Technical Memorandum 540

Environmental and Habitat Priorities

2012 CSO Control Program Review

FINAL

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King County

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Acronyms

CFU	Coliform forming unit
CIG	University of Washington Climate Impacts Group
COC	Chemical of Concern
CSO	Combined sewer overflow
DO	Dissolved oxygen
DOH	Washington State Department of Health
Ecology	Washington State Department of Ecology
EAA	Early Action Area
EBDRP	Elliott Bay/Duwamish Restoration Program
EPA	U.S. Environmental Protection Agency
ESA	Endangered Species Act
HCP	Habitat Conservation Plan
IPCC	Intergovernmental Panel on Climate Change
LC50	Lethal concentration that kills 50 percent of test animals
LDW	Lower Duwamish Waterway
LDWG	Lower Duwamish Waterway Group
NMFS	National Marine Fisheries Service
NPDES	National Pollutant Discharge Elimination System
ODEQ	Oregon Department of Environmental Quality
PCB	Polychlorinated biphenyl
PNW	Pacific Northwest
PPCP	Pharmaceuticals and personal care products
RI	Remedial Investigation
RWSP	Regional Wastewater Services Plan
SLR	Sea level rise
SMP	Sediment Management Plan
SMS	Sediment Management Standards
SQS	Sediment Quality Standards
TBT	Tributyltin
TSS	Total suspended solids
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service
WAC	Washington Administrative Code
WSDOT	Washington State Department of Transportation
WRIA	Water Resource Inventory Area
WTD	King County Wastewater Treatment Division

EXECUTIVE SUMMARY

This technical memorandum (TM) was prepared for the King County Wastewater Treatment Division (WTD) in support of the 2012 Combined Sewer Overflow (CSO) Control Program Review. The objective of the TM is to provide an update on new science that has become available since the 1999 Regional Wastewater Services Plan (RWSP) that should be considered in reviewing priorities for CSO control. This TM presents and evaluates current environmental and habitat priorities related to King County's efforts to prioritize control of CSOs. Uncontrolled CSO sites (where control projects are currently not being implemented) discharge CSOs to Elliott Bay, Duwamish River, Lake Washington Ship Canal, Lake Union, and the Montlake Cut. The environmental and habitat priorities identified in this TM are based on a review of existing studies produced by King County and other entities covering a variety of subjects related to ecological and human health in the Puget Sound region including sediment quality, water quality, threatened and endangered species, climate change, and habitat improvement.

When the RWSP was prepared in 1999, human health risk was primarily viewed as pathogen exposure, which was the primary driver for prioritizing CSO control where there is greatest potential for primary contact (e.g., Lake Washington shores, Puget Sound beaches). Puget Sound Chinook salmon and bull trout had just recently been listed as threatened under the Endangered Species Act (ESA) and it was unknown how this listing affected the CSO control program. Furthermore, sediment contamination was just becoming an issue that needed attention and it was uncertain to what extent CSO discharges are responsible.

Since 1999, more information is known about the water and sediment quality of receiving waters and the effects of CSOs. Water and sediment contamination has been linked to bioaccumulation of toxins in fish and shellfish. As a result, human consumption of fish and shellfish containing toxins has been identified as an important human health risk that can result in cancer. In addition to Chinook salmon, several other aquatic species in the Puget Sound region have been listed as threatened or endangered under the ESA including steelhead, killer whale, and three species of rockfish.

According to the previous CSO control program review, the next highest priority for CSO control efforts are the University and Montlake CSOs because of the amount of boating in the area, which could result in secondary contact with the water. However, based on the evaluation of environmental priorities presented in this TM, secondary contact with water from boating is a low risk and there does not appear to be an overall consensus for prioritizing control of CSOs in one water body over the other based on scientific drivers. However, current high priority efforts to remediate sediment contamination and eliminate ongoing sources of contamination in the Lower Duwamish Waterway (LDW) represents an institutional driver for controlling CSOs, which applies to sediment quality and human health environmental priorities. Table ES-1 summarizes CSO control priority decisions based on an evaluation of environmental priorities.

Table ES-1. CSO Control Area Priority Based on Evaluation of Environmental Priorities.

Environmental Priority	CSO Control Area Priority Status				Qualifiers		
	Duwamish River/ Elliott Bay Priority	Lake Washington Ship Canal Priority	Montlake Cut Priority	No Difference in Priority	Scientific Driver	Institutional Driver	Insufficient Data/ Imbalance of Data
Water Quality				X			X
Sediment Quality	X					X	X
Human Health							
Pathogens (incidental ingestion)				X			X
Chemicals (fish consumption)	X					X	X
Ecological Health	X				X		X
Climate Change				X			

The following subsections summarize the CSO control priority decisions for each environmental priority.

- **Water Quality.** Considering the nature of existing water quality conditions, there is no apparent preference for prioritizing CSO control in one area over the other. The Duwamish River, Lake Washington Ship Canal, and Montlake Cut are all of moderate water quality condition and are known to have harmful concentrations of fecal coliform (an indicator of harmful bacteria), nutrients, and dissolved oxygen. Each of these water bodies receive high volumes of pollutants from other sources (especially stormwater) that degrade water quality on a more consistent basis and therefore, removal of CSOs is not expected to have a substantial benefit in one water body over the other. Furthermore, the input of pollutants from other sources is heightened at the same time as CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs. Additional studies are necessary to determine for certain which water body has worse water quality conditions due to pollutant loading from sources other than CSOs.

  Based on CSO discharge volume, it is also difficult to determine where removal of CSOs would have a substantial water quality benefit in one water body over the other when considering flushing rate and dilution.

- **Sediment Quality.** Current high priority efforts to remediate sediment contamination and eliminate ongoing sources of contamination in the LDW present an institutional driver for prioritizing control of CSOs in the Duwamish River/Elliott Bay. Sediment remediation efforts are not yet underway in the greater Lake Union and therefore, the Lake Washington Ship Canal and Montlake Cut area are of lower priority for control.

  An ongoing question has been to what extent CSOs are capable of contaminating sediments after they have been remediated and if they do, does it make sense to control CSOs prior to remediation efforts. Based on sediment monitoring, some recontamination of sediments (PCBs, PAHs, and phthalates) is occurring at the

Norfolk and Diagonal/Duwamish CSO sites, but evaluations do not strongly link it to uncontrolled CSO sites. Similar studies have not been conducted in the Lake Washington Ship Canal or Montlake Cut because remediation has not occurred in these water bodies. Therefore, it is difficult to prioritize CSO control in one water body over the other based on scientific factors.

- **Human Health.** Risks associated with pathogen exposure were the primary driver for prioritizing control of CSOs near Puget Sound Beaches. Pathogen exposure is no longer a priority driver for control of CSOs in the Duwamish River/Elliott Bay from a scientific perspective because unlike the Puget Sound beach areas, baseline (i.e., background) conditions present a risk from other sources and therefore, control of CSOs would do little to reduce an ongoing risk. The same situation applies for chemical exposure. There is a lack of studies to demonstrate risks associated with baseline conditions in the Lake Washington Ship Canal and Montlake Cut, but there are reasons to suspect this could be the case.

  There is no human health scientific driver for CSO control prioritization at this time. However, the sediment remediation and source control efforts are underway in the LDW aimed at reducing chemical exposure associated with seafood consumption, presents an institutional driver for prioritizing control of CSOs in this water body.

- **Ecological Health.** Based on potential exposure effects to juvenile Chinook salmon in close proximity of outfalls, CSO sites in the Duwamish River/Elliott Bay area should receive a higher priority for control when compared to the Lake Washington Ship Canal and Montlake Cut. CSOs occur predominantly over a period extending from October through April. During this time, out-migrating juvenile Chinook salmon in the Duwamish River are more susceptible to adverse effects when compared to returning adult Chinook salmon in the Lake Washington Ship Canal/Montlake Cut.

  However, the potentially adverse effects of pollutants from CSOs on juvenile Chinooks may not be distinguishable from the effects of high volumes of similar pollutants from other sources (especially stormwater). The input of pollutants from other sources is heightened at the same time as CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs.

- **Climate Change.** Based on the effects of climate change, there is no apparent preference for prioritizing CSO control in one area over the other. However, sea-level rise attributed to climate change could have less of an effect on CSOs in the Lake Washington Ship Canal and Montlake Cut, because the locks maintain a higher surface water elevation in these water bodies relative to Elliott Bay and the Lower Duwamish River.

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1.0. INTRODUCTION

This technical memorandum (TM) was prepared for the King County Wastewater Treatment Division (WTD) in support of the 2012 Combined Sewer Overflow (CSO) Control Program Review. The objective of the TM is to provide an update on new science that has become available since the 1999 Regional Wastewater Services Plan (RWSP) that should be considered in reviewing priorities for CSO control. This TM presents and evaluates current environmental and habitat priorities related to King County's efforts to prioritize control of CSOs. The Washington State Department of Ecology (Ecology) considers a CSO site controlled when discharges have been reduced to an average of one untreated discharge per year (WAC 173-245-020). According to King County's National Pollutant Discharge Elimination System (NPDES) permit CSO control Plan Update, all of King County's remaining uncontrolled CSO sites must be controlled by 2030. Environmental and habitat priorities were identified to support prioritizing where control efforts will occur next. Uncontrolled CSO sites (where control projects are currently not being implemented) discharge CSOs to Elliott Bay, Duwamish River, Lake Washington Ship Canal, Lake Union, and the Montlake Cut. Figure 1-1 shows the locations of all of the uncontrolled CSO sites, and Table 1-1 provides a list of the CSO sites located in the Duwamish River/Elliott Bay, Lake Washington Ship Canal, Lake Union, and Montlake Cut areas. A control project has been implemented for the Dexter Avenue CSO; however, it did not achieve complete control. The volume of overflows was dramatically reduced, but the frequency still exceeds the standard. Additional technical assessments are underway to complete control of the Dexter Avenue CSO. Therefore, Lake Union is not evaluated as one of the remaining CSO priority control areas in this TM.

Table 1-1. Uncontrolled King County CSO Sites.

DSN	Name of Uncontrolled CSO Site	Duwamish River/Elliott Bay	Lake Washington Ship Canal	Lake Union	Montlake Cut
028	King Street Regulator	X			
029	Kingdome (Connecticut Street) Regulator	X			
030	Lander Street	X			
031	Hanford at Rainier (Hanford #1)	X			
032	Hanford #2	X			
036	Chelan Avenue Regulator	X			
038	Terminal 115 Overflow	X			
039	South Michigan Regulator	X			
041	Brandon Street Regulator	X			
042	West Michigan Regulator	X			
004	11th Avenue NW		X		
008	3rd Avenue W		X		
009	Dexter Avenue Regulator			X	
014	Montlake Regulator				X
015	University Regulator				X

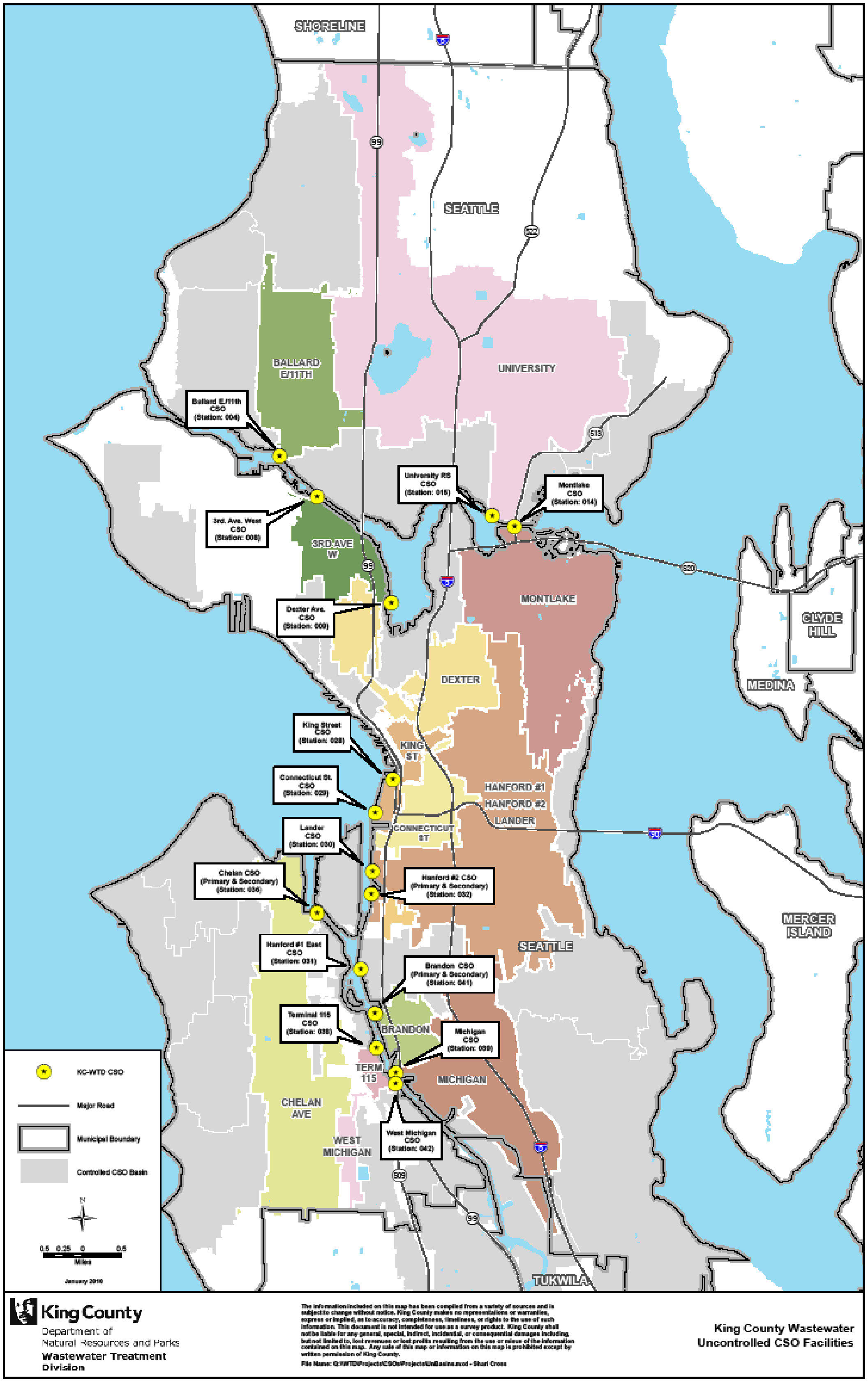

Figure 1-1. Location of Uncontrolled CSO Sites.

