenic to the estuary. However, the water quality model would overpredict measured PCB and arsenic concentrations in the estuary unless CSO inputs are small relative to other sources. Furthermore, measurements of PCB and arsenic concentrations in CSOs corroborate the model-based conclusion that the magnitude of these inputs is small relative to other sources. As a third line of evidence, the Duwamish Estuary is known to be the site of sediment PCB “hot spots” due to historical releases, and arsenic is known to occur naturally at high levels in Puget Sound, and is no higher in the estuary than in the greater sound. Taken together, these lines of evidence strongly indicate potential seafood consumption risks to people under both baseline and without CSO conditions.

The finding relating the study area risks to the greater Puget Sound is simply based on comparing PCB and arsenic concentrations in seafood collected from the Duwamish River and Elliott Bay to the same species collected from elsewhere in Puget Sound. The Duwamish Estuary and Puget Sound samples were collected and analyzed using the same sampling and analysis methods, which improves the reliability of data comparisons.

The WQA found some health risk to net fishers on the Duwamish River and Elliott Bay, and to swimmers at Duwamish Park and Duwamish Head from arsenic and PCBs, but no health risk from chemicals to SCUBA divers at Seacrest Park or to windsurfers in Elliott Bay. No differences were discerned in the health risks to net fishers or swimmers under baseline and without CSO conditions.

These results are based on average sediment and water concentrations estimated with the Duwamish Estuary model. One source of exposure uncertainty is uncertainty about the accuracy of the assumptions about how much people use the estuary for the various activities we considered. We assessed these uncertainties through sensitivity analysis, using low, medium and high values for exposure parameters to get a range of risk estimates. We also identified the level of exposure associated with a one in a million cancer risk estimate for the direct contact exposure pathways (swimming, net fishing, SCUBA diving, and windsurfing). Cancer risks greater than one in a million only occurred for the high swimming and net fishing exposure scenarios.

A second significant source of uncertainty in these risk estimates is uncertainty about the model for estimating chemical adsorption across the skin. The model we used is the model recommended by the U.S. EPA for assessing dermal exposure. The recommendations are based on an U.S. EPA analysis of dermal adsorption that included a detailed overview of the mechanisms, measurement techniques and mathematical models of dermal adsorption (U.S. EPA 1992). The methodologies presented in that overview are theoretically derived, and subject to further revision by U.S. EPA. The procedures are described as “not official Agency guidance, rather they represent the judgments of the authors and are offered as a starting point for Agency programs to adopt/modify in light of programmatic considerations” (*ibid.*). As such, this is a source of model structural uncertainty that cannot be quantified based on current information and understanding. We can say, based on the available information, that the seafood consumption probably poses greater risks than dermal adsorption, that seafood consumption and dermal adsorption risks likely have the same principal sources (sediment PCBs and naturally occurring arsenic) and that mitigating potential seafood consumption risks by controlling the source would likely also mitigate potential dermal adsorption risks.

Uncertainty about the conclusion that removing CSOs would have no discernable effect on health risks to net fishers or swimmers is low. We have a reasonably good understanding that other sources are principally responsible for the PCBs and arsenic to which people are exposed. Therefore, removing CSOs is expected to have little or no effect on risks to netfishers or swimmers from PCBs.

The WQA found risks from CSO viruses and Giardia to people who swim during or immediately after a CSO event, primarily in the Duwamish River and along the shore of Elliott Bay.

These results are based on estimated exposures to modeled virus and *Giardia* concentrations in the river and bay resulting from CSO discharges. We have high confidence in this conclusion, because viruses and *Giardia* are present in relatively high concentrations in untreated sewage, and the CSOs are the largest source of untreated sewage in the Duwamish Estuary. However, there were at least two uncertainties that prevent us from being equally confident regarding the absolute magnitude of these predicted risks. First, we did not have virus and *Giardia* concentration data in CSO discharges, but instead estimated these concentrations from limited site-specific and national average data. Recognizing this uncertainty, we used conservatively high estimates of virus and *Giardia* concentrations in CSO discharges in our model in an attempt not to underestimate risks from pathogens. Second, we did not have virus and *Giardia* concentration data in the Duwamish River and Elliott Bay, which made model calibration impossible and reduced certainty in the modeled virus and *Giardia* concentrations. Because the model was not calibrated for viruses and *Giardia*, we do not know whether the model is over- or under-predicting their concentrations resulting from CSO discharges and the absolute magnitude of the risk predictions remains somewhat uncertain.

