Section 6

Environmental Baseline

This section describes the current environmental conditions of the seven action areas of the SBE. The environmental baseline provides the foundation for analyzing proposed changes in the action area and benefits or impacts to listed species. Action areas have been combined when the current conditions within those areas affect a larger or common waterbody (*e.g.*, Lake Washington and Puget Sound). The following are the seven action areas for the Seattle Biological Evaluation (see Figure 1).

1. North Lake Washington
2. South Lake Washington
3. Lake Washington Ship Canal
4. Lower Green/Duwamish
5. North Seattle/Puget Sound
6. South Seattle/Puget Sound
7. Elliott Bay

There are 49 stream systems within the City of Seattle (Tabor *et al* 2006). Five of these streams are considered major watersheds based on the size of the watershed and amount of available stream habitat. These environmental baseline conditions of the five streams are described below in the action area they are found. The other streams are mentioned but not described. Fish species found within these streams are provided.

6.1 North Lake Washington and South Lake Washington Action Areas

The North Lake Washington and South Lake Washington action areas are combined for the purposes of this section because they experience similar environmental conditions.

North Lake Washington and South Lake Washington Action Areas

Lake Washington is part of Water Resource Inventory Area (WRIA) 8. WRIA 8 also includes the Sammamish River and Lake Sammamish, their tributaries, and the Cedar River watershed. Lake Washington is the largest lake in Washington State west of the Cascade Mountains, with a surface area of 22,138 acres (8,959 ha). It is about 20 miles (32.2 km) long with over 50 miles (80.5 km) of shoreline. Mercer Island in the southern part of the lake has an additional 30 miles (48.3 km) of shoreline. The City of Seattle borders the west side of the lake with 20.1 miles (32.3 km) of shoreline within the city limits. The main inflow to the system is the Cedar River, which was rerouted from the Green/Duwamish watershed to flow into the southeast corner of Lake Washington in 1916. The Cedar River contributes about 53% of the lake's mean annual inflow. The Sammamish River flows into the northeast corner of Lake Washington and contributes about 27% of the inflow. Numerous other small tributaries, including Thornton, Taylor, Juanita, Kelsey, Lyon and May creeks, also drain into Lake Washington. Thornton and Taylor creeks are the major City of Seattle creeks that drain to Lake Washington (see Figure 2).

The Lake Washington shoreline has been dramatically altered over the last 100 years. The physical changes that have occurred include lowering of the lake, loss of riparian vegetation, loss of large woody debris, modification of the substrate composition in front of bulkheads, shading of shallow water areas by overwater structures, the addition of new types of habitats (piers and pilings), and a reduction in the amount of shallow water habitat that is available to juvenile salmon (Warner and Fresh 1998, Kahler *et al.* 2000).

Before 1916, Lake Washington drained through the Black River into the Duwamish River and then into Elliott Bay. However, with construction of the Lake Washington Ship Canal (Ship Canal) in 1916, Lake Washington's outlet to Puget Sound became the Ship Canal. The Hiram M. Chittenden Locks (Locks) system maintains a higher water level in the Ship Canal and Lake Washington than in the tidally-influenced area of Puget Sound, just west of the Locks.

Fourteen streams are located within the North Lake Washington (four streams) and South Lake Washington (ten streams) action areas. Thornton Creek (North Lake Washington) and Taylor Creek (South Lake Washington) are described below. Table 6-1 identifies the location of the other streams and any fish species found within the stream (Tabor *et al* 2006).

Table 6-1

Smaller streams and fish present within the North Lake Washington and South Lake Washington action areas.