The environmental and habitat priorities identified are based on a review of existing studies produced by King County and other entities covering a variety of subjects related to ecological and human health in the Puget Sound region including sediment quality, water quality, threatened and endangered species, climate change, and habitat improvement. King County updated these topics in the 2006 CSO Control Program Review and 2008 CSO Control Plan Update (King County, 2006; King County, 2008); however, the intent of this TM is to address science developments since the RWSP was published in 1999.

The organization of this report includes background information on previously established CSO control priorities, current environmental and habitat priorities related to CSOs, and the effect that those priorities have on prioritizing the control of remaining CSOs.

1.1 Background

Agencies with CSOs in Washington implement cycles of CSO control planning with the NPDES permit cycle. The 1999 RWSP and its major update to King County's CSO control plan was being developed while King County implemented two significant control projects. The Denny/Lake Union CSO control project would control King County's largest CSO at Denny Way (Myrtle Edwards Park), its single CSO into Lake Union, and the City of Seattle's East Lake Union CSOs. The Henderson/MLK/Norfolk project would control King County's last uncontrolled CSOs into Lake Washington, as well as the Norfolk CSO, its most upstream CSO into the Duwamish River. Both projects were completed in 2005 but the Denny and Dexter controls have required adjustments to achieve full control. The RWSP prioritized the remaining CSO projects to protect public health, the environment, and threatened/endangered species.

In 1999 when the RWSP was prepared, human health risk was primarily viewed as pathogen exposure, which was the primary driver for prioritizing CSO control where there is greatest potential for primary contact (e.g., Lake Washington shores, Puget Sound beaches). Puget Sound Chinook salmon and bull trout had just recently been listed as threatened under the Endangered Species Act (ESA) and it was unknown how these listings would affect the CSO control program. Furthermore, sediment contamination was just becoming an issue that needed attention and it was uncertain to what extent CSOs are responsible.

King County (1999a) has predicted that there would be limited improvement of conditions for aquatic life, wildlife, and people using the Duwamish River if CSO discharges are controlled because existing conditions are largely attributed to historic practices that resulted in sediment contamination. Furthermore, degradation of water and sediment quality attributed to CSOs is minimal when compared to other sources of pollutants in the Duwamish River and pollutants entering from upstream segments of the Green River. King County (1999a) concluded that CSO pollution is a very small part of a larger problem mainly because of the dilute pollutant concentrations of CSOs and the brief and infrequent loading and exposure to CSOs. Pathogen exposure could occur during overflows and for up to 48 hours after. Therefore, King County has prioritized control efforts for areas where there is more risk associated with direct human contact with harmful bacteria and chemicals in CSOs. As a result the Puget Sound beach control efforts are currently underway.

Since the 1999 RWSP, the CSO control program has identified the following four priority areas for control including anticipated completion date and justification for their priority ranking.

Priority Area 1 is underway, and the remaining priorities are scheduled for completion by year 2030.

- Priority Area 1 (ongoing, 2013 completion), CSOs near Puget Sound beaches to reduce potential exposure of harmful bacteria and pollutants to people participating in recreation activities along beaches. Common activities include swimming and beach play in the summer, and windsurfing and diving during winter months.
- Priority Area 2 (2015 completion), University/Montlake CSOs. This area was given high priority because of the amount of boating in the area, which could result in secondary contact with the water. Limited primary contact recreation also does occur.
- Priority Area 3 (2027 completion), CSOs along the Duwamish River and in Elliott Bay. These projects were given third priority because studies indicate that the level of pollution originating upstream of CSOs was high enough to dwarf improvements by CSO control programs (King County, 1999a). Limited wading and beach play does occur in a few areas and tribal net fishing could lead to contact with contaminants from the water and sediments.
- Priority Area 4 (2030 completion), CSOs at the West End of the Lake Washington Ship Canal. This area was given last priority because significant CSO control has already been accomplished in this area.

1.2 City of Seattle CSO Control

At the time of the 1999 RWSP, King County understood that the City of Seattle CSO control program was nearly complete with only a few projects needed along the Lake Washington Ship Canal. One of the RWSP projects was defined as a joint project to control both County and City CSOs. Soon after adoption of the RWSP, information became available that many City CSOs would require additional controls. The City identified six priority areas in addition to their Lake Washington Ship Canal CSOs in their 2000 CSO Control Plan Amendment, including:

- Windermere (upstream of the County's University CSO in Montlake Cut)
- Magnolia (upstream of the County's Magnolia CSO in Elliott Bay)
- Delridge (upstream of the County's Harbor and Chelan CSOs in Duwamish River)
- Diagonal (into the Diagonal storm drain, shared with the County's Hanford 1 CSO in Duwamish River)
- Genesee (upstream of the County's Hanford @ Rainier CSO on Lake Washington)
- Henderson (upstream of the County's Henderson CSO project on Lake Washington).

The City's recent 2010 CSO Control Plan Amendment identifies additional areas needing CSO control.

In assessing King County CSO control priorities, the benefits must be viewed in relation to City control priorities. The County and City are coordinating their current planning to identify any cost effective collaborative project opportunities and to determine were environmental priorities are aligned. Decisions on these will be shaped by a variety of issues, including each agency's environmental priorities.

1.3 Study Areas

This TM focuses on environmental and habitat priorities near remaining King County uncontrolled CSO sites (located in Elliott Bay, Duwamish River, Lake Washington Ship Canal, and the Montlake Cut) and environmental elements that are affected by CSOs. The focus of discussion is based on remaining priority areas in need of control including Duwamish River/Elliott Bay, Lake Washington Ship Canal, and the Montlake Cut. Uncontrolled CSO sites within Elliott Bay are near the mouth of the Duwamish River and share similar environmental conditions and therefore these two water bodies are considered a single priority area for control and are discussed together. In many places throughout this TM, discussion of the Lake Washington Ship Canal and Montlake Cut is combined because they share similar environmental conditions.

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2.0. ENVIRONMENTAL PRIORITIES

This section reevaluates environmental priorities in light of new science developments since the 1999 RWSP.

King County and other entities have conducted many studies examining the environmental effects of CSOs on human and ecological health and environmental conditions near CSOs including sediments, water, habitat, and aquatic organisms. King County has also examined to what extent CSOs have contributed to current environmental conditions. Environmental priorities related to CSOs include water quality, sediment quality, human health effects, ecological health effects (including effects on threatened and endangered species), and climate change.

Information on each of these priorities is presented in the following sections, including implications for CSO control and prioritization.

2.1 Water Quality

Water quality in the Puget Sound region is determined based on Washington state standards established by Ecology. Standards are "established to sustain public health and public enjoyment of the waters and the propagation and protection of fish, shellfish, and wildlife" (Ecology, 2010). The water quality standards established by Ecology are as restrictive as or more restrictive than national water quality standards established by the EPA.

2.1.1 Water Quality Conditions

Ultimately, all remaining uncontrolled CSO sites directly or indirectly discharge CSOs into the Puget Sound. Results of water quality monitoring indicate that in general, the overall water quality in the Puget Sound is good based on general water quality parameters such as bacteria, nutrients, salinity, temperature, chlorophyll, dissolved oxygen, solids, and transparency (King County, 2007a). For example, fecal coliform in offshore waters is consistently low and meets Washington state standards, with the majority of samples having either no detectable levels or 1 colony forming unit (CFU)/100 ml. Most dissolved oxygen concentrations are above 5.0 mg/L, which is considered adequate for aquatic life. Nutrient conditions are below the Washington State chronic criterion.

Duwamish River/Elliott Bay

Water quality conditions in the Duwamish River and Elliott Bay present no risk to aquatic life based on general water quality parameters and a low level of risk based on levels of harmful chemicals (King County, 1999a). However, at times, the Duwamish River and Elliott Bay contain measurable quantities of several types of harmful chemicals (e.g., arsenic, benzo(a)anthracene, benzo(g,h,i)perylene, copper, fluoranthene, lead, nickel, polychlorinated biphenyls [PCBs], tributylin [TBT], zinc) in the water column that exceed acute or chronic aquatic life screening levels (Note: exceedances of a screening level does not indicate risk to aquatic life; it only means that presence or absence of risk cannot be determined without further investigation). The Duwamish River is included on Ecology's (2008) Water Quality Assessment 303(d) list as containing several areas of impaired waters. Water quality standard exceedances include fecal coliform, pH, and dissolved oxygen. Elliott Bay has water quality standard exceedances for fecal coliform.

There are no long-term water quality monitoring stations on the Duwamish River; however, Ecology has a station on the lower Green River in Tukwila at river mile 12.4 (approximately 7 miles upstream of Lower Duwamish River) which informs conditions in the vicinity and entering the Duwamish. At this station, overall water quality is of moderate concern based on the water year 2009 summary. Fecal coliform bacteria frequently exceed water quality standards. Constituents exceeding the usual range of data include several forms of nitrogen, phosphorus, suspended solids, and turbidity.

The Duwamish River receives many point sources of pollution such as stormwater outfalls conveying untreated stormwater from residential, commercial, and industrial sites, and from street runoff. CSOs are another source, which are largely comprised of stormwater. In addition, runoff of pollutants is conveyed to the Duwamish River from upstream sources in the Green River watershed. The lower reaches of the Green River occur in a highly developed basin dominated by land uses associated with increased pollutant loadings (Herrera, 2007), including:

- Commercial and industrial land uses exhibit significant positive correlations with ammonia nitrogen, total zinc, and dissolved iron loading.
- High-density residential land use exhibits significant positive correlations with fecal coliform bacteria and dissolved zinc loading.
- Agriculture is strongly correlated with orthophosphate phosphorus, total phosphorus, and dissolved copper loading.

Effective impervious area in the basin has a significant positive correlation with loading of E. coli, ammonia nitrogen, total copper, total mercury, and total and dissolved zinc.

Lake Washington Ship Canal/Montlake Cut

King County (2010) rates Lake Union (including Lake Washington Ship Canal and Montlake Cut) as having moderate water quality based on 2007 monitoring results. However, phosphorous values in Lake Union during the summer of 2007 were high, reaching into the poor water quality range. High phosphorous contributes to nuisance blooms of aquatic plants that deplete dissolved oxygen concentrations when they decay. Between 2004 and 2008, at least 50 percent of monitoring stations on Lake Union were below the lake standard for fecal coliform. King County is continuing monitoring to detect existing and potential problems with the stormwater and wastewater treatment system that could be responsible for high fecal coliform concentrations.

The Lake Washington Ship Canal and Montlake Cut are included on the Ecology's (2008) Water Quality Assessment 303(d) list as containing several areas of impaired waters. Water quality standard exceedances include total phosphorus, lead, fecal coliform, and aldrin.

The Lake Washington Ship Canal and Montlake Cut occur within a heavily urbanized watershed draining residential, commercial, and industrial neighborhoods, which represent sources of fecal coliform, ammonium nitrogen, zinc, copper, and mercury. During the summer months, dissolved oxygen concentration is near zero within the hypolimnion (i.e., deep water layer), which is a result of microbial activity consuming oxygen and less flushing due to summer low flows. In addition, surface water temperatures exceed 20 degrees Celsius during summer months, which is the upper incipient lethal temperature for salmon (King County, 2007b). The temperature of

Lake Washington is warming at a rate of 0.026 degrees Celsius per year (Arhonditsis et al., 2004). For more information on temperature effects on salmon, see Section 2.4 (*Ecological Health*).

2.1.2 CSO Effects on Water Quality

CSOs contribute to degradation of water quality by contributing untreated wastewater and stormwater constituents including harmful bacteria (i.e., pathogens), nutrients (e.g., phosphorus), dissolved heavy metals (e.g., mercury, zinc, copper), and measurable quantities of harmful chemicals. However, because of the infrequent nature of CSOs, the effect on water quality is much less than other largely uncontrolled sources, such as stormwater runoff.

The pollutant concentration levels are similar for each remaining uncontrolled CSO site. During CSO events, wastewater constituents dilute immediately when mixed with stormwater in combined sewer pipes. Both wastewater and stormwater constituents eventually dilute to levels below water quality standards once they enter receiving water bodies. The quality of receiving water is of particular concern during CSO events within the zone where effluent is mixing with the receiving waters. The effect of CSOs on baseline water quality is highly dependent on the rate of flushing within the receiving water body. CSOs tend to occur more frequently during the winter/spring months when inflows from rivers promote high rates of flushing in the Duwamish River, Lake Washington Ship Canal, and Montlake Cut.

2.1.3 Water Quality CSO Control Priorities and Implications

Considering the nature of existing water quality conditions, there is no apparent preference for prioritizing CSO control in one area over the other. The Duwamish River, Lake Washington Ship Canal, and Montlake Cut are all of moderate water quality condition and are known to have harmful concentrations of fecal coliform (an indicator of bacteria harmful to human health), nutrients, and dissolved oxygen. Each of these water bodies receive high volumes of pollutants from other sources (especially stormwater) that degrade water quality on a more consistent basis and therefore, removal of CSOs is not expected to have a substantial benefit in one water body over the other. Furthermore, the input of pollutants from other sources is heightened at the same time as CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs. Additional studies are necessary to determine for certain which water body has worse water quality conditions due to pollutant loading from sources other than CSOs.

Based on CSO discharge volume, it is also difficult to determine where removal of CSOs would have a substantial water quality benefit in one water body over the other when considering flushing rate and dilution. CSOs in the Duwamish River discharge substantially higher volumes when compared to the Lake Washington Ship Canal and Montlake Cut; however the residence time is short considering the time that it takes to flush out to Elliott Bay and the greater Puget Sound is less than 40 hours. The U.S. Geologic Survey estimated that the average time for surface waters from river mile 12.3 to reach the mouth of the Duwamish River is about 40 to 55 hours (USACE, 1983). CSOs on the Duwamish River occur between the mouth and river mile 6.