In addition to the risk estimates based on virus and *Giardia* evidence, we evaluated fecal coliform concentrations as they compared to levels used in State standards. Fecal coliform concentrations indicate risks to people who swim in, or consume shellfish from, the Duwamish River or along the shoreline of Elliott Bay under both baseline and without CSO conditions. Based on fecal coliform concentrations, risk reductions are indicated along the Elliott Bay shoreline near the Denny Way CSO with CSO removal. We have a high degree of confidence in the fecal coliform information as corroborative evidence. It is based on measured and modeled fecal coliform concentrations throughout the Duwamish Estuary. We believe the level of uncertainty about the fecal coliform concentrations in the estuary is relatively low, and the significance of the CSO contributions reasonably well characterized by the model. There is some uncertainty associated with the correlation between fecal coliform concentrations and the potential for infection and/or illness. However, fecal coliform concentrations generally were substantially higher than the standards that are designed to be protective of public health, reducing this uncertainty.

5.3 Precautions For Future Investigations

We consider the key findings of this WQA to be reliable and usable for making decisions about future controls on CSOs in the Duwamish Estuary. However, we want to caution potential future investigators who may choose to apply or build on this work. Our main precaution is that the water and sediment quality model, though calibrated with hydrodynamic and water quality data, has not yet been tested with independent data, and has not been subject to thorough sensitivity analyses. The model was calibrated using default point estimates for all its physicochemical parameters, by adjusting inputs from other sources. It is important that any future application of *any* model be closely scrutinized to see whether it will provide the type and reliability of information the investigator is seeking.

Sources of model uncertainty come from two areas, uncertainty from field sampling methods and measurements, and model assumptions. The model was calibrated against measurements recorded in the field. As a result, there are two areas from which uncertainty is generated: taking measurements and making predictions. Any uncertainty in measurements is propagated into the model and its predictions. In addition, the model itself adds uncertainty because it is at best an approximation of the Duwamish Estuary. Sensitivity analysis can show how perturbations in a model affect its predictions, and give insight into important sources (i.e., parameters, equations) of model structural uncertainty.

Results of the hydrodynamic calibration indicate that the model realistically predicts the water elevation and salinity distributions in our calibration data set, and indicates that the model can estimate the transport of a conservative dissolved substance. For velocity, the model appears to realistically reproduce the harmonic velocity structure but, tends to under-predict the tidally averaged water velocity in the salt wedge. The greatest effect of this uncertainty is on predictions of suspended solids settling onto sediment beds. Horizontal distributions of suspended solids that settle slowly relative to horizontal water movement are not greatly affected by smaller horizontal velocities in the salt wedge. Under-prediction of the horizontal velocity will primarily affect fast-settling solids. If the salt wedge velocity is, as we suspect, under-predicted, fast-settling particles will not travel as far before settling onto the sediment bed.

The mass calibration was performed using the calibrated hydrodynamic model to simulate water flow. The mass calibration included adjustment of total suspended solid (TSS) concentration at the Green River and Elliott Bay boundaries and settling velocities. Since the TSS concentration and associated settling velocities were adjusted to match observed conditions, any deficiencies in the hydrodynamic velocities were compensated for in the calibrated settling velocity.

The mass calibration provided estimates of other source loads. It minimized the difference in means observed and predicted concentrations, and reduced the bias in estimates of the mean. However, the model represents the estuary as a set of boxes or cells, each of which is itself well-mixed, so the model is likely to underestimate variability if used to estimate acute exposures occurring over areas smaller than the model's boxes. This is not a problem for estimating exposures to populations occupying areas larger than the model's boxes, or for estimating time-averaged exposures. For estimating sediment concentrations at a finer spatial resolution, we would recommend developing a nearfield sediment model.