Stream	Action Area	Fish Species Present
Inverness Creek	North Lake Washington	None
Yesler Creek	North Lake Washington	Not accessible
Ravenna Creek	North Lake Washington	Rainbow trout
Washington Park Creek	South Lake Washington	Cutthroat trout Prickly sculpin Threespine stickleback Smallmouth bass Goldfish Brown bullhead Common carp
Interlaken Creek – East Reach	South Lake Washington	None
Interlaken Creek – Middle Reach	South Lake Washington	None
Interlaken Creek – West Reach	South Lake Washington	None
Madrona Creek	South Lake Washington	None
Unnamed Creek LW01	South Lake Washington	None
Frink Creek	South Lake Washington	None
Mount Baker Creek	South Lake Washington	None
Mapes Creek	South Lake Washington	Threespine stickleback

6.1.1 Water Quality

Although the watershed is highly urbanized, the current status of water quality in Lake Washington is generally very good. This is due in part to the high quality of water entering Lake Washington from tributaries such as the Cedar and Sammamish rivers. In addition, water quality in Lake Washington was dramatically improved when wastewater was diverted away from the lake by King County (formerly Metro) in the 1960s. However, localized water and sediment quality problems such as elevated concentrations of metals, bacteria, nutrients, and organic compounds have been found in the vicinity of major storm drain and combined sewer overflows (CSO) during storm events (EVS 2000).

King County (2003) noted that Lake Washington rapidly recovered from the eutrophic conditions that existed in the 1950s and 1960s after wastewater diversion. The report also noted a recent trend of decreasing total phosphorus concentrations between 1993 and 2001. From 1990 to 2001, whole-lake total phosphorus concentrations averaged 15 µg/L during January when the lake is well mixed. Likewise, summer total phosphorus concentrations have averaged 16 µg/L over the same time period. These total phosphorus levels along with dissolved oxygen concentrations and deficit rates indicate that Lake Washington is in a mesotrophic (aging) condition (King County 2003). However, the study noted that because Lake Washington is sensitive to phosphorus loading, particularly from external sources, holding phosphorus loadings at or below current levels will be key to maintaining present day water quality conditions (King County 2003).

Lake Washington is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies for water, sediment, fish tissue, and habitat. The 303(d) listings are summarized in Table 6-2.

Table 6-2

Summary of 303(d) listings for Lake Washington

	Category		
Media	**2[1]**	**4C[2]**	**5[3]**
Water	Ammonia-N Fecal coliform bacteria Lead Mercury Total PCBs		Fecal coliform bacteria Total Phosphorus
Sediment	Sediment bioassay		Sediment bioassay
Fish tissue	2,3,7,8-TCDD TEQ		Total PCBs 2,3,7,8-TCDD 4,4'-DDT 4,4'-DDE Total Clordane
Habitat		Invasive Exotic Species	

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body is impaired by a non-pollutant that cannot be addressed through a water quality improvement project (total maximum daily load (TMDL) or pollution control program).

[3]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.

Source: Ecology 2008

Most of the Seattle area swimming beaches (Magnuson Beach off-leash area, Matthews Beach, Madison Beach, Mount Baker Park, Seward Park, and Pritchard Park) are listed as impaired waterbodies (Category 5) for fecal coliform bacteria. Madrona Beach is listed as a water of concern (Category 2) for fecal coliform bacteria.

6.1.2 Sediment Quality

Sediment in Lake Washington contains elevated concentrations of metals, tributyltin, polychlorinated biphenyls (PCBs), polynuclear aromatic hydrocarbons (PAHs), phthalates, and dibenzofuran (Moshenberg 2004). Samples were collected in 1999 to 2001 from multiple sites throughout Lake Washington (including ten stations along the Seattle shoreline) and tested for metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, silver, and zinc), semivolatile organic compounds, pesticides, and PCBs. In the absence of freshwater sediment standards, a sediment quality triad analysis—which uses sediment chemistry, bioassays, and benthic data—was used to evaluate toxicity. The most impacted sites in Lake Washington are located near the Henderson combined sewer overflow and the Sayer site, which is the area used to prepare boats for the Seafair hydroplane races (Moshenberg 2004).