Substantially lower volumes of discharge occur at CSOs in the Montlake Cut; however, the residence time is longer because discharge flows into Lake Union which takes about one week to flush into the Puget Sound. CSO discharge quickly dilutes in Lake Union. In addition, although flushing time is longer in Lake Union compared to the Duwamish River, much more volume of water is flowing through the Montlake Cut, Lake Union, and Lake Washington Ship Canal.

The lowest volume of CSO discharge occurs in the Lake Washington Ship Canal, and this discharge could be flushed to the Puget Sound as quickly as (or quicker than) the Duwamish River based on flow rates and proximity to the Puget Sound.

Source control is perhaps the most effective way of eliminating pollutants. In addition to ongoing CSO control efforts by King County and the City of Seattle, Washington State is taking steps to reduce pollution at the source to improve water quality conditions. For example, restrictions on phosphorus concentrations in laundry and dishwashing soaps, nutrient management plans for dairies, and a ban on use of copper in vehicle brake pads.

As water quality-based permit limits are increasingly applied to CSO treatment facilities, it may be necessary to increase dilution, improve treatment technologies, and/or enhance source control to ensure compliance. Some environmental groups are requesting that Ecology require that water quality standards be achieved at the end of pipes rather than at the edge of mixing zones (King County, 2006). Should water quality standards change to end-of-pipe regulations, more emphasis would need to be placed on improved treatment technologies and enhanced source control.

Future changes in water quality standards resulting in more prohibitive pollution levels could also require improvements in treatment technologies and enhanced source control. Currently, the Oregon Department of Environmental Quality (ODEQ) is revising standards for toxic pollutants, which are intended to protect human health based on the higher levels of fish consumed by many Oregonians (ODEQ, 2010). The revised fish consumption rate, which includes salmon, is 175 grams (g) per person per day (24, 8-ounce meals per month), which is 10 times higher than the previous Oregon state and existing national fish consumption rate of 17.5 g/day (ODEQ, 2008). The 175 g/day rate applies to people in the Pacific Northwest, in which fish and shellfish are a part of their diet. This rate is based in part on fish consumption studies examining Washington state tribes, including the Tulalip, Squaxin Island, and Suquamish Indian Tribes. ODEQ is planning to release proposed water quality standards for public comment in early 2011 and anticipates submitting the revised standards to the EPA for approval in mid-2011.

There is concern in Oregon that installing end-of-pipe treatment to comply with criteria that are more stringent could cause severe economic hardship for cities or industrial dischargers. In some circumstances, treatment technologies capable of attaining criteria may not be available (SAIC, 2008). ODEQ and EPA are investigating implementation tools and approaches that are legally defensible under the Clean Water Act and will provide alternatives where meeting effluent limits based on water quality standards is either infeasible or prohibitively expensive. Some of these tools include compliance schedules, toxics reduction programs based on the amount of toxic pollutants entering a municipal treatment plant, intake credits, and variances. An intake credit is a means to account for pollutants in a facility's intake water when calculating effluent limits.

Although the upcoming changes in water quality standards in Oregon state do not apply to Washington state, Ecology has indicated that they will start reviewing state water quality standards based on fish consumption in fall 2010 (Brooks, 2010).

In addition, the EPA is planning to propose a limited set of targeted changes to national water quality standards regulation to improve its effectiveness in helping restore and maintain the chemical, physical, and biological integrity of the nation's waters. The EPA expects to publish a proposed rule in the Federal Register in summer 2011 (EPA, 2010). Specifically, the EPA is considering providing clarity in the following key areas:

- Anti-degradation implementation methods
- Administrator's determination
- Designated uses
- Variances to water quality standards
- Triennial review scope and requirements
- Updating regulation to reflect court decisions.

King County needs to consider these potential regulatory changes in its planning.

2.2 Sediment Quality

Sediment quality in the Puget Sound region is determined based on Washington standards established by Ecology. The Sediment Management Standards (SMS) rule outlines specific standards and decision-making processes to protect biological resources and remediation of contaminated sediment. At this time, the SMS includes chemical and biological standards for Puget Sound marine sediments, but lacks standards for freshwater sediments (Ecology, 2009). However, Ecology has established freshwater Sediment Quality Guidelines (SQGs) for developing remediation standards at freshwater sites. Ecology is currently considering revisions to the SMS rule to provide freshwater sediment standards.

2.2.1 Sediment Quality Conditions, Remediation, and Source Control

Historic and current land uses have resulted in contamination of sediments within the Duwamish River, Elliott Bay, and Lake Union. Typical historic and current sources of contamination include raw sewage, industry, stormwater, and CSOs. However, with current levels of source control provided by the County's industrial waste program and CSO control to date, CSOs are considered a minor contribution to sediment contamination when compared to historic inputs from raw sewage outfalls and industrial discharges (King County, 1999a). At the time of the RWSP sediment concerns were gaining attention. Subsequently the Lower Duwamish was listed as a Superfund site and the Harbor Island Superfund waste extended across the East Waterway. In response to the Superfund status of the LDW and violation of sediment standards, King County and other entities have initiated remediation efforts in the Duwamish River and Elliott Bay. King County has characterized sediment conditions in areas of the Ship Canal and Lake Union, but due to the lack of freshwater standards and funding for multi-agency partnerships has not initiated remediation actions.

Duwamish River/Elliott Bay

The following sections present current sediment quality conditions in the Duwamish River/Elliott Bay, and actions being taken to remediate contaminated sediments and control current sources of pollution contributing to contamination.

Sediment Quality Conditions

King County prepared a Sediment Management Plan (SMP) that involved assessing sediment contamination near seven CSOs in the Duwamish River and Elliott Bay that were listed on the Washington State Contaminated Sites list (King County, 1999b). The areas were assessed for their risk, preferred remediation approach, partnering opportunities, and potential for recontamination after remediation. The following priorities were determined for remediation:

- High priority: King Street CSOs
- Medium/high priority: Hanford and Lander Street CSOs
- Medium priority: Denny CSOs
- Low/medium priority: Chelan Avenue CSOs
- Low priority: Brandon Street CSOs.

The SMP reaffirmed that uncontrolled CSO sites are not expected to re-contaminate sediments, but highlighted the need for more information about CSOs as an ongoing or historical contributor to contamination. Contamination of sediments with chemicals (e.g., PCBs) was identified as resulting mainly from historical inputs. Therefore, the SMP recommended that sediment remediation near CSO sites proceed ahead of CSO control, except near the Denny Way CSO site (controlled in 2005) where recontamination was a concern.

King County is a member of the Lower Duwamish Waterway Group (LDWG) along with the City of Seattle, Port of Seattle, and The Boeing Company. The LDWG has completed a remedial investigation (RI) for the LDW including identification of Early Action Areas (EAAs) and human and ecological health risk assessments (Winward, 2007a; Winward, 2007b; Winward, 2008). Results of the human and ecological health risk assessments are provided in Section 2.3 (*Human Health*) and Section 2.4 (*Ecological Health*).

Information below summarizes results of the RI:

- Common surface (top 10 centimeters) contaminants include PCBs, metals, polycyclic aromatic hydrocarbons (PAHs), and phthalates.
- Historically contaminated sediments are being covered by cleaner more recently deposited sediment, thereby providing passive remediation.
- Areas of high chemical concentrations in surface and subsurface sediment (hot spots) are generally found in areas with low net sedimentation rates.
- Areas of predicted high sedimentation and known high chemical concentration could be as a result of localized disturbance events or recent/ongoing sources of contamination.

- Localized areas near large storm drains, CSO sites, or other upland sources may have persistently elevated concentrations of some chemicals, regardless of upland source control actions.
- Hot spots are not showing passive recovery and therefore are considered Category 1 Sediment Management Areas (SMAs) along with areas of moderate levels of chemical concentrations totaling 80 acres that require active remediation.
- Category 2 SMAs require less active remediation, and Category 3 SMAs can be recovered passively.
- Five “hot spot” sites are identified as EAAs for remediation including Duwamish/Diagonal, Slip 4, Boeing Plant 2/Jorgensen Forge, Terminal 117, and Norfolk.

Sediment transport modeling on behalf of LDWG further confirmed that historically contaminated sediments are being covered by cleaner, more recently deposited sediment (i.e., passive remediation) (QEA, 2008). More than 99 percent of new sediment that deposits in the LDW originates upstream in the Green/Duwamish River, where concentrations of key chemicals such as PCBs are much lower than they are in certain areas of the LDW. Less than one percent of new sediment originates from storm drains, CSO sites, and streams that discharge directly into the LDW.

Remediation Efforts

King County has teamed with the Port of Seattle since 2003 on the Harbor Island East and West Waterway Superfund effort. Remediation of the area near the uncontrolled Hanford #2 and Lander Street CSO sites is currently being completed in the East Waterway by the Port of Seattle (King County, 2009).

King County is also teamed with the City of Seattle as part of the Elliott Bay/Duwamish Restoration Program (EBDRP). The goals of the EBDRP include remediation of contaminated sediments associated with King County and City of Seattle CSOs and storm drains, restoration of habitat in Elliott Bay and the Duwamish River, and control of potential sources of contaminants. King County and the City of Seattle remediated sediments at the Norfolk and Duwamish/Diagonal EAAs in 1999 and 2004, respectively, as part of the EBDRP.

In 1990, King County and the U.S. Army Corps of Engineers (USACE) sponsored the Denny Way CSO capping project. King County has monitored the effectiveness of the cap at containing sediment for the past 17 years (King County, 2009). Chemical concentrations have increased in the cap due to possible recontamination from continued CSO discharges. In 1997, cadmium, copper, lead, mercury, silver, PAHs, PCBs and phthalates exceeded SQS chemical criteria. Following the completion of the Denny Way CSO control project in 2005 (Elliott West CSO treatment facility and new outfall), a Phase 2 remediation of nearshore areas around the old outfall was implemented. The remediation was completed in early 2008, followed by initiation of a six-year post-remediation monitoring program. The need for a third phase of remediation will be assessed based on that monitoring.

Sediment remediation is anticipated near the King Street CSO site, pending decisions by the Washington State Department of Transportation (WSDOT) to move forward in remediating the area near their Coleman Dock ferry terminal expansion. King County recommends further monitoring and evaluation of sediment needs at the King Street and Connecticut Street (i.e., the Kingdome) CSO sites (King County, 2009). Any need for remediation at the Kingdome CSO site will be decided under the Harbor Island/East Waterway Superfund action.

The LDWG has identified alternatives for remediating sediments within the LDW (ENSR, 2009). Alternatives range from "no action" after completing remediation of EAAs to maximum removal and upland disposal requiring extensive dredging. The time of construction for action alternatives ranges between approximately 5 and 20 years, roughly in the time period between 2020 and 2035. The LDWG, Ecology, and EPA are currently evaluating alternatives.

Source Control

Source control efforts in the Duwamish River basin are being implemented concurrently with remediation of EAAs. Ecology is leading the Source Control Working Group, which is made up of the EPA, City of Seattle, King County, Port of Seattle, Puget Sound Clean Air Agency, and City of Tukwila. The group is implementing a source control program that will ultimately reduce sources of contaminants entering the LDW. Potential ongoing sources include storm water runoff, CSOs, industrial wastewater discharges, deposition from uncontrolled or partially controlled air emissions (from motor vehicles and the burning of wood and fossil fuels), illicit discharges and spills, erosion of contaminated bank material, and upstream contributions from the Green River. Initial source control efforts have focused on source identification at the five EAAs that are being remediated as non-time critical removal actions.

Ecology identified that a comparison of risk-based sediment concentrations with background concentrations is necessary. EPA generally does not require cleanup levels below urban background concentrations because of the potential for recontamination from sources unrelated to the site. For example, most of the key risk-based goals for total PCBs concentrations in sediment are below background concentrations in Puget Sound reference areas. Under Ecology's regulations, when background concentrations would result in recontamination of the site to levels that exceed cleanup levels, that portion of the cleanup action that addresses cleanup below area background concentrations may be delayed until the offsite sources of hazardous substances are controlled. In these cases, the cleanup action will be considered an interim action until cleanup levels are attained.

Lake Washington Ship Canal/Montlake Cut

Sediment Quality Conditions

King County (2004) conducted a sediment analysis in Lake Sammamish, Lake Washington, and Lake Union to determine what the contaminants of concern were, if there is a measurable response to contamination, if contaminants are causing the response, which lakes are most impacted, and to identify the potential sources of contamination. The greater Lake Union was sampled including Union Bay, Portage Bay, Ship Canal, and Salmon Bay. Based on the analysis, the following conclusions were reached that apply to the greater Lake Union:

- Lake Union is more impacted by chemical contamination than Lake Washington and Lake Sammamish based on sediment contamination, bioassay results, and benthic invertebrate community alteration.
- Lake Union sediment is generally more toxic than other freshwater lakes.

- Sediment quality guidelines (SQGs) are exceeded at all sampled locations for multiple criteria. PCBs were the chemical group that most frequently exceeded SQGs, followed by metals, PAHs, and phthalates.
- Zinc, lead, and copper were close to ubiquitous throughout sediments of Lake Union.
- Sediment contamination is associated with a variety of biological effects, including toxicity to multiple species and impaired benthic community structure.
- Organic contaminant concentrations (e.g., PCBs, PAHs) were more closely correlated with sediment toxicity than metal concentrations.
- Organic contaminants tend to occur in complex mixtures that can be toxic in an additive manner.
- Highest contaminant concentrations were found in the near-shore areas of Lake Union.
- Contaminant concentrations in Lake Union were more affected by proximity to contaminant source (Gasworks Park, shipyards, etc.), and typically less affected by grain size and depth.
- Zinc and copper were highly correlated, suggesting a common source, which could include roadway runoff and paint from shipyards.
- Likely sources of PAHs include the Gasworks Park site in Lake Union and industrial processes.