It is expected that the chemical calibration (by adjusting boundary conditions) would to some extent offset errors in the hydrodynamic calibration, allowing a reasonable fit to the field data. To the extent that this may have occurred in this initial parameterization of the model, its predictive power is limited (i.e., because the hydrodynamics and boundary conditions contain offsetting errors). For this assessment, we did not attempt to extrapolate beyond the time period for which we initialized the model.

A second important caveat about the model is that a linear interpolation scheme was used to set initial sediment concentrations in model cells for which we had no sediment concentration data. This could create an overestimation or underestimation bias in initial sediment concentrations, depending on where sediments have been sampled, and the nature of the sources. The worst case scenario is a localized ("hot spot") contaminant that has only been sampled in the hot spot and at the boundaries of the study area. In this case, the linear interpolation scheme would reduce initial sediment concentration as a function of distance from the hot spot, whereas a more realistic approach would be to reduce initial sediment concentration as a function of the square of the distance from the hot spot.

One way we dealt with the problems we encountered with the sediment initialization was to run the model for ten years, to allow sufficient time for initial sediments to become buried. This allowed us to better discern the difference between baseline and without CSO risks to organisms living on or in the sediment surface layer, because over time new sediments become an increasingly large fraction of the total surface sediment layer, and the importance of the initial conditions diminishes. While this approach was useful for comparing baseline and without CSO risks, a better initialization of the model, coupled with a more thorough hydrodynamic calibration, would clearly be preferred. Nonetheless, the model is useful for investigating the relative importance of CSOs in determining surface sediment concentrations, and it shows that at the level of resolution represented by the model's 512 grid cells, CSOs have little discernable impacts on sediment chemical concentrations. We would not recommend the model for estimating absolute sediment concentrations at specific locations, without a better sediment initialization and further attention to the velocity calibration in the salt wedge.

6. NEXT STEPS

The findings of the CSO WQA provide scientific information to support decisions to be made for the control of CSOs and help to identify the best means of providing protection for aquatic life, wildlife, and people who use the resources of the Duwamish River and Elliott Bay.

As decision-makers address the County's CSO control program, we anticipate questions will emerge for which we will need to collect additional information or perform additional analyses using existing data. The project team has developed a list of topics that, if addressed, will provide significant additional information to assist in the design of CSO control projects and/or selecting alternative means of reducing risk. There are four general issues that could benefit from further work to refine the existing model and expand the geographical area evaluated:

- CSO-related issues
- Watershed-level issues
- Endangered Species Act
- Public education and outreach

6.1 CSO Related Issues

6.1.1 Issues

1. Further refine the existing CSO WQA model to increase certainty and assure value of its continued use in CSO control planning.
2. Validate the existing CSO WQA model to increase certainty and build credibility with stakeholders and the public.
3. Utilize the CSO WQA hydrodynamic and risk assessment model to optimize design of future CSO control projects to achieve greatest reduction of risk.
4. Utilize the CSO WQA model as one of the tools to prioritize CSO control projects.

6.1.2 Recommendations

- Design and implement a sampling program to verify the model's predictions of sediment transport and chemical concentrations.

- Increase the certainty of the risk predictions for human pathogens by collecting samples for pathogen analysis from CSOs and storm drains that discharge to the river and the bay. This information will enhance decisions on the value of providing disinfection and dechlorination for CSO treatment.

- Further assess organic enrichment as a CSO caused stressor to help define the value of control of specific CSOs. This will be important to do because organic carbon has been shown in the benthic analyses to be a source of risk in the immediate areas of sediment deposition around CSO and storm drain discharges.

- Collect additional water column field data to be used in model validation.

- Include knowledge about which stressors are causing elevated risks when selecting a CSO control strategy.

6.2 Watershed and ESA Related Issues

6.2.1 Issues

One of the objectives of the WQA was to develop a tool that could be used to develop a watershed management plan to improve water quality throughout the watershed. The hydrodynamic and risk assessment models developed for the Duwamish River and Elliott Bay can be expanded and linked to basin models for the Green River watershed and can include information specific to sources other than CSOs.