The Washington State Department of Health has recently issued advisories against the consumption of the northern pike minnow (squawfish) that come from Lake Washington due to observed bioaccumulation of PCBs and mercury (WDOH 2005). Other species that were found to have elevated PCB concentrations were large yellow perch greater than 10.5 inches (25.4 cm) and large cutthroat trout greater than 12 inches (30.5 cm). The study advises only a moderate consumption of these species of fish (WDOH 2005).

6.1.3 Shoreline and Aquatic Habitat

Lowering Lake Washington exposed 1,334 acres (540 ha) of shallow water habitat, reducing lake surface area by 7%, and decreasing the shoreline by 10.5 miles (16.9 km), a 12.8% reduction (Chrzastowski 1981). The most extensive changes occurred in the sloughs, delta areas, and shallows of the lake. The area of freshwater marshes decreased from an estimated 1,136 acres (460 ha) before construction of the Locks to 74 acres (30 ha) by the early 1980s (Chrzastowski 1981). The mouths of tributaries entering the lake have moved some distance to the new lake shoreline, often across what had previously been a relatively shallow sloped alluvial delta (Warner and Fresh 1999). Historically, the mouths of the tributaries often presented fish passage problems due to shallow depth. Some of these areas continue to present fish passage problems today. New wetlands and riparian zones have developed in the former shallow-water habitats of Union Bay and Portage Bay since the Ship Canal was completed (Dillon *et al.* 2000).

Lake Washington water level elevations are maintained through conjunctive operation of the Ship Canal's large and small locks, spillway gates, smolt passage flumes, and saltwater drain system. The water level typically fluctuates 2 feet (0.6 m) each year, from a low of 20 feet (6 m) in December to a high of 22 feet (6.7 m) (Corps datum) in May. There are 4 periods of seasonal operation:

1. The spring refill period from February 15 until May 1, when the lake level is allowed to rise to 22 feet (6.7 m)

2. The summer conservation period, when the lake level is maintained at 22 feet (6.7 m) as long as possible, and involuntary drawdown begins usually in late June or early July

3. The fall drawdown period beginning at the onset of the autumn rains and continuing until December 1
4. The winter holding period, from December 1 through February 15, when the lake level is maintained at 20 feet (6.1 m)

The shoreline riparian and littoral (intertidal) zones of Lake Washington have undergone considerable change since pre-settlement times. Shoreline vegetation has changed dramatically from a dense undergrowth of small trees, brush, and tule grass to landscaped residential properties with bulkheads where most natural vegetation has been removed. An estimated 81% of the shoreline in Lake Washington east of the Montlake Cut has bulkheads and more than 2,700 residential piers (NMFS 2007). Eurasian water-milfoil dominates the aquatic vegetation in the shallow-water habitat along the shoreline. Milfoil has replaced the native aquatic vegetation and altered the substrate characteristics of much of the littoral zone of the lake (Patmont *et al.* 1981).

6.1.4 Habitat Access: Barriers

Lake Washington has no physical barriers to salmonid migration. Water temperatures during the summer and early fall may be too high and may impede fish migration in the Ship Canal (see section 6.2.1, Water Quality).

6.1.5 Non-Native and Predator Fish in Lake Washington

The Lake Washington Basin contains more than 50 freshwater and anadromous fish species (Table 6-3). More than 20 of these species are non-native species introduced into the system by agencies and private individuals over the last 140 years. Cutthroat trout, and possibly prickly sculpin, appear to exhibit the greatest predation rate overall in Lake Washington.

Predation rates in Lake Washington may have increased due to four major factors (City of Seattle 2003). First is that littoral zone habitats have been extensively modified over the last 100 years with the changes in lake level; construction of piers, docks, and bulkheads; removal of large woody debris; and the expansion of milfoil. Second is the population size of predator species. Third is the effect of water temperature on predator consumption rates. An increase in water temperatures increases the metabolic rate of predators, increasing consumption rates. Fourth is the introduction of non-native, piscivorous fish into Lake Washington. Non-native piscivores introduced into Lake Washington include smallmouth bass, largemouth bass, rainbow trout (which can only be sustained by hatchery releases), hatchery-produced Chinook and coho salmon, and yellow perch.