The *King County Sediment Management Plan* will be updated within the next few years, and will reevaluate sediment quality in the Lake Washington Ship Canal near County CSOs (Bruce Nairn, personal communication, May 27, 2010). Characterization will be coordinated with the County's CSO post-construction monitoring plan for control projects. King County will seek partnerships with Ecology and other entities having management responsibilities in determining next steps and appropriated actions for cleanup.

The Lake Union Action Team was initiated in the mid-1990s to evaluate contaminated sediments in Lake Union (including the Lake Washington Ship Canal) and to develop an action plan. This process was suspended until regulatory agency funding and resources become available. An assessment of the areas around Salmon Bay has also been discussed more recently. King County recommends further monitoring and evaluation of sediment needs at the Ballard, 11th Avenue NW, and 3rd Avenue West CSO sites as part of the Salmon Bay planning effort, and at the Dexter CSO site in coordination with the Lake Union Action Team work (King County, 2009).

There currently are no sediment remediation efforts planned or underway for the Lake Washington Ship Canal and Montlake Cut.

2.2.2 CSO Effects on Sediment Quality

CSOs release untreated wastewater and stormwater constituents including dissolved and particulate heavy metals and chemicals adsorbed to organic and inorganic particles that settle to the bottom. Based on monitoring, evidence suggests that CSOs can cause contamination of sediments near the outfalls. King County (2004) found that one of the most impacted sites in Lake Washington was located in close proximity to the Atlantic Beach Park (station 4903B) near the shared storm drain and both King County's and Seattle's Henderson CSOs. This site also exhibited statistically reduced growth and survival of benthic invertebrates. However, when compared to Sediment Quality Guidelines, contaminant concentrations were only slightly elevated.

2.2.3 Sediment Quality CSO Control Priorities and Implications

Current high-priority efforts to remediate sediment contamination and eliminate ongoing sources of contamination in the LDW present an institutional driver for prioritizing control of CSOs in the Duwamish River/Elliott Bay. Sediment remediation efforts are not yet underway in the greater Lake Union and therefore, the Lake Washington Ship Canal and Montlake Cut area are of lower priority for control.

An ongoing question has been to what extent CSOs are capable of contaminating sediments after they have been remediated and if they do, does it make sense to control CSOs prior to remediation efforts. Based on sediment monitoring, some recontamination of sediments (PCBs, PAHs, and phthalates) is occurring at the Norfolk and Diagonal/Duwamish CSO sites, but evaluations do not strongly link it to uncontrolled CSO sites. Similar studies have not been conducted in the Lake Washington Ship Canal or Montlake Cut because remediation has not occurred in these water bodies. Therefore, it is difficult to prioritize CSO control in one water body over the other based on scientific factors.

At the Norfolk EAA and CSO site, a 5-year post-remediation sampling effort was completed in 2007 (King County, 2009). Early monitoring results suggested that erosion of unremediated shoreline areas were responsible for re-contaminating the site. In addition, storm water outfalls nearby convey stormwater from Boeing properties and I-5, which may be contributing to recontamination of the site (King County, 2005a). Additional remediation was conducted to address the recontamination.

At the Duwamish/Diagonal EEA (remediation completed in 2004), King County is participating in a 10-year post-remediation sampling program being implemented through 2013 (King County, 2009). PCBs are increasing to near SQS levels, but are not expected to exceed them. Phthalates are increasing and may reach pre-cleanup levels in the future. It is difficult to determine if King County's Hanford #1 CSO is the source of recontamination because a large City of Seattle stormwater outfall and City CSOs also discharge at the site. King County has accelerated the control project for this CSO to begin in 2011, and Seattle planning for their CSO is underway.

Monitoring of sediment at the Denny Way CSO site revealed that chemical concentrations had increased in the cap due to possible recontamination from continued CSO discharges (King County, 2009). This was the one site predicted to recontaminate as a result on on-going untreated discharge (King County, 1999a). The Denny CSO control project was completed in 2005 and is undergoing adjustments to complete control.

Several CSO sites have already been controlled within the Duwamish Waterway and Elliott Bay and therefore are no longer considered sediment recontamination risks:

- Denny Way CSO site was substantially controlled in 2005.
- The Norfolk CSO to the Norfolk EAA site was controlled in 2005.

- Duwamish East CSO at the Duwamish/Diagonal EAA site has been controlled since the Seattle pump station (part of Diagonal treatment plant system) was replaced in 1969.
- The East Marginal CSO at the Slip 4 EAA site, which is planned for remediation, has been controlled since the Seattle pump station (part of Diagonal treatment plant system) was replaced in 1964.

However, several uncontrolled CSO sites could pose a risk of re-contaminating sediments where remediation has already occurred, is occurring, or is prioritized based on presence of EAAs or hot spots:

- The Hanford (#1) at Rainier CSO site remains uncontrolled at the Duwamish/ Diagonal EAA where remediation has occurred. King County has accelerated the control project for this CSO to begin in 2011, and Seattle planning for their CSO is underway.
- The Hanford(#2) and Lander Street CSO sites remain uncontrolled in the East Waterway where remediation is being completed.
- The Terminal 115 CSO site remains uncontrolled in the vicinity of hot spots (not identified as EAAs) that remain to be remediated.

2.3 Human Health

Risks to human health in the Duwamish River/Elliott Bay, Lake Washington Ship Canal, and Montlake Cut include pathogen and chemical exposure from a variety of sources.

2.3.1 Pathogen Exposure Risk

Potential infections and diseases contracted by humans that are caused by pathogens contained in fecal matter include dysentery, hepatitis, and leptospirosis. Some common sources of pathogen (contained in fecal matter) release to water bodies include stormwater runoff, leaky septic tanks, CSOs, agricultural runoff, and direct fecal input from domestic and wild animals. When exposed to humans, unless treated, pathogens can cause severe illness and possibly death.

The most significant pathogen exposure route to humans is by incidental ingestion during direct water contact activities, but other direct ways that pathogenic microorganisms (e.g., bacteria, viruses) may enter the body include skin contact, inhalation, or through an open cut or wound. Also, people can be exposed to pathogens through shellfish consumption, which is considered an indirect exposure. Humans may incidentally ingest pathogens during recreational activities such as swimming, scuba diving, windsurfing, net fishing, recreational seafood collection, boating, kayaking, and parasailing. The risk of ingesting pathogens is less for activities where it is less likely to come in contact with surface water (e.g., boating).

Duwamish River/Elliott Bay

King County (1999b) examined risks to humans from pathogen exposure under baseline conditions (with and without the influence of CSOs) within the Duwamish River and Elliott Bay. Fecal coliform concentrations were used as the basis of the risk characterization, which is an indicator of pathogenic microorganisms, but themselves are not pathogenic to humans. The risk characterization concluded that under baseline conditions:

- The Duwamish River frequently does not have acceptable water quality presenting risks of infection from direct exposure during fishing, swimming, windsurfing, and scuba diving.
- Elliott Bay has acceptable water quality with the exception of the shoreline north and west of the Denny Way CSO. The Denny Way CSO has since been controlled.
- Neither the Duwamish River nor Elliott Bay has acceptable water quality for harvesting shellfish for purposes of consumption.

Lake Washington Ship Canal/Montlake Cut

There are no similar studies for the Lake Washington Ship Canal, Montlake Cut, or greater Lake Union that characterize risks to humans from pathogen exposure with or without the influence of CSOs. However, primary recreation uses have been observed (e.g., swimming, windsurfing) indicating potential for exposure. These water bodies are included on the Ecology's (2008) Water Quality Assessment 303(d) list of impaired waters due to high fecal coliform concentrations. In addition to CSOs, these water bodies receive high volumes of storm water that is another source of pathogens. Scientific studies are needed to evaluate risk, but it is likely that, with or without CSOs, these water bodies have unacceptable pathogenic water quality conditions that could be a risk for primary contact recreation uses.

CSO Effects on Pathogen Exposure

CSOs release harmful pathogenic microorganisms that can cause illnesses in humans that can lead to death (as described above). The risk of CSOs alone having a harmful effect on humans from pathogen exposure ultimately depends on the extent of human activity in water bodies near CSOs at times during and immediately after CSO discharge events. As effluent is released, it dilutes within the surrounding water body and therefore risk minimizes with distance from the outfall depending on the duration and volume of discharge. In addition, risk of pathogen exposure is further minimized when a CSO event ceases because microorganisms will die-off within approximately 6 days, based on observed reductions in fecal coliform concentrations (King County, 1999b). Viruses will die-off within approximately 1 day, but can persist up to 14 days in sediment. *Giardia* can persist for up to approximately 14 days.

Risk characterizations conducted by King County for the Duwamish River and Elliott Bay found that risk of infections from viruses and *Giardia* attributed to CSO discharges exceeds risk thresholds applicable to recreational marine waters less than 5 percent of the time (King County, 1999b). During CSO discharges, risks of infection from *Giardia* and viruses due to CSOs could be as high as 1 person in 100 during all activities studied. These risks of infection from CSOs decrease to less than 1 person in 1,000 within 6 hours after discharge.

Pathogen Exposure CSO Control Priorities and Implications

Risk assessments conducted by King County concluded that risk of infection from direct contact with pathogens 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. However, this reduction in risk during and soon after CSO events is insignificant because removal of CSOs would not eliminate ongoing baseline risks that are attributed to other sources.

Similar risk assessments have not been conducted for the Lake Washington Ship Canal, Montlake Cut, or the greater Lake Union; however, it is safe to assume that there is a similar risk of infection from direct contact with pathogens during and soon after CSO events. There is a possibility that there could also be a baseline risk in absence of CSO discharges due to other sources that are known to be present (e.g., stormwater), but studies are needed to confirm this. If this is the case, it is difficult to prioritize CSO control in one water body over the other based on pathogen exposure. If there is no baseline risk or it is demonstrated to be much less of a risk within the Lake Washington Ship Canal or Montlake Cut, then removal of CSOs in these water bodies would have more of an effect on reducing risk and those CSOs should be prioritized.

2.3.2 Chemical Exposure Risk

Exposure to toxic chemicals in the water or sediments can cause several forms of cancer (e.g., skin, organ, gastrointestinal) or several other forms of non-carcinogenic effects (e.g., liver toxicity, kidney toxicity, immunotoxicity, neurological impairment) to humans. Chemical exposure scenarios can include incidental ingestion, skin contact, and consumption of seafood. Humans may be exposed to chemicals in water and sediment through a variety of direct exposure activities, such as swimming and scuba diving.

Humans may also be exposed to chemicals through indirect activities, such as the consumption of seafood. Bioaccumulation of harmful chemicals in seafood is a result of food-chain transfer via consumption of benthic organisms that bioaccumulate chemicals from exposure to contaminated sediments. On August 3, 2005, the Washington State Department of Health (DOH) released a health advisory for the LDW warning people not to eat resident fish or crab taken from the area based on PCBs contamination in samples (DOH, 2010). The DOH recommends against eating rockfish and not more than two meals per month of flatfish in Elliott Bay. Currently, DOH does not have any fish consumption health advisories specifically for the Lake Washington Ship Canal, Montlake Cut, or greater Lake Union. However, in 2004, based on PCBs contamination, the DOH released a health advisory for Lake Washington, warning people not to eat Northern pike minnow and carp, limited yellow perch to one meal per week, and limited cutthroat trout to one meal per month.

Duwamish River/Elliott Bay

Two extensive human health risk assessments evaluating chemical exposure have been conducted for the Duwamish River/Elliott Bay area including a component of the *King County Combined Sewer Overflow Water Quality Assessment for the Duwamish River and Elliott Bay* (King County, 1999) and a component of the *Remedial Investigation* conducted by the LDWG (Winward, 2007a). Conclusions from these studies are summarized in the following sections.

King County CSO Water Quality Assessment

King County (1999b) conducted a human health chemical exposure characterization for the Duwamish River and Elliott Bay and concluded that humans engage in a wide variety of recreational activities that result in direct exposure to chemicals in water and sediment including swimming, scuba diving, wading, sailing, windsurfing, boating, kayaking, parasailing, water skiing, and jet skiing. There are many access points along the shoreline of the river and bay for recreational activities. In addition, many people collect fish and shellfish for food and recreation. Specifically, people line fish, net fish, and gather shellfish and other organisms (e.g., mussels, crabs, sea cucumbers, seaweed). People also consume fish, shellfish, and other organisms from the river and bay, which represents an indirect exposure to chemicals.

Direct Chemical Exposure Risk

King County (1999b) conducted a human health risk characterization for chemical exposure by combining the results of the exposure characterization with toxicological information. For all direct exposure pathways (e.g., swimming), the characterization concluded that there are no non-carcinogenic health risks expected at baseline chemical concentrations (with and without influence of CSOs).

However, the characterization concluded that under baseline chemical concentrations (with and without influence of CSOs), there are the following cancer risks.

- Net Fishing (Duwamish River): Potential lifetime cancer risks of about 1 person in 100,000 from arsenic and PCBs in sediments for people who net fish in the Duwamish River 90 times per year.

- Swimming (Duwamish River and Elliott Bay): Potential lifetime cancer risks above 1 person in 1,000,000 from arsenic and PCBs in sediments for young children who swim 24 times per year.

There is no significant cancer risk associated with windsurfing or scuba diving.

It is difficult to quantitatively assess population risk because of the difficulties in obtaining an accurate assessment of the size of the exposed population. The numbers of individuals who engage in net fishing or recreational activities is unknown.

Indirect Chemical Exposure Risk (Seafood Consumption)

For seafood consumption (indirect exposure pathway), King County (1999b) concluded that there are several chemicals of potential concern (COPCs) in tissues at risk of causing non-carcinogenic health risks under baseline conditions (with and without influence of CSOs). Under high exposure assumptions, COPCs that present risk include arsenic, lead, mercury, and PCBs, of which arsenic and PCBs pose the most risk. Under medium and low exposure assumptions, only arsenic and PCBs pose a risk. As an example of a medium exposure assumption, an adult would have to eat 102 meals and a child 44 meals of salmon from the Duwamish per year before PCBs become a risk.