6.2.2 Recommendations

- Develop a watershed level model for the Green River that can be used in determining an appropriate total maximum daily load for stressors causing excess risk to aquatic life, wildlife, and people using the resources of this watershed.

- Work with other jurisdictions to collect samples from other sources such as storm drains, groundwater, agricultural runoff, etc., to allow more accurate assumptions for modeling.

- Identify sources of human pathogens to the Green River and collect data to quantify the concentrations of specific pathogens.

- Verify estimated dietary risks to juvenile salmon by collecting and analyzing additional data for chemical stressors and water quality parameters.

- Utilize the risk assessment model to assess risk to juvenile salmon at other sites in the Green River and other King County watersheds, including the portion of the Green River that is important for salmon smoltification.

6.3 Public Education and Outreach

6.3.1 Issues

1. The findings of the CSO WQA are of significant interest to people who use the study area for recreational purposes. The information can help individuals decide how they may want to modify their current use of these resources and how they may want to work to reduce the existing risks.

2. The findings of the CSO WQA can be used to educate people regarding ways in which they can reduce risks to aquatic life and wildlife by changing their own day-to-day practices.

3. Presenting "risk information" is a useful tool for the public and decision makers, but it requires a great amount of explanation for people to understand and use the information.

6.3.2 Recommendations

- Design and implement a public outreach and education program to inform the citizens of King County about the findings of the CSO WQA.

- Provide information about how individual behaviors can be modified to reduce risks to themselves and to aquatic life and wildlife.

- Expand the fish consumption survey to include the Puget Sound beaches of King County, other fishing seasons, and fishers using boats in addition to piers and beaches.

- Evaluate how best to communicate information about ecological and human health risks to the public and decision makers.

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8. GLOSSARY

assessment endpoint - An explicit expression of the environmental value that is to be protected.

benthos - The community of aquatic organisms living in or on the bottom sediments.

biomarker – A biological indicator of exposure to a stressor, for example liver lesions in English sole.

carcinogenic - Capable of causing cancer.

constituent of potential concern (COPC) – Chemical, physical or biological constituents in the environment that potentially pose risk.

combined sewer overflow (CSO) - Discharges of combined sewage and storm water during wet weather. It occurs to relieve the sewer system as it becomes overloaded with normal sewer flow and increased storm runoff. The term is also used to denote a pipe that discharges these flows.

conceptual model - A conceptual model describes a series of working hypotheses of how a stressor might affect ecological components. The conceptual model also describes the ecosystem potentially at risk, the relationships between measures of effect and assessment endpoints, and exposure scenarios.

community - An assemblage of populations of different species within a specified location in space and time.

depuration – General term for less or disappearance of a substance from an organism by any active or passive transport mechanism, including diffusion and metabolic transformation.

disturbance - Any event or series of events that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment.

diversity - A measure (index) to characterize the numbers of different aquatic organisms (different taxa) that inhabit aquatic communities. Also a measure of ecological community structure.

ecological risk assessment – The process that evaluates the likelihood that adverse effects may occur or are occurring as a result of exposure to one or more stressors.

ecosystem - The biotic (living) community and abiotic (nonliving) environment within a specified location in space and time.

EEC – Estimated exposure concentration.

epibenthos - Refers to organisms (mainly invertebrates and fish) living near (just above) bottom sediments and not living in the bottom sediments.

exposure - Co-occurrence of or contact between a stressor and an ecological component.

exposure scenario - A set of assumptions concerning how an exposure may take place, including assumptions about the exposure setting, stressor characteristics, and activities that may lead to exposure.

fate - The form and location of a chemical material resulting from transport and transformation.

genera - Taxonomic category including one or more species which have certain fundamental characteristics in common.

lines of evidence - Formerly weight of evidence. A discussion in the ecological risk assessment that provides the risk manager with insight about the confidence of the conclusions reached in the risk assessment by comparing the positive and negative aspects of the data including uncertainties identified during the process.

measure (measurement endpoint) - A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. Measurement endpoints are often expressed as the statistical or arithmetic summaries of the observations that comprise the measurement.

model - A system of postulates, data, and inferences presented as a mathematical description of an entity or the relationships of several or more variables.