Table 6-3

Migratory and freshwater fish of the Lake Washington basin

Common name	Scientific name	Life-history strategy
Native Species		
Western brook lamprey	*Lampetra richardsoni*	Stream resident
Pacific lamprey	*Lampetra tridentate*	Anadromous
River lamprey	*Lampetra ayresi*	Anadromous

Common name	Scientific name	Life-history strategy
White sturgeon	*Acipenser transmontanus*	Anadromous
Pygmy whitefish	*Prosopium coulteri*	Adfluvial
Mountain whitefish	*Prosopium williamsoni*	Fluvial
Cutthroat trout	*Oncorhynchus clarki clarki*	Anadromous, adfluvial, resident
Steelhead and rainbow trout	*Oncorhynchus my kiss*	Anadromous, adfluvial, resident
Dolly Varden	*Salvelinus malma*	Anadromous
Bull trout	*Salvelinus confluentus*	Adfluvial, anadromous
Coho salmon	*Oncorhynchus kisutch*	Anadromous
Chinook salmon	*Oncorhynchus tshawytscha*	Anadromous
Sockeye salmon and kokanee	*Oncorhynchus nerka*	Anadromous, adfluvial, resident
Chum salmon	*Oncorhynchus keta*	Anadromous
Pink salmon	*Oncorhynchus gorbuscha*	Anadromous
Longfin smelt	*Spirincus thaleichthys*	Anadromous, adfluvial
Redsided shiner	*Richardsonius balteatus*	Resident
Longnose dace	*Rhinichthys cataractae*	Resident
Northern squawfish	*Ptychocheilus oregonensis*	Lake resident
Peamouth chub	*Mylocheilus caurinus*	Lake resident
Speckled dace	*Rhinichthys osculus*	Resident
Largescale sucker	*Catastomus macrocheilus*	Resident
Three-spine stickleback	*Gasterosteus aculeatus*	Resident
Coastrange Sculpin	*Cottus aleuticus*	Resident
Shorthead sculpin	*Cottus confuses*	Resident
Torrent sculpin	*Cottus rhotheus*	Stream resident
Prickly sculpin	*Cottus asper*	Resident
Riffle sculpin	*Cottus gulosus*	Stream resident
Reticulate sculpin	*Cottus perplexus*	Resident

Common name	Scientific name	Life-history strategy
Olympic mudminnow	*Novumbra hubbsi*	Stream resident
Non-Native Species		
American shad	*Alosa sapidissima*	Anadromous
Lake whitefish	***Coregonus clupeaformis***	Lake resident
Brown trout	*Salmo trutta*	Adfluvial, anadromous
Atlantic salmon	*Salmo salar*	Anadromous
Brook trout	*Salvelinus fontinalis*	Stream resident
Lake trout	*Salvelinus namaycush*	Lake resident
Weather loach	*Misgurnus anguillicaudatus*	Lake resident
Common carp	*Cyprinus carpio*	Lake resident
Grass carp	*Ctenopharyngodon idella*	Lake resident
Goldfish	*Carassius auratus*	Stream or lake resident
Tench	*Tinca tinca*	Lake resident
Channel catfish	*Ictalurus punctatus*	Lake resident
Brown bullhead	*Ameiurus nebulosus*	Lake resident
Black bullhead	*Ameiurus melas*	Lake resident
Largemouth bass	*Micropterus salmoides*	Stream or lake resident
Smallmouth bass	*Mictropterus dolomieu*	Stream or lake resident
Black crappie	*Pomoxis nigromaculatus*	Lake resident
White crappie	*Pomoxis annularis*	Lake resident
Warmouth	*Lempomis gulosus*	Lake resident
Bluegill	*Lepomis macrochirus*	Lake resident
Pumpkinseed sunfish	*Lepomis gibbosus*	Lake resident
Yellow perch	*Perca flavescens*	Lake resident
Chinese weather loach	*Misgurnus Angullicaudatus*	Lake resident
Walleye	*Sander vitreus*	Stream or lake resident
Source: American Fisheries Society 1991		