For seafood consumption, King County also concluded that there are several COPCs (e.g., arsenic, PAHs, phthalate, PCBs) in tissues at risk of causing cancer under baseline conditions (with and without influence of CSOs). Of note are the following risks:

- Relatively high lifetime risk of developing cancer from exposure to arsenic and PCBs for people who eat seafood from the area every day (about 1 person in 1,000 to 1 person in 100, depending on the type of seafood).

- Lifetime cancer risk greater than 1 person in 1,000,000 for people who catch and eat seafood from the area on average about two times per month (a fairly common occurrence based on King County fishing survey).

Although a cancer risk was identified, it was not possible to derive reliable estimates of the number of people consuming seafood at the estimated exposure levels. However, it is expected that the number of people who consume seafood at the high level of daily consumption is very small due to the small number of people who reported this frequency in a fishing survey conducted by King County.

Lower Duwamish Waterway Group Remedial Investigation

According to studies conducted by the Lower Duwamish Waterway Group in support of sediment remediation efforts, the primary concern for human health in the Duwamish River is consumption of resident fish, shellfish, and crab containing harmful chemicals (e.g., PCBs).

As part of the sediment Remedial Investigation conducted for the LDW, a Human Health Risk Assessment was conducted, which concluded the following related directly to risks from exposure to contaminated sediments (Winward, 2007a):

- Direct contact with sediments during commercial net fishing, clamming, or beach play in the LDW and consumption of seafood from the LDW are primary exposure scenarios. Risk associated with swimming is insignificant, and there is no LDW-specific data to estimate the degree to which humans may be directly exposed to sediments via beach play or clamming scenarios. However, there are known exposure conditions that could occur under current tribal net fishing scenarios within the LDW.
- The highest risk to public health is indirect contact through consumption of seafood containing chemicals derived from sediments including resident fish (not including salmon), crabs, and clams with lower risks associated with activities that involve direct contact with sediment, such as clamming, beach play, and net fishing. Based on health-protective exposure assumptions, estimated cancer risks in the LDW were determined to be highest for the seafood consumption scenarios. Chemicals that pose a risk to human health include PCBs, arsenic, PAHs, dioxins, and furans.
- Tribal members typically eat three meals of resident fish or shellfish per week based on Tulalip Tribe eating habits. There is limited data available on the amount of resident seafood currently being harvested and consumed from the LDW. However, the LDW supports a salmon fishery for the Muckleshoot Tribe and represents a tribal usual and accustomed fishing area.
- Subsistence seafood consumption rates (e.g., Native American tribal members) of resident fish, crabs, and clams result in lifetime excess cancer risk that exceeds the EPA target risk range. A portion of risk is related to anthropogenic background concentrations of chemicals.
- Nineteen chemicals were identified as chemicals of concern (COCs), which have a cancer risk estimate greater than 1 in 1,000,000 ($1x10^{-6}$).

The Feasibility Study prepared in support of LDW sediment remediation identified that the primary remedial action objective is to reduce human health risks associated with the consumption of resident LDW seafood by reducing surface sediment concentrations of COCs to protective levels (ENSR, 2009). The secondary remedial action objective is to reduce human health risks associated with direct contact to sediment and incidental sediment ingestion.

Lake Washington Ship Canal/Montlake Cut

Based on a review of available information, the Duwamish River and Elliott Bay have received more attention related to the risks of consuming fish when compared to the Lake Washington

Ship Canal and Montlake Cut, which is in large part attributed to the human health risk assessments that have been conducted in support of sediment remediation efforts.

There are no similar studies for the Lake Washington Ship Canal, Montlake Cut, or greater Lake Union that evaluate users and risks from chemical exposure with or without the influence of CSOs. However, recreational activities have been observed within or near these water bodies (e.g., swimming, wading, sailing, windsurfing, boating, kayaking) indicating potential for exposure. In addition, people are also known to fish and consume fish from the greater Lake Union area. Unlike the Duwamish River and Elliott Bay, there are no shellfish (e.g., crabs, mussels) being caught from the greater Lake Union area which could slightly reduce risks in comparison. Tissue studies are needed to determine the concentrations of COPCs in fish; however, there is potential for carcinogenic chemicals based on sediment studies that confirm the presence of carcinogenic chemicals at high levels (King County, 2004). Scientific studies are needed to evaluate risk, but there is potential under baseline conditions (with or without CSOs), that these water bodies present some cancer risk for fishing and seafood consumption.

CSO Effects on Chemical Exposure

CSOs release a variety of harmful chemicals that can cause cancer and other non-carcinogenic effects (as described above). CSOs potentially contribute to poor water and sediment quality, which in turn can be exposed to humans and present a cancer risk for certain activities (e.g., net fishing, swimming, and seafood consumption) as discussed above. However, CSO discharges contribute low levels of the harmful chemicals that occur in nearby contaminated sediments when compared to other sources (e.g., industrial) that have historically contributed to sediment contamination.

Chemical Exposure CSO Control Priorities and Implications

CSOs release harmful chemicals into the water and sediment that can cause cancer in humans through direct or indirect exposure. Risk assessments conducted by King County for the Duwamish River and Elliott Bay concluded that under baseline conditions (with or without influence of CSOs), there are cancer risks associated with direct exposure (net fishing and swimming) and indirect exposure (seafood consumption). Therefore, removal of CSOs would not reduce this risk.

Similar risk assessments have not been conducted for the Lake Washington Ship Canal, Montlake Cut, or the greater Lake Union to determine if baseline conditions in these water bodies present a risk of cancer. However, there is potential for there to be a baseline risk because studies indicate widespread sediment contamination, which could be contributing to bioaccumulation in fish. It is known that people fish in these water bodies and it is likely that there is fish consumption. If this is the case, it is difficult to prioritize CSO control in one water body over the based on chemical exposure because removal of CSOs would not reduce the risk.

Because removal of CSOs does not reduce risk of cancer from chemical exposure, there is no scientific driver to prioritize control in one water body over the other. However, sediment remediation and source control efforts are underway in the LDW, which presents an institutional driver for prioritizing control of CSOs in this water body.

2.4 Ecological Health

The ecological health of the Duwamish River, Elliott Bay, Lake Washington Ship Canal, and Montlake Cut is measured based on the status of key species that are potentially affected by CSOs, which includes aquatic and wildlife species that have a primary association with aquatic habitat. For purposes of this review, ecological health is discussed largely in terms of existing habitat and water quality conditions and the effects of CSOs as they relate to threatened and endangered species. CSOs occur in two watersheds (Water Resource Inventory Areas [WRIAs]) that support these species including Lake Washington/Cedar/Sammamish (WRIA 8) and the Green/Duwamish and Central Puget Sound (WRIA 9).

2.4.1 Threatened and Endangered Species Presence

Protection of federally listed threatened and endangered species under the Endangered Species Act (ESA) that are at risk of extinction is a primary priority of the CSO control program. The following species listed by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) occur within the vicinity of uncontrolled CSO sites:

- Puget Sound Chinook Salmon (*Oncorhynchus tshawytscha*): Threatened
- Puget Sound Steelhead (*Oncorhynchus mykiss*): Threatened
- Bull Trout (*Salvelinus confluentus*): Threatened
- Puget Sound/Georgia Basin Boccaccio (*Sebastes paucispinis*): Endangered
- Puget Sound/Georgia Basin Canary Rockfish (*Sebastes pinniger*): Threatened
- Puget Sound/Georgia Basin Yelloweye Rockfish (*Sebastes ruberrimus*): Threatened
- Southern Resident Killer Whale (*Orcinus orca*): Endangered.

Duwamish River/Elliott Bay

Salmonids

The Duwamish River supports runs of summer/fall Chinook salmon, winter steelhead, and summer steelhead (SalmonScape, 2010; King County, 2005b). In addition, the Duwamish River supports migratory bull trout (King County, 2005b). The Duwamish River is utilized by these species primarily for the purposes of migration and rearing. Suitable habitat for spawning occurs further upstream within the Green River. The Duwamish River is designated as critical habitat by USFWS and NMFS for Chinook salmon and bull trout. Designation of critical habitat for steelhead is currently under development.

The Duwamish/Green River supports a distinct population of Chinook salmon (Ruckelshaus et al., 2006), which is comprised primarily of fish propagated in hatcheries and to a lesser extent, those fish that spawn in the wild. Adult Chinook salmon begin to enter the Duwamish River in mid-June, peaking in August (Ruggerone et al., 2004). Juvenile Chinook (fry and fingerlings) are present in the Duwamish River from January to mid-July (King County, 2005b). Sub-yearlings tend to congregate in the Duwamish River between river mile 5.5 and 6.5 throughout the outmigration period, which has been postulated to be a critical estuarine transition zone where the river and salt water wedge initially mix.

There are two Green/Duwamish River basin winter steelhead stocks including the native wild spawning population and the early timing hatchery stock. The majority of steelhead is comprised of hatchery summer steelhead. Adult summer steelhead enter the Duwamish River from April through October (King County 2005).

The Puget Sound, including Elliott Bay, supports various runs of Chinook salmon, steelhead, and bull trout. These species utilize the Puget Sound primarily for foraging, rearing, and migration to and from spawning habitats in rivers and streams. Chinook fry have been found in late January/early February along several Elliott Bay shorelines and at the mouth of the Duwamish River (Nelson et al., 2004). Chinook fingerlings are common from mid-May to late June, coinciding with fingerling outmigration from the Green/Duwamish River (King County 2005).

Rockfish

The Puget Sound supports all three species of listed rockfish including boccaccio, canary rockfish, and yelloweye rockfish. Most boccaccio are found south of Tacoma Narrows; however, boccaccio have been observed off Alki (Miller and Borton, 1980). Based on catch records, the population of boccaccio has dramatically declined in the Puget Sound as evidenced by not a single observance between 1996 and 2007 (NMFS, 2009). In North Puget Sound, boccaccio have always been rare in surveys of the recreational fishery.

Canary rockfish are most common off the coast of central Oregon. Within the Puget Sound, the frequency of canary rockfish catch has declined to 0.56 percent in the 1990s, compared to over 6 percent in the 1960s. Canary rockfish is widely distributed throughout the Puget Sound, from Bellingham to Tacoma; however, there have only been few observations in the Central Puget Sound (Miller and Borton, 1980). The distribution of canary rockfish is patchy, as there does not appear to be a strong refugial population anywhere (NMFS, 2009).

Yelloweye rockfish are common from central California northward to the Gulf of Alaska. The yelloweye rockfish has only been observed infrequently south of the San Juan Islands; however, it has been observed along nearshore areas within Elliott Bay (Miller and Borton, 1980). Within the North Puget Sound, the frequency of yelloweye rockfish catch has decreased from a high of >3 percent in the 1970s to a frequency of 0.65 percent. There is no evidence of spatially structured populations occurring in the Puget Sound and there are concerns that South Puget Sound populations are no longer viable, possibly due to low dissolved oxygen concentrations (NMFS, 2009).

Killer Whale

The Puget Sound supports Southern resident killer whale (Southern Residents). NMFS designates the entire Puget Sound as critical habitat for Southern Residents (Federal Register, 2006). Southern Residents occur in the Puget Sound principally during the late spring, summer, and fall. The Southern Residents population is comprised of three family groups of whales that have been named the J, K, and L pods.

Lake Washington Ship Canal/Montlake Cut

The Lake Washington Ship Canal and Montlake Cut support runs of fall Chinook salmon and winter steelhead (SalmonScape, 2010). In addition, these water bodies support bull trout. These water bodies are utilized by these species primarily for the purpose of migration and rearing because suitable habitat for spawning does not exist. Both water bodies are designated as critical habitat by USFWS and NMFS for Chinook salmon and bull trout. Designation of critical habitat for steelhead is currently under development.

NMFS identifies two independent populations of Chinook salmon in the Lake Washington system including Sammamish and Cedar River populations (Ruckelshaus et al. 2006). Most of the Sammamish River basin population is comprised of Green River-origin Chinook raised at the Issaquah Hatchery, whereas the Cedar River population is composed more of wild Chinook.

Adult Chinook salmon migrate through the Lake Washington Ship Canal and Montlake Cut between August and November, with peak migration occurring in October enroute to rivers and streams to spawn (SPU and USACE, 2008). Lake Washington juvenile Chinook salmon migrate to the ocean in their first year. Juvenile Chinook salmon are found migrating through the Lake Washington Ship Canal and Montlake Cut in late May, June, and July with peak migration occurring in June. Juvenile Chinook salmon have a tendency to hold in Lake Union for 1 to 7 days typically occurring off shore in deeper water (>8-10 m), which could be attributed to low water clarity and perceived predation risk along the nearshore.

Adult steelhead migrate through the Lake Washington Ship Canal and Montlake Cut between March and September, with peak migration occurring in May enroute to rivers and streams to spawn (SPU and USACE, 2008). Juvenile steelhead migrate through these water bodies between April and June with peak migration occurring in May. Unlike Chinook salmon, juvenile steelhead will reside in freshwater for 2 years prior to migrating to the ocean. During their freshwater residence, juvenile steelhead rear in tributaries, rivers, and lakes, including Lake Union.

2.4.2 Ecological Health Conditions

This section focuses on current ecological health conditions in the Duwamish/Elliott Bay, Lake Washington Ship Canal, and Montlake Cut that are considered important factors contributing to the decline of threatened and endangered salmonids. The emphasis on salmonids is based in part on the extensive research that has been conducted in support of salmonid recovery. The ESA listing of rockfish and killer whales is relatively recent and the factors for decline are not as completely understood. However, reductions in salmonid populations are a leading factor in the decline of killer whales, which depend on salmonids as a primary component of their diet. Therefore, improving conditions for salmonids should promote recovery of killer whales.

The Duwamish River/Elliott Bay has similar ecological health conditions that pose risks to salmonids including poor habitat and water quality conditions. Salmonid exposure to pollutants in the water column is more of a concern than pollutants in sediments. According to the *Baseline Ecological Health Risk Assessment* conducted for the LDW, ecological risks to fish and wildlife from sediment contamination are relatively low, with the exception of risks to river otter from PCBs via seafood consumption (Winward, 2007b).

Duwamish River/Elliott Bay

Within the Duwamish River and Elliott Bay survival risks for salmonids include poor habitat and water quality conditions.