plankton - Microscopic plants and animals living freely or weakly swimming in surface waters.

population - An aggregate of individuals of a species within a specified location in space and time.

probability - The likelihood that a parameter will assume a particular state or value (e.g., the probability that exposure to a chemical will cause a fish kill is one in one hundred).

problem formulation - A phase of ecological risk assessment that establishes the goals, scope, and focus of the assessment. It is a systematic planning step that identifies the major factors to be considered in the assessment and is linked to regulatory and policy requirements. Its outcome is a conceptual model that describes how a given stressor might affect the ecological components of the environment.

receptor – An ecological component being evaluated for risk.

richness - A measure (number of species) characterizing the variety of organisms in aquatic communities. Also a measure of ecological community structure.

risk characterization - A phase of ecological risk assessment that integrates the results of the exposure and ecological effects analyses to evaluate the likelihood of adverse ecological effects associated with exposure to a stressor. The ecological significance of adverse effects is discussed, including consideration of the types and magnitudes of effects, their spatial and temporal patterns, and the likelihood of recovery.

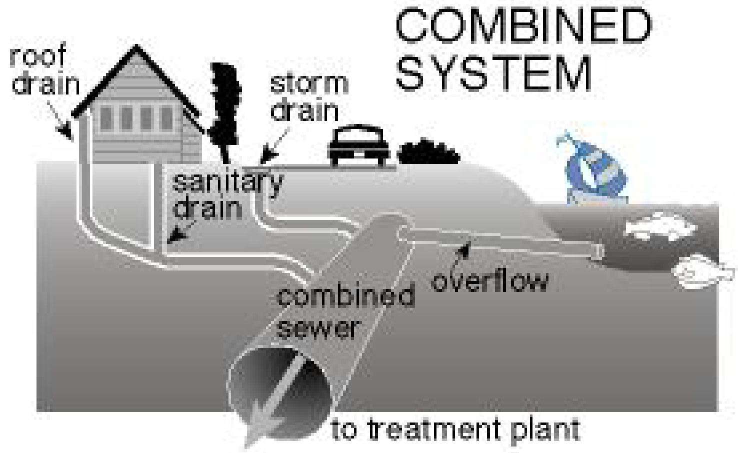
risk management - A phase of risk assessment that includes discussions between the risk assessor and risk manager that paves the way for regulatory decision making. These discussions ensure that the results of the risk assessment are clearly and fully presented. The results of the risk assessment process are used along with other inputs to evaluate risk management options.

scouring – The loss of sediment layers through the resuspension and movement of sediment away from a particular location.

smolt - A salmon or trout that is outmigrating from freshwater to marine water and is adapting to marine life. The lifestage where a salmon or trout takes on the silvery color of an adult.

source - An entity or action that releases to the environment or imposes on the environment a chemical, physical, or biological stress or stressor.

stressor - Any physical, chemical, or biological entity that can induce an adverse effect.



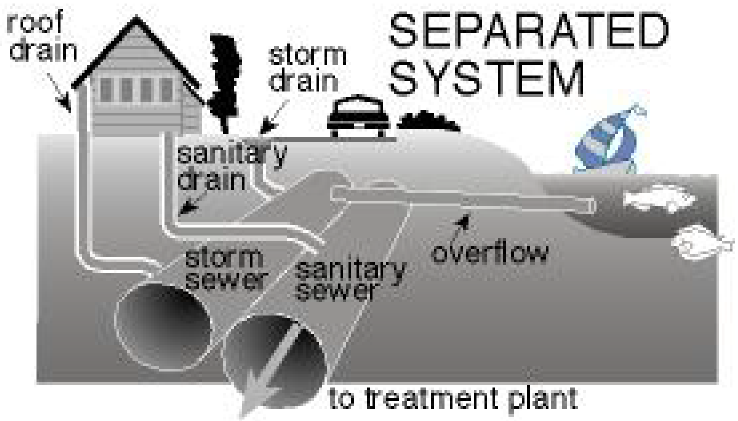


Figure 1-1.
Schematic Representation
of Combined and
Separated Sewer Systems