Extensive sampling of 1,875 predators in southern Lake Washington from February to June 1995 to 1997 found only 15 juvenile Chinook salmon in the stomachs of cutthroat trout, prickly sculpin, smallmouth bass, and largemouth bass. Most of the predation loss was attributed to prickly sculpin, a substantially larger population than the other predators. Predatory fishes were thought to have consumed fewer than 10% of juvenile Chinook salmon that entered the lake from the Cedar River (Tabor *et al.* 2004c). Smallmouth bass become more prevalent in shallow areas in May and June and were always associated with an overhead structure (Tabor and Piaskowski 2002).

Both smallmouth bass and juvenile Chinook salmon may be found in the littoral zone from January until mid-May. However, predation rates are low primarily due to low water temperatures. Bass consumption rates increase as water temperatures warm. Smallmouth bass prefer temperatures above 68º F (20º C) when they feed most actively, and feed little when temperatures are below 50º F (10º C) (Wydoski and Whitney 2003).

In mid-May, water temperatures warm, which results in increased consumption rate of smallmouth bass, but at this time, Chinook salmon begin to move into deeper water (Tabor *et al.* 2004c). In addition, juvenile Chinook tend to use finer substrates than do bass and cottids (Tabor et al. 2004c). Smallmouth bass tend to use shoreline areas devoid of vegetation and composed of gravel and cobble that have a gradual slope and a drop-off (Pflug and Pauley 1984). Table 6-4 summarizes lake residency findings for juvenile salmon (Tabor *et al.* 2004c).

Table 6-4

Lake Washington residency findings for juvenile salmon predation

Parameter	**Finding**
Habitat	The influence of habitat on juvenile salmon survival to outmigration is linked to habitat overlap with predators. Some degree of habitat segregation occurs that may limit predation mortality for young-of-year outmigrants.
Water Temperature	Influences the extent to which juvenile salmon use shoreline habitat. As temperatures warm, juveniles appear to use deeper water.
	Influences smallmouth and largemouth bass habitat use, consumption rates, and activity level. At lower temperatures (50 ºF or 10 ºC), bass tend to be inactive. Bass prefer temperatures about 68 ºF or 20 ºC or higher.
	May be an important control on predation rate. At lower temperatures, juvenile salmon and bass may use similar habitat, but feeding rate is low. At warmer temperatures, feeding rates increase, but juvenile salmon may be less common in the best bass habitat, and move to deeper water.
Substrate	Young-of-year Chinook salmon tend to use openwater areas with finer gravel and sand substrates. They will use woody debris for cover during the day. They generally avoid overwater structures. As they grow, they move to deeper water.
	Bass tend to use areas with coarser substrates or aquatic vegetation and are less likely to avoid overwater structures.

Parameter	Finding
Age	Chinook juveniles can aggregate and feed near the surface during the day.
	Predation rate reflects body size of predator species and juvenile salmon. Larger cutthroat trout are found in the limnetic zone, whereas smaller trout tend to be found in the littoral zone. Most consumed salmon during the spring appear to be young-of-year fish.
	Population level predation rates overall may be small for young-of-year salmon. Fewer than 10% of juveniles entering Lake Washington from the Cedar River may be consumed by piscivorous fish.
Source: Tabor *et a*l 2004c	

6.1.6 Thornton Creek (North Lake Washington Action Area)

The Thornton Creek system, located in northeast Seattle, drains a 7,402-acre (2,995 ha) watershed (Figure 6). Thornton Creek has a channel length of 20.7 miles (33.3 km), which includes two main forks, the North Branch and the South Branch (otherwise known as Maple Leaf Creek), and 20 tributaries. About 53% of the land use in Thornton Creek watershed is residential (single- and multi-family), 26% is dedicated to roads and rights-of-way, and 8% is commercial and industrial. Only 9% of the watershed area is in parks, green space or vacant land.