Estuarine-reared juvenile Chinook salmon rely on the Duwamish River for adaptation to salt water and growth prior to entering the Puget Sound and ocean. Juvenile Chinook are present in the marine nearshore for extensive periods of time, and may be the most nearshore dependent salmonid in WRIA 9 (Brennan et al., 2004). They rely on shallow estuarine and freshwater wetland habitat (e.g., marshes, mudflats, forested swamps), which is severely limiting in the Duwamish River.

Urban and industrial development practices along the Duwamish River estuary have simplified and straightened the remaining channel, severely reducing riparian function, and eliminated habitat as a result of dredging, channelization, and filling of 97 percent of the estuarine mudflats, marshes, and forested riparian swamps (King County, 2005). Extensive fragmentation and disconnection of remaining and marginalized habitats has occurred in this portion of the watershed. Urban and industrial practices have displaced habitat, reduced habitat complexity including reduction of amount and size of large woody debris and reduction of side channel and other off-channel habitats. Over 90 percent of the lower Duwamish River is armored (60 percent with riprap and 24 percent with steel or concrete bulkheads). Approximately 48 percent of the shoreline has no vegetation, and 30 percent is blackberry; nearly 10 percent is landscaped/ ornamental, 6 percent is other invasive shrubs, and 3 percent is immature deciduous vegetation.

Prior to construction of levees, the upper Duwamish River was prone to flooding and supported about 200 hectares of wetlands that have drastically reduced to only about 7 hectares (King County, 2005). Along the lower Duwamish River, extensive estuarine habitats were common, but today are currently found only in small patches. Estimates for historical estuarine mudflats and estuarine wetlands are approximately 901 hectares and 74 hectares, respectively. Only about one percent of the mudflats and 11 percent of tidal marshes are present today (estimates represent 1986 conditions [Blomberg et al., 1988]). Dredging for maintenance of navigation now leaves only a thin margin of tide flats along the shoreline with an artificially deepened central channel from about river mile 5.0 to Elliott Bay. Kellogg Island is an exception, which contains densely vegetated riparian habitat and intertidal wetlands that represent a majority of the remaining intertidal wetlands in the Duwamish River (Simenstad et al., 1991). Historically, Elliott Bay provided vital habitat for both juvenile and adult salmonids. It provided approximately 350 hectares of tide flats and three small tidal marshes, which have been filled and highly altered (King County, 2005).

In addition, temperature is a probable factor for decline of salmonids in the Green/Duwamish basin (Kerwin and Nelson, 2000). Temperature monitoring in the Duwamish River has revealed summer temperatures between 18 and 21 degrees Celsius, which represents a potential impairment and blockage of migration for adult salmonids and reduced survival of juvenile salmonids (King County, 2005).

In addition, dissolved oxygen, total suspended solids, and metals are water quality factors responsible for the decline of salmonids in the Duwamish River (Kerwin and Nelson, 2000). Ongoing development patterns and land uses have significantly polluted or degraded water and sediment quality in the remaining channel via stormwater and wastewater effluents and historic industrial contaminants. Several chemicals in the sediments pose potential risks to benthic organisms, most notably bis(2-ethylhexyl)phthalate, 1,4-dichlorbenzene, mercury, PAHs, PCBs, and TBT (King County, 1999a). Risks to the benthic community can potentially translate to risks to salmonids via food-chain transfer (bioaccumulation in prey), reduction in function of immune systems, or from potential toxicity to prey organisms (reduction in available food). Additional information on baseline conditions pertaining to water and sediment quality is presented in Section 2.1(*Water Quality*) and Section 2.2 (*Sediment Quality*).

Lake Washington Ship Canal/Montlake Cut

There are several factors contributing to the decline of salmonids in the Lake Washington basin, which includes the Lake Washington Ship Canal and Montlake Cut. Survival risks for juvenile salmon includes hesitation before entering the Montlake Cut (may be due to lack of shallow habitat), elevated water temperature, large number of overwater structures, armored banks, and potential impacts from predation by northern pike minnow, largemouth bass, cutthroat trout, and piscivorous birds (SPU and USACE, 2008). In addition, sediment contaminants can have food-chain transfer risks to salmonids as mentioned above.

A primary concern for the ecological health within the Lake Washington Ship Canal and Montlake Cut is related to high lake temperatures during the summer. King County (2007b) monitoring results of water temperatures in Lake Sammamish, Lake Washington, and Lake Union have revealed a warming trend that is linked to climate change (see Section 2.5, *Climate Change*).

Higher surface water temperatures exceeding 20 degrees Celsius within Lake Union and Lake Washington have been attributed to adverse and lethal effects on salmonids including sockeye and Chinook (King County, 2007b). King County has established an Index of Thermal Stress, which produces degree-day values above a chosen threshold. A threshold of 20 degrees Celsius was chosen because it is the upper incipient lethal temperature for salmon, which is the water temperature at which approximately half of the population would survive with permanent exposure. In addition, salmon face a higher risk of disease at high temperatures.

Elevated water temperatures are suspected to have caused the apparent loss of approximately half of the 2004 sockeye salmon run between the Hiram M. Chittenden Locks and spawning grounds in the Cedar River and other Lake Washington tributaries. Based on King County surface water temperature data from 1964 through 2006, there is no statistically significant trend, but there is a distinct upward trend beginning in 1980. The highest Index of Thermal Stress estimates occur in 1998 and 2004, 2 years that have anecdotally been noted for high incidence of pre-spawn mortality (Chinook in 1988 and sockeye in 2004). The lethal effects of surface water temperatures on salmonids are anticipated to increase with predicted increases in air temperatures (see Section 2.5, *Climate Change*).

In addition, warming trends may be affecting food supply to upper trophic levels in the lake. The long-term warming trends in Lake Washington have resulted in spring stratification beginning about 16 days earlier than it did 40 years ago (Winder and Schindler, 2004). In response to earlier onset of stratification, the spring phytoplankton bloom occurs about 19 days earlier than it did in 1962, which might be a factor in the observed decline in *Daphnia* abundance (the main consumers of the spring phytoplankton bloom and the primary prey for sockeye salmon fry).

2.4.3 CSO Effects on Ecological Health

Of all the threatened and endangered species in the vicinity of CSO sites, salmonids (Chinook, steelhead, and bull trout) are most likely to be affected by CSOs because they migrate through the water bodies where CSOs occur (e.g., Duwamish River, Lake Washington Ship Canal, Montlake Cut), and are more closely associated with shoreline habitats where CSOs occur.

Salmonids

All of the ESA-listed salmonids that occur in the Duwamish River, Elliott Bay, Lake Washington Ship Canal, and the Montlake Cut have potential to come in direct contact with CSOs at some point in their life history (e.g., juvenile, adult) associated with migration and rearing. CSOs occur predominantly over the period between October through April; therefore, based on residence times, juvenile Chinook in the Duwamish River and adult Chinook in the Lake Washington Ship Canal and Montlake Cut are most likely to come in contact with CSOs. To a lesser extent, adult steelhead in the Duwamish River, Lake Washington Ship Canal/Montlake Cut, and juvenile steelhead in the Lake Washington Ship Canal/Montlake Cut are likely to come in contact with CSOs.

CSOs can have several potential types of adverse effects on listed fish species including physical disturbances (e.g., displacement of out-migrating salmon by high water velocities), effects due to chemical exposure (e.g., dissolved metals, endocrine disrupting chemicals), and effects due to changes in conventional water quality parameters (e.g., dissolved oxygen, total suspended solids).

Dissolved Metals

Dissolved metals including zinc, copper, cadmium, and chromium can adversely affect fish behavior at much lower concentrations than the acute water quality standards. Recently, ESA consultations have focused on stormwater discharges of dissolved copper and zinc to water bodies containing ESA-listed fish. There are three known physiological pathways of metal exposure and uptake within salmonids: (1) gill surfaces can uptake metal ions which are then rapidly delivered to biological proteins (Niyogi et al., 2004); (2) olfaction (sense of smell) receptor neurons, and (3) dietary uptake. The most direct pathway is through the gills (Niyogi et al., 2004).

Zinc

A review of zinc toxicity studies reveals several effects to freshwater fish including reduced growth, behavioral alteration (avoidance), reproduction impairment, increased respiration, decreased swimming ability, increased jaw and bronchial abnormalities, hyperactivity, hyperglycemia, and reduced survival (Eisler, 1993). Juveniles are more sensitive to elevated zinc concentrations than adults are.

The zinc acute water quality standard for marine waters is 90 µg/L; however, avoidance in juvenile rainbow trout exposed to dissolved zinc in a zinc sulphate solution has been documented with an increase of 5.6 µg/L over background zinc concentrations between 3.0 µg/L and 13.0 µg/L (Sprague, 1968). When making general comparisons between lethal and sublethal endpoints tested on juvenile rainbow trout, the sublethal effects (5.6 µg/L) occur at concentrations approximately 75 percent less than lethal effects (24 µg/L) (EPA, 1980; Hansen et al., 2002). Even relatively low concentrations (5.6 µg/L, established for juvenile rainbow trout) resulted in avoidance of the plume. The worst case 120-hour LC50 for dissolved zinc in a zinc chloride solution (at pH 7.5, hardness 30, and temperature 8.0 degrees C) is 35.6 µg/L for juvenile bull trout averaging 30 mm total length and is 23.9 µg/L for juvenile rainbow trout averaging 54 mm total length (Hansen et al., 2002).

Copper

Dissolved copper is acutely toxic to fish at low concentrations. Typical effects of copper exposure to fish include:

- Impaired disease resistance
- Disrupted migration (via avoidance of copper-contaminated areas)
- Hyperactivity
- Impaired respiration
- Disrupted osmoregulation
- Pathology of kidneys, liver, and gills
- Impaired function of olfactory organs and brain
- Altered blood chemistry
- Enzyme activity (Eisler, 1998).

Olfactory inhibition decreases the ability of salmonids to recognize and avoid predators and navigate back to natal streams for spawning purposes, resulting in decreased adult spawning success and increased predation on juvenile Chinook and juvenile steelhead. Although salmonids will actively avoid copper, if they are unable to do so, olfactory function will be impaired within the first few minutes of exposure. The avoidance of a chemical plume can cause a fish to leave refugia and to occupy less suitable habitat, increasing its chances of predation and decreasing its ability to find prey.

Baldwin et al. (2003) exposed coho salmon to various concentrations of copper to evaluate the sublethal effects on the sensory physiology, specifically the olfactory system of juvenile fish. Baldwin et al. (2003) demonstrated that short pulses of dissolved copper at concentrations as low as 2 µg/L reduced olfactory sensory responsiveness within 10 minutes such that the response evoked by odorants was reduced by approximately 10 percent. At a copper concentration of 10 µg/L, a concentration which will regularly occur in stormwater and CSOs, responsiveness was reduced by 67 percent within 30 minutes, an exposure time that is less than typical discharge times for stormwater and CSO outfalls. They calculated copper concentration neurotoxic thresholds sufficient to cause olfactory inhibition as 2.3 to 3.0 µg/L. Baldwin et al. (2003) also referenced three studies that reported copper exposures over 4 hours cause cell death of olfactory receptor neurons within rainbow trout, Atlantic salmon, and Chinook salmon. When they compared their results to the acute EPA Water Quality Criteria for dissolved copper (13 µg/L for 100 mg/L hardness), they determined that a 1-hour discharge at the acute EPA Water Quality Criteria could be expected to cause up to a 50 percent loss of sensory capacity among coho salmon in freshwater habitats. Notably, Baldwin et al. (2003) determined that water hardness did not influence the toxicity of copper to coho salmon sensory neurons.

The acute copper water standard for marine waters is 4.80 µg/L; however, recent research that NMFS has cited suggests that dissolved copper concentrations exceeding 2.0 µg/L over background, when background concentration is less than 3.0 µg/L, can adversely affect fish behavior (Sandahl et al., 2007). This represents the new impact threshold established by NMFS.

In particular, at these concentrations there was a 50 percent reduction in olfactory response and a 40 percent reduction in predator avoidance response (ibid).

Endocrine Disrupting Chemicals

Compounds found in pharmaceuticals and personal care products (PPCPs) can have various effects including cytotoxic, oxidative, and endocrine-disrupting effects on aquatic organisms including fish. Endocrine Disrupting Chemicals (EDCs) are a class of chemicals that occur in natural or synthetic hormones, PPCPs, industrial byproducts, plastics, and pesticides. EDCs mimic, inhibit, or alter the hormonal regulation of the immune, reproductive, or nervous systems or other parts of the endocrine system. Pharmaceuticals including synthetic estrogen are a common source of EDCs in wastewater. Pharmaceutical chemicals vary in their capacity to be absorbed in the human body, leading in some cases to a large proportion of ingested drugs eliminated in the feces without being biomodified (Trudeau et al., 2005). Pharmaceutical compounds leaving the human body can be biologically active and persistent in the aquatic environment. Wastewater treatment technologies have varied success at removing PPCP chemicals and EDCs. For these reasons, adverse effects on fish from PPCP chemicals and EDCs in treated wastewater have become an emerging concern that needs to be studied further. At this time, there are no water quality standards or established biological thresholds for determining effects according to the ESA.

Scientific literature focuses on effects of PPCPs and EDCs in treated sewage effluents rather than CSO effluent. Treated sewage effluents often contain a mixture of PPCP chemicals and EDCs in low concentrations. Although diluted with stormwater, CSO effluent contains higher concentrations of PPCP chemicals and EDCs in absence of conventional or specialized treatment.

In general, it is difficult to quantify the potential for fish exposure to pharmaceuticals due to the variable persistence of pharmaceuticals or their component compounds in the aquatic environment and throughout the wastewater treatment process and the potentially synergistic dynamics between multiple compounds. According to the scientific literature, PPCP residues in aquatic systems are unlikely to pose a risk in terms of acute toxicity (Fent et al., 2006). Toxic effects of individual PPCPs generally occur at concentrations much higher than what is found in the environment (Schnell et al., 2009). However, there is evidence that mixtures of drugs can have additive and synergistic effects (Schnell et al., 2009) which could increase risk, especially if PPCP chemical concentrations increase in the environment. Mixtures of drugs sharing common mechanisms of action or similar chemical structure can have additive effects, whereas combined toxicity of dissimilar compounds might occur at concentrations lower than expected due to synergistic effects.