6.1.6.1 Water Quality

Thornton Creek has a large number of storm drains that deliver stormwater runoff to the watercourse. Two hundred sixteen storm drains flow into the creek. No combined sewer overflows exist in Thornton Creek.

Thornton Creek is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies. The 303(d) listings are summarized in Table 6-5.

Table 6-5

Summary of 303(d) listings for Thornton Creek (including S.F. Thornton Creek and Maple Leaf Creek)

	Category	
Media	**2[1]**	**5[2]**
Water	Mercury Dissolved oxygen Lead	Temperature Dissolved oxygen Fecal coliform bacteria

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.

Source: Ecology 2008

King County has been collecting monthly samples near the mouth of Thornton Creek since about 1972. Samples are analyzed for conventional water quality indicators (temperature, dissolved oxygen, fecal coliform bacteria, pH, total suspended solids, and turbidity), metals, and nutrients. Summary statistics for conventional water quality parameters from monthly samples collected by King County (undated) between 1972 and 2005 are shown in Table 6-6.

Table 6-6

Summary statistics for conventional water quality parameters in Thornton Creek near mouth

	DO* (mg/L)	Temp. (degree C)	Fecal coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
No. of samples	394	450	451	399	401	402
Minimum	6.9	1.6	14	6.4	0.6	0.1
Maximum	14.7	23.2	31,000	11.2	180	66
Median	10.5	11.3	690	7.5	5.7	3.2
Mean	10.5	11.1	1,507	7.5	15.0	6.3
5th percentile	8.8	5.4	115	6.9	2.0	1.2
95th percentile	12.6	16.2	5,500	7.9	56	22.9

*DO: dissolved oxygen

Source: Reference Station 0434. King County (undated)

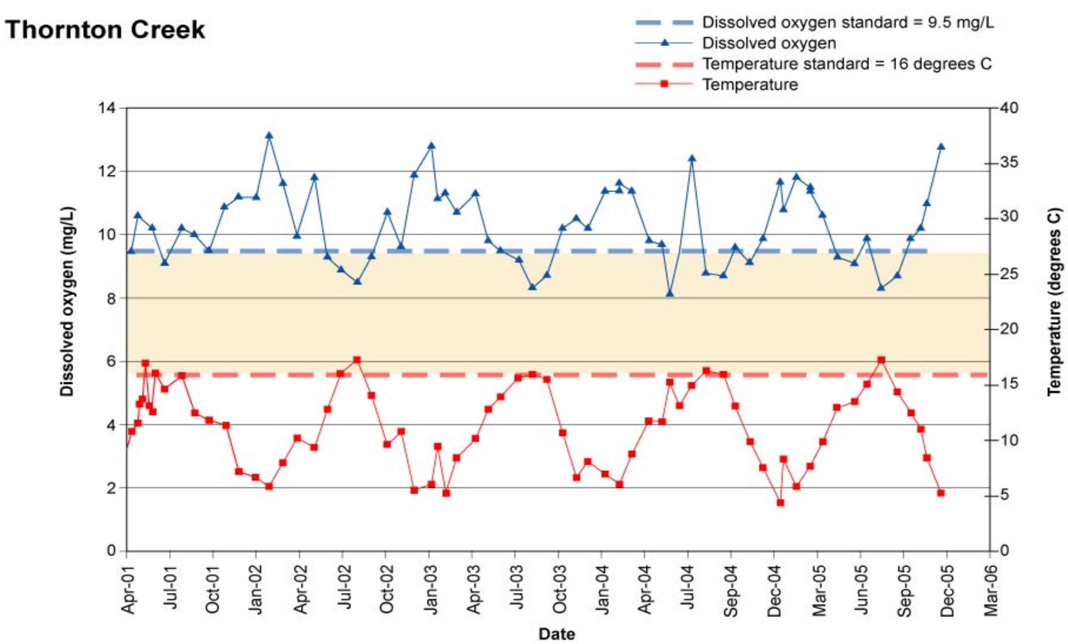
Figure 6: Thornton Creek Watershed

Water quality is currently being investigated as a potential contributor to the unusually high rates of coho salmon pre-spawn mortalities reported in urban creeks in the Puget Sound since 1999 (Reed *et al.* 2003). Between 1999 and 2005, pre-spawn mortality rates in Thornton Creek averaged 79% (McMillian 2006, SPU unpub. data). Pre-spawn mortality surveys were stopped in 2010 to analyze and publish the data and to define a path to move forward with the pre-spawn mortality issue and to pinpoint the causal factors (Davis, J. USFWS pers. comm. 2011).

As shown in Figure 7, dissolved oxygen and temperature typically exhibit a seasonal trend with higher temperatures and lower dissolved oxygen concentrations in the warm summer months. Thornton Creek frequently does not meet state water quality standards for temperature and dissolved oxygen during the summer months (mid-June through mid-September). Temperature and dissolved oxygen excursions (points at which these parameters exceed limits) are probably related to the lack of riparian vegetation throughout most of its length. Thornton Creek passes through private property; consequently the riparian zones are largely unprotected.

Figure 7

Dissolved oxygen and temperature in Thornton Creek



Station 0434. King County (undated).
Note: The areas between the two dashed lines show the samples that do not meet state water quality standards.

Dissolved oxygen and temperature in Thornton Creek

Thornton Creek also frequently exceeds state water quality standards for fecal coliform throughout the year. Annual geometric mean levels exceeded the standard for extraordinary primary contact recreation (50 cfu/100 mL) in all of the last ten years (480-1,200 cfu/100 mL) and 93% to 100% of the samples exceeded 100 cfu/100 mL. Under the state water quality standards, no more than 10% of all samples are permitted to exceed 100 cfu/100mL.

Metal concentrations within Thornton Creek are relatively low with the exception of mercury. Mercury was found to exceed the chronic toxicity criterion for aquatic life, but concentrations were below the laboratory reporting limit. Thornton Creek is a water of concern for mercury.

Nutrient levels in Thornton Creek are generally high and frequently exceed recommended water quality criteria. For example, total phosphorus concentrations in Thornton Creek (7-413 µg/L) frequently exceed the U.S. EPA (1976) water quality criterion (100 µg/L), which establishes a desired goal for the prevention of nuisance plant/algal growth in streams or other flowing waters not discharging directly to lakes or impoundments. In addition, total nitrogen concentrations in Thornton Creek (50-2,000 µg/L) frequently exceed U.S. EPA (2000) recommended nutrient criterion for streams in the western United States (340 µg/L for Ecoregion II). These criteria represent conditions in surface waters that are minimally impacted by human activities and are designed to prevent eutrophication and water quality problems associated with nutrient enrichment.

Concentrations of toxic materials in Thornton Creek are generally low. Ammonia-nitrogen levels were consistently below toxic levels. For metals, only dissolved lead exceeded the state water quality standards under non-storm flow conditions. The U.S. Geological Survey (USGS) has also found low levels of some pesticides in stormwater, sediment, and fish tissue collected from Thornton Creek (Voss and Embrey 2000). Stormwater samples collected from the north fork, south fork, and mouth of Thornton Creek contained detectable levels (0.013-0.16 µg/L) of several herbicides and their metabolites (2,4-D, 2,6-dichlorbenzmide, atrazine, dichlobenil, MCPA, mecoprop, pentachlorophenol, prometon, simazine, tebuthiuron, and trichlorpyr) and two insecticides and one insecticide metabolite (carbaryl, diazinon, and 4-nitrophenol at concentrations ranging from 0.003-0.154 µg/L). With the exception of diazinon, concentrations were below reported toxic effects levels for aquatic organisms. In 2003, the U.S. EPA cancelled diazinon product registrations and restricted the sale of this pesticide to existing stocks. As a result, diazinon concentrations in Thornton Creek should begin to decline as existing stocks are depleted.