A significant concern with pharmaceuticals in the aquatic environment is the introduction of estrogens (e.g., ethinylestradiol) and EDCs in sufficiently high concentrations that the reproduction of aquatic vertebrates (e.g., fish) is affected. Estrogens have both organizational (disturbed gonadal development) and activational (suppressed ovulation) effects on reproduction. Organizational effects tend to be permanent and can result in reduced fertility (Liney et al., 2005; Parrot and Blunt, 2005). Activational effects are generally reversible (Gunnarsson et al., 2009). It has been shown that ethinyl estradiol can alter the gonadal development of fish at exposure concentrations below 10 ng/l, well within the range of concentrations of this compound in surface waters near some studied sewer treatment plants (Metcalfe et al., 2001).

Total Suspended Solids

Total suspended solids (TSS) are a pollutant commonly occurring in CSO effluent in the form of suspended sediments. Elevated suspended sediments (or turbidity) may disrupt normal behaviors (i.e., ability to successfully feed, move, and/or shelter) but are not expected to kill fish. Salmonids are adapted to naturally occurring pulses of suspended sediment and the frequency of CSOs tends to be infrequent. However, CSOs could contribute to chronic exposure of TSS and adverse behavioral effects to fish when considering cumulative discharges from other sources (e.g., city CSOs, stormwater outfalls).

Sediments settling out of turbid water can adversely affect salmonid embryos and fry emergence from redds; however, this does not apply to King County CSOs, which occur in areas where spawning does not occur. Applicable to CSOs, turbid water can disrupt feeding and cause physiological stress and reduced growth (Bash et al., 2001; Berg and Northcote, 1985; Bisson and Bilby, 1982; Waters, 1995). Effects of turbidity on fish are diminished or aggravated by the season, frequency, and the duration of the exposure (not just the TSS concentration), and by the life stage of the species.

The first behavioral response of fish to turbidity is avoidance (DeVore et al., 1980; Birtwell et al., 1984; Scannell, 1988). Exposure duration is a critical determinant of physical or behavioral effects. Salmonids have evolved in systems that periodically experience short-term pulses (days to weeks) of high suspended sediment loads, often associated with flood events, thus adult and larger juvenile salmonids appear to be little affected by the high concentrations of suspended sediments that occur during storm and snowmelt runoff episodes (Bjorn and Reiser, 1991). However, research indicated that chronic exposure can cause physiological stress responses that can increase maintenance energy and reduce feeding and growth (Lloyd, 1987; Servizi and Martens, 1991).

Dissolved Oxygen

Dissolved oxygen (DO) is one of the most important conventional water quality parameters for salmonids and other aquatic life. Potential effects to salmonids from exposure to low DO concentration can include reduced growth, reproduction, or mortality. CSO discharges typically occur during the winter and spring. Low DO is more of a concern for salmonids in the summer when baseline DO concentrations decrease resulting from high water temperatures. However, growth and decay cycles of phytoplankton occur at all times of the year, and CSOs could be a small contributor to low DO concentrations caused by nutrient input resulting in adverse effects on fish when considering cumulative discharge from other sources (e.g., agricultural runoff).

CSO effluents can have low DO concentrations and can contain organic materials and nutrients that have the potential to reduce DO concentrations in receiving waters. Anthropogenic input of organic matter and phytoplankton decay may decrease levels of oxygen. Most bacteria that utilize organic matter for food consume dissolved oxygen. Hypoxia results when the rate of oxygen consumption, mostly by bacteria decomposing organic material in the water column, exceeds the rate of oxygen production by photosynthesis and by replenishment at the air/water interface. When the system is overloaded with organic material, oxygen consumption by bacteria may increase to the point where conditions can no longer support aquatic life.

CSOs are a small source of nutrient loading including nitrogen and phosphorus. Other sources include nonpoint agricultural and urban runoff, rivers and streams, and the Pacific Ocean. Addition of nutrients such as nitrogen and phosphorus can have a considerable effect on DO concentrations, especially in nearshore habitats where CSOs can occur. Increases in nitrogen and phosphorus from wastewater or fertilizers can result in sudden increases in aquatic plant and phytoplankton growth, particularly in areas with reduced circulation. An increase in phytoplankton biomass can cause a decline in DO concentrations as the phytoplankton cells respire and decay.

Persistent Bioaccumulative Toxins

The King County WTD started preparing a Habitat Conservation Plan (HCP) for all its activities that have any potential for “take” under the ESA. In April 2005, after completion of Phase I and after meetings with the Services (USFWS, NMFS), the HCP effort was stopped due to uncertainties of the effects on listed species from treated effluent.

As part of the process to develop a HCP, the WTD reviewed available information to assess potential for King County secondary treatment plant effluent discharges to contribute to any bioaccumulation of persistent bioaccumulative toxins (PBTs) and endocrine disrupting chemicals (EDCs) (King County, 2002). The WTD found that 12 PBTs appear to be bioaccumulating in the Puget Sound food web contained in pesticides, PCBs, dioxins, and furans. In addition, mercury is bioaccumulating in the food web and has been detected in secondary effluent, reclaimed water, biosolids, and CSOs. Not enough data are available to determine if County effluents and CSOs are significant contributors of mercury relative to other sources.

Chemicals and metals bound to sediment remain biologically relevant because they may be incidentally ingested by water column organisms or be accumulated by benthic organisms that are in turn prey sources for salmonid species.

Rockfish

CSOs are unlikely to directly affect listed rockfish because their presence is generally scarce in the Central Puget Sound. Furthermore, adult listed rockfish species are not likely to be affected because the CSO outfalls are typically shallow or at the surface, and rockfish are most common between 160 and 820 feet depth (NMFS, 2010). Adults generally move into deeper water as they increase in size and age and usually exhibit strong site fidelity to rocky bottoms and outcrops. If listed rockfish species happen to occur in Elliott Bay near uncontrolled CSO sites (e.g., King Street and Kingdome CSO sites), there is potential for CSOs to have more of a direct effect on juveniles and subadults, which are more common in shallower water and are associated with rocky reefs, kelp canopies, and artificial structures, such as piers and oil platforms.

According to NMFS (2009), chemical contamination and high nutrient loading are primary threats to the continued existence of listed rockfish species. Therefore, CSOs could be a small contributor to the decline of listed rockfish species.

Killer Whale

CSOs could have an indirect effect on killer whales through the bioaccumulation of CSO pollutants (e.g., PCBs) in fish, which are the primary prey for killer whales. Research indicates that the Southern Residents contain high levels of PCBs content that exceed thresholds known to have health effects in other marine mammals (17 mg/kg lipid). The PCBs content in Southern Residents is consistent with high PCBs concentrations in Puget Sound biota. Fish are the major dietary component of Southern Residents and salmon are preferred. In addition to a sufficient biomass of prey species, the prey must not have amounts of contaminants that exceed levels that can cause mortality or reproductive failure in Southern Residents (NMFS, 2008). Because of their long life span, position at the top of the food chain, and their blubber stores, killer whales accumulate high concentrations of contaminants. Organochlorines, such as PCBs, and many other chemical compounds and heavy metals known to occur in CSOs are a concern because of their ability to induce immune suppression, reproductive impairment, or other physiological damage. There have been several sightings of killer whales in Elliott Bay near the mouth of the Duwamish River. However, killer whales are unlikely to directly be affected by CSOs because they are unlikely to be in the near vicinity of CSO outfalls during discharge events typically occurring during the winter or early spring. Southern Residents typically arrive to the Puget Sound in May or June and depart in October or November; however, their whereabouts during the winter and early spring is uncertain.

2.4.4 Ecological Health CSO Control Priorities and Implications

Based on potential exposure effects in close proximity of outfalls, CSO sites in the Duwamish River/Elliott Bay area should receive a higher priority for control when compared to the Lake Washington Ship Canal and Montlake Cut. CSOs occur predominantly over a period extending from October through April. During this time, juvenile Chinook salmon in the Duwamish River and adult Chinook salmon in the Lake Washington Ship Canal/Montlake Cut are most likely to come in contact with CSOs. Control of CSO sites in the Duwamish River/Elliott Bay has potential to have more of an effect on Chinook salmon survival and recovery when compared to the Lake Washington Ship Canal/Montlake Cut for the following reasons:

- The higher frequency and volume of CSOs in the Duwamish River has potential to have more harmful exposure of pollutants to juvenile Chinook salmon when compared to adult Chinook salmon in the Lake Washington Ship Canal/Montlake Cut.
- Juvenile Chinook salmon reside in the Duwamish River for a longer duration for rearing purposes when compared to adult Chinook salmon migration residence time in the Lake Washington Ship Canal/Montlake Cut.
- Juvenile Chinook salmon are more susceptible to adverse effects caused by pollutants when compared to adult Chinook salmon.

However, the potentially adverse effects of pollutants from CSOs on juvenile Chinooks may not be distinguishable from the effects of high volumes of similar pollutants from other sources (especially stormwater). The input of pollutants from other sources is heightened at the same time as CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs.

CSOs are not considered a primary reason for the decline of threatened and endangered species. Considering the typically infrequent and short duration of CSO discharges, the exposure of harmful chemicals is far less than the exposure resulting from untreated stormwater discharges. However, they can have direct and indirect adverse effects. Harmful chemicals such as dissolved metals and EDCs in CSO effluent have potential to adversely affect ESA-listed salmonids, especially within the mixing zone where concentrations are likely to exceed biological effect thresholds (copper and zinc). Based on zinc and copper concentrations in CSO effluent, fish could be exposed to lethal concentrations of zinc and copper within the mixing zone (between

20 and 40 feet for existing and proposed CSO outfalls that discharge to marine waters). However, death of fish is unlikely during a discharge event because avoidance of metals is likely before there is enough exposure time to result in death. King County conducted bioassays with effluent from the Brandon Street CSO, which 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 (King County, 1999a). However, exposure could adversely affect behavior, which could indirectly result in mortality (e.g., increased vulnerability to predators). Exposure to EDCs in CSO effluent could contribute to adverse affects on fish related to gonadal development and ovulation; however, additions studies are necessary to examine the effects of infrequent exposure from CSOs.

CSO treatment facilities planned for the future will need to address these effects and may need to consider advanced treatment technology having application to intermittent discharges in accordance with ESA compliance. The effects of treated CSO effluent alone would not jeopardize the existence of threatened and endangered salmonids; however, an adverse effect would require formal consultation with the USFWS and NMFS (Services). As a reasonable prudent measure, the Services could require any available advanced treatment applicable to intermittent discharges to minimize the potential for take of listed species. King County should continue to monitor technology developments.

2.5 Climate Change

Climate change as defined by the Intergovernmental Panel on Climate Change (IPCC) includes any change in climate over time due to natural variability of human activity (IPCC, 2001). The IPCC has concluded that climate change is at least partially due to human activities, especially the creation of greenhouse gases by burning of fossil fuels. The effects of climate change are expressed in terms of temperature, precipitation, and sea-level rise in the following sections.

2.5.1 Temperature

Climate models project an average rate of warming of approximately 0.5°F per decade through the 2050s, which is greater than past rates (CIG, 2010). For comparison, the observed rate of 20th century Pacific Northwest (PNW) warming was approximately 0.2°F per decade, with an approximate rate of 0.4°F per decade in the second half of the 20th century.

The average annual temperature is projected to increase 2.0°F by the decade of the 2020s, 3.2°F by the 2040s, and 5.3°F by the 2080s, relative to 1970-1999 average temperature. The projected change is substantially greater than the 1.5°F increase observed in the PNW during the 20th century.

Temperatures are projected to increase across all seasons with most models projecting the largest temperature increases during the summer (June-August).

2.5.2 Precipitation

The projected change in average annual precipitation for all models combined is near zero (CIG, 2010). However, existing seasonal patterns of precipitation could be emphasized. Just over half of the models and scenarios analyzed show an increase in winter (December-February) precipitation in the 2020s and 2040s, with increases more likely by the 2080s. More than 70 percent of models and scenarios analyzed agree that summer precipitation will decrease. A larger percentage of overall winter precipitation is expected to fall as rain rather than snow due to warmer winter temperatures. Droughts may become more common due to the effects of warmer temperatures and reduced winter snowpack on late summer stream flows.

2.5.3 Sea Level Rise

The four main drivers of local sea level rise (SLR) are (1) global SLR driven by the thermal expansion of the ocean; (2) global SLR driven by the melting of land-based ice; (3) local dynamical SLR driven by changes in wind, which push coastal waters toward or away from shore; and (4) local dynamical SLR driven by local movement of the land itself, due to tectonic forces (Mote et al., 2008). The University of Washington Climate Impacts Group (CIG) and Ecology estimate that local SLR in the Puget Sound region will be between 3 and 22 inches by 2050 and between 6 and 50 inches by 2100. The range represents very low to very high SLR estimates; however, calculations have not formally quantified the probability of these estimates, and therefore, these estimates are for advisory purposes only. Based on the current science, the medium estimate (6 inches by 2050 and 13 inches by 2100) for the SLR in the Puget Sound closely matches the global SLR projected by the fourth Assessment Report of the IPCC.

2.5.4 Climate Change CSO Control Priorities and Implications

Based on the effects of climate change, there is no apparent preference for prioritizing CSO control in one area over the other. However, sea-level rise attributed to climate change could have less of an effect on CSOs in the Lake Washington Ship Canal and Montlake Cut because the locks maintain a higher surface water elevation in these water bodies relative to Elliott Bay and the Lower Duwamish River.

Increases in temperature, precipitation, and sea level rise could have several effects on CSO sites and other wastewater facilities located in low-lying areas:

- Increased rate of river flooding and undermining of nearby sewer pipes and facilities
- Increased infiltration into pipes, resulting in higher water tables
- Increased possibility of inflow of river and estuary water into the combined sewer at outfalls
- Increased inflow into sanitary and combined sewers from impaired drainage of stormwater systems.

These effects may require the need for increased sizing of facilities (e.g., larger pump stations and storage facilities), higher facility elevations with respect to nearby water bodies, increased pumping, and enhanced flood and storm surge protections. Larger facilities may be necessary to accommodate increased combined sewer flows resulting from precipitation shifts from snow to rain, with more intense peak flow events.

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3.0. HABITAT PRIORITIES

This section presents habitat priorities for the Duwamish River/Elliott Bay and Lake Washington Ship Canal/Montlake Cut CSO control areas. The shores of these water bodies have been largely developed as a result of industrial and residential practices resulting in loss of nearshore habitat and riparian vegetation. Riparian habitats including wetlands have been cleared and filled. Shorelines have been modified by placement of armoring (e.g., concrete, riprap, bulkheads) and overwater structures (e.g., docks). In addition to controlling CSOs, nearshore habitat restoration is necessary to support recovery of threatened and endangered salmonids. Nearshore habitat provides valuable juvenile salmonid rearing habitat. Studies have concluded that there is not enough habitat capacity in the Duwamish River to support wild and hatchery stocks of juvenile Chinook salmon and that restoration of large amounts of off-channel habitat is necessary (Ruggerone and Jeanes, 2004).

The following sections present habitat improvement priorities for restoration within the Duwamish River/Elliott Bay and the Lake Washington Ship Canal/Montlake Cut areas.

3.1 Duwamish River/Elliott Bay

Within the Duwamish River, shallow estuarine and freshwater wetland habitat (e.g., marshes, mudflats, forested swamps) is severely limiting. Juvenile Chinook are present in the marine nearshore for extensive periods of time, and may be the most nearshore dependent salmonid in WRIA 9 (Brennan et al., 2004). Estuarine-reared Chinook fry rear in the Duwamish River for up to three months before entering the Puget Sound. The filling of mudflats and the straightening and widening of the former channel have completely altered the estuarine habitat, which are important to juvenile salmon for adapting to saltwater, rapid growth, and survival.

Habitat for salmonids can be improved by creating and restoring a variety of habitats adjacent to and off the main channel such as estuarine and freshwater marshes, forested wetlands, and side channels, and floodplain habitat. A priority area for restoration of rearing habitat is the upper end of the estuary where fish initially reach marine waters where high densities of juvenile Chinook salmon have been observed during multiple years (Nelson et al., 2004).

Related to habitat improvement in the Duwamish River/Elliott Bay, King County (2005) has hypothesized:

- Expanding and enhancing the Duwamish River, particularly vegetated shallow subtidal and intertidal habitats and brackish marshes by restoring dredged, armored and filled areas will enhance habitat quantity and quality and lead to greater juvenile salmon residence time, greater growth, and higher survival.
- Enlarging the Duwamish River estuarine transition zone habitat by expanding shallow water and slow water areas will enhance habitat quantity and quality of this key Chinook salmon rearing area, leading to greater juvenile salmon residence time, greater growth, and higher survival.
- Protecting, creating, and restoring habitat that provides refugia (particularly side channels, off channels, and tributary access), habitat complexity (particularly pools) for juvenile salmon over a range of flow conditions and at a variety of locations (e.g.,

mainstem channel edge, river bends, and tributary mouths) will enhance habitat quality and quantity and lead to greater juvenile salmon residence time, greater growth, and higher survival.

- Protecting and enhancing pocket estuaries (i.e., small non-natal smaller estuaries, lagoons, spits) and salmon-bearing and non-salmon bearing tributary mouths by maintaining/restoring tributary mouths will increase the quantity of key habitat and lead to greater juvenile salmon growth and survival.

3.2 Lake Washington Ship Canal/Montlake Cut

Juvenile migrants would benefit from habitat restoration actions that reduce predator abundance and predator efficiency (particularly cutthroats, sculpins, and bass). Predation on juvenile Chinook appears to be driven primarily by habitat conditions that limit cover for juvenile Chinook migration and rearing, and increase exposure to predators, such as bank hardening and reductions in sandy shallow water habitat, large wood debris, and overhanging shoreline vegetation.

The WRIA 8 Chinook Salmon Conservation Plan makes several recommendations for improving migration and rearing habitat in Lake Washington, which could be applied to areas within the greater Lake Union (WRIA 8 Steering Committee and Forum, 2005):

- Reduce bank hardening by replacing bulkheads and riprap with sandy beaches with gentle slopes designed to maximize littoral areas with a depth of less than 1 meter.
- The outmigration of juvenile Chinook would benefit from improved shoreline connectivity. The use of mesh dock surfaces or community docks would reduce the severity of predation on juvenile Chinook.

The following recommendations are made for the Lake Washington Ship Canal and Locks (WRIA 8 Steering Committee and Forum, 2005):

- Options to reduce water temperatures in the Ship Canal should be evaluated.
- Protect and restore water quality to prevent adverse impacts to key life stages from fine sediments, metals (both in sediments and water), and other toxics.
- Riparian vegetation should be restored to provide cover for juvenile migrants.

4.0. CSO CONTROL PRIORITY CONCLUSIONS

Previous studies (King County, 1999a, 1999b) have concluded that there would be limited improvement of conditions for aquatic life, wildlife, and people if CSO discharges are controlled. However, CSOs are one contributor to poor water and sediment quality, which has adverse effects on ecological and human health.

According to NPDES permit requirements, all remaining uncontrolled CSOs need to be controlled by 2030. King County is faced with the decision of prioritizing the next phase of CSO control projects in the Duwamish River/Elliott Bay, Lake Washington Ship Canal, or Montlake Cut.

According to the previous CSO control program review, the next highest priority for CSO control efforts are the University and Montlake CSOs because of the amount of boating in the area, which could result in secondary contact with the water. However, based on the evaluation of environmental priorities presented in this TM, secondary contact with water from boating is a low risk and there does not appear to be an overall consensus for prioritizing control of CSOs in one water body over the other based on scientific drivers. However, current high priority efforts to remediate sediment contamination and eliminate ongoing sources of contamination in the LDW represents an institutional driver for controlling CSOs, which applies to sediment quality and human health environmental priorities. Table 4-1 summarizes CSO control priority decisions based on an evaluation of environmental priorities.

Table 4-1. CSO Control Area Priority Based on Evaluation of Environmental Priorities.

Environmental Priority	CSO Control Area Priority Status				Qualifiers		
	Duwamish River/ Elliott Bay Priority	Lake Washington Ship Canal Priority	Montlake Cut Priority	No Difference in Priority	Scientific Driver	Institutional Driver	Insufficient Data/ Imbalance of Data
Water Quality				X			X
Sediment Quality	X					X	X
Human Health							
Pathogens (incidental ingestion)				X			X
Chemicals (fish consumption)	X					X	X
Ecological Health	X				X		X
Climate Change				X			

4.1 Water Quality

Considering the nature of existing water quality conditions, there is no apparent preference for prioritizing CSO control in one area over the other. The Duwamish River, Lake Washington Ship

Canal, and Montlake Cut are all of moderate water quality condition and are known to have harmful concentrations of fecal coliform (an indicator of bacteria harmful to human health), nutrients, and dissolved oxygen. Each of these water bodies receive high volumes of pollutants from other sources (especially stormwater) that degrade water quality on a more consistent basis and therefore, removal of CSOs is not expected to have a substantial benefit in one water body over the other. Furthermore, the input of pollutants from other sources is heightened during CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs. Additional studies are necessary to determine for certain which water body has worse water quality conditions due to pollutant loading from sources other than CSOs.

Based on CSO discharge volume, it is also difficult to determine where removal of CSOs would have a substantial water quality benefit in one water body over the other when considering flushing rate and dilution. CSOs in the Duwamish River discharge substantially higher volumes when compared to the Lake Washington Ship Canal and Montlake Cut; however the residence time is short considering the time that it takes to flush out to Elliott Bay and the greater Puget Sound is less than 40 hours. The U.S. Geologic Survey estimated that the average time for surface waters from river mile 12.3 to reach the mouth of the Duwamish River is about 40 to 55 hours (USACE, 1983). CSOs on the Duwamish River occur between the mouth and river mile 6.

Substantially lower volumes of discharge occur at CSOs in the Montlake Cut; however, the residence time is longer because discharge flows into Lake Union which takes about one week to flush into the Puget Sound. Although, CSO discharge quickly dilutes in Lake Union. In addition, although flushing time is longer in Lake Union compared to the Duwamish River, much more volume of water is flowing through the Montlake Cut, Lake Union, and Lake Washington Ship Canal.

4.2 Sediment Quality

Current high priority efforts to remediate sediment contamination and eliminate ongoing sources of contamination in the LDW present an institutional driver for prioritizing control of CSOs in the Duwamish River/Elliott Bay. Sediment remediation efforts are not yet underway in the greater Lake Union and therefore, the Lake Washington Ship Canal and Montlake Cut area are of lower priority for control.

An ongoing question has been to what extent CSOs are capable of contaminating sediments after they have been remediated and if they do, does it make sense to control CSOs prior to remediation efforts. Based on sediment monitoring, some recontamination of sediments (PCBs, PAHs, and phthalates) is occurring at the Norfolk and Diagonal/Duwamish CSO sites, but evaluations do not strongly link it to uncontrolled CSO sites. Similar studies have not been conducted in the Lake Washington Ship Canal or Montlake Cut because remediation has not occurred in these water bodies. Therefore, it is difficult to prioritize CSO control in one water body over the other based on scientific factors.

4.3 Human Health

CSOs present human health risks from pathogen and chemical exposure. Risks associated with pathogen exposure were the primary driver for prioritizing control of CSOs near Puget Sound

Beaches. Pathogen exposure is no longer a priority driver for control of CSOs in the Duwamish River/Elliott Bay from a scientific perspective because unlike the Puget Sound beach areas, baseline (i.e., background) conditions present a risk from other sources and therefore, control of CSOs would do little to reduce an ongoing risk. The same situation applies for chemical exposure. There is a lack of studies to demonstrate risks associated with baseline conditions in the Lake Washington Ship Canal, and Montlake Cut, but there are reasons to suspect this could be the case. Further explanation is provided in the subsections below.

There is not scientific driver for CSO control prioritization at this time. However, sediment remediation and source control efforts are underway in the LDW aimed at reducing chemical exposure associated with seafood consumption, presents an institutional driver for prioritizing control of CSOs in this water body.

4.3.1 Pathogen Exposure

CSOs release harmful pathogenic microorganisms that can cause illnesses in humans that can lead to death if not treated (e.g., dysentery, hepatitis, and leptospirosis). Risk assessments conducted by King County concluded that risk of infection from direct contact with pathogens 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. However, this reduction in risk during and soon after CSO events is insignificant because removal of CSOs would not eliminate ongoing baseline risks that are attributed to other sources (e.g., stormwater runoff, leaky septic tanks, CSOs, agricultural runoff, and direct fecal input from domestic and wild animals).

Similar risk assessments have not been conducted for the Lake Washington Ship Canal, Montlake Cut, or the greater Lake Union; however, it is safe to assume that there is a similar risk of infection from direct contact with pathogens during and soon after CSO events. There is a possibility that there could also be a baseline risk in absence of CSO discharges due to other sources that are known to be present (e.g., stormwater), but studies are needed to confirm this. If this is the case, it is difficult to prioritize CSO control in one water body over the other based on pathogen exposure. If there is no baseline risk or it is demonstrated to be much less of a risk within the Lake Washington Ship Canal or Montlake Cut, then removal of CSOs in these water bodies would have more of an effect on reducing risk and those CSOs should be prioritized.

4.3.2 Chemical Exposure

CSOs release harmful chemicals into the water and sediment that can cause cancer in humans through direct or indirect exposure. Risk assessments conducted by King County for the Duwamish River and Elliott Bay concluded that under baseline conditions (with or without influence of CSOs), there are cancer risks associated with direct exposure (net fishing and swimming) and indirect exposure (seafood consumption). Therefore, removal of CSOs would not reduce this risk.

Similar risk assessments have not been conducted for the Lake Washington Ship Canal, Montlake Cut, or the greater Lake Union to determine if baseline conditions in these water bodies present a risk of cancer. However, there is potential for there to be a baseline risk because studies indicate widespread sediment contamination, which could be contributing to bioaccumulation in fish. It is known that people fish in these water bodies, and it is likely that there is fish consumption. If this is the case, it is difficult to prioritize CSO control in one water body over the other based on chemical exposure because removal of CSOs would not reduce the risk.

4.4 Ecological Health

Based on potential exposure effects in close proximity of outfalls, CSO sites in the Duwamish River/Elliott Bay area should receive a higher priority for control when compared to the Lake Washington Ship Canal and Montlake Cut. CSOs occur predominantly over a period extending from October through April. During this time, juvenile Chinook salmon in the Duwamish River and adult Chinook salmon in the Lake Washington Ship Canal/Montlake Cut are most likely to come in contact with CSOs. Control of CSO sites in the Duwamish River/Elliott Bay has potential to have more of an effect on Chinook salmon survival and recovery when compared to the Lake Washington Ship Canal/Montlake Cut for the following reasons:

- The higher frequency and volume of CSOs in the Duwamish River has potential to have more harmful exposure of pollutants to juvenile Chinook salmon when compared to adult Chinook salmon in the Lake Washington Ship Canal/Montlake Cut.
- Juvenile Chinook salmon reside in the Duwamish River for a longer duration for rearing purposes when compared to adult Chinook salmon migration residence time in the Lake Washington Ship Canal/Montlake Cut.
- Juvenile Chinook salmon are more susceptible to adverse effects caused by pollutants when compared to adult Chinook salmon.

However, the potentially adverse effects of pollutants from CSOs on juvenile Chinooks may not be distinguishable from the effects of high volumes of similar pollutants from other sources (especially stormwater). The input of pollutants from other sources is heightened during CSO discharge events when runoff rates are high, thereby dwarfing the effects of input from CSOs.

4.5 Climate Change

Based on the effects of climate change, there is no apparent preference for prioritizing CSO control in one area over the other. However, sea-level rise attributed to climate change could have less of an effect on CSOs in the Lake Washington Ship Canal and Montlake Cut because the locks maintain a higher surface water elevation in these water bodies relative to Elliott Bay and the Lower Duwamish River.

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