6.1.6.2 Sediment Quality

Several organochlorine pesticides (dieldrin, chlordane, DDD, DDE, DDT, methoxychlor) ranging in concentration from 1.2 µg/kg to 8.1 µg/kg were also found in streambed sediment near the mouth of Thornton Creek (MacCoy and Black 1998). Freshwater sediment standards have not been established in Washington State. Interim sediment quality guidelines have been developed by the Canadian Council of Ministers of the Environment (1995). Sediment samples from Thornton Creek exceeded the threshold effects level of the interim Canadian sediment quality guidelines for DDD and DDE. DDE concentrations in Thornton Creek sediments also exceeded the probable effects level (the concentration above which biological effects are usually or always observed). Other organic compounds found in the streambed sediment include polynuclear aromatic hydrocarbons (concentrations of individual PAH compounds ranged from 19-310 µ/kg, with total low molecular weight PAH of 368 µ/kg and total high molecular weight PAH of 2,340 µ/kg), phthalates (estimated at 10-990 µ/kg), phenol (estimated at 29 µ/kg), p-cresol (estimated at 35 µ/kg), and several other PAH compounds (15-71 µ/kg). Some of the PAH compounds exceeded the threshold effects levels, but none exceeded the probable effects levels.

In addition, several organochlorine pesticides (5.3-97 µg/kg wet weight), and PCBs (310 µg/kg wet weight) were found in sculpin tissue samples collected at the mouth of Thornton Creek during the USGS study (MacCoy and Black 1998).

6.1.6.3 Shoreline and Aquatic Habitat

Factors limiting aquatic habitat within Thornton Creek include altered hydrology and peak high flow events, loss of floodplain connectivity, shortage of gravel recruitment, restricted access to upstream habitat, and loss of riparian vegetation.

Thornton Creek contains severely degraded aquatic habitat. The creek channel is highly simplified, with a plane-bed channel type, abundant glide habitat, low riffle-to-pool ratios and a thin and irregularly distributed substrate layer. The creek width averages less than 12 feet (3.6 m) wide, reduced from former widths of about 30 feet (9.1 m) that allowed the aquatic system to function in a more natural manner. The channel is also incised, with bank heights averaging 4 to 6 feet (1.2-1.8 m) above the streambed, compared with bank heights of less than 1 foot (0.3 m) in less impacted reaches of Thornton Creek. The high bank heights in combination with the square shape of the channel severely restrict the connection between the floodplain and the channel.

The hydrology of Thornton Creek has been severely altered and the creek experiences higher than historic peak flows during storm events. Incision, armoring, and encroachment prevent the stream from meandering across the floodplain to create and maintain habitat diversity and dissipate energy. This results in a very simple channel structure—lack of backwater areas and deep pools—in which fish are unable to find refuge or rearing opportunities. Adult fish spawning areas are also limited.

Streambank armoring and channelization have reduced gravel recruitment in Thornton Creek. The lack of instream structure, in combination with the high flow velocities, results in poor gravel retention in the system, with the exception of Meadowbrook Pond. The lack of coarse sediment limits the production of bottom-dwelling insects that other animals feed upon.

Extensive urban development and encroachment have also resulted in a loss of healthy native riparian habitat. High-quality vegetation occurs in disconnected patches along a small portion of Thornton Creek's banks, especially within parks. Areas without mature vegetation consist of residential yards or are dominated by invasive plant species. The lack of riparian vegetation minimizes both terrestrial insects and leaf litter that fuel aquatic production. Restoration activities conducted by the City of Seattle throughout Thornton Creek are improving riparian conditions and instream habitat.

Fish Use

Fish that can be found in Thornton Creek include cutthroat and rainbow trout, steelhead, Chinook, coho, chum, and sockeye salmon, peamouth chub, large-scale sucker, three-spine stickleback, prickly sculpin, coast-range sculpin, lamprey, and long-nose dace. Nonnative fish species have been introduced to Thornton Creek and include rock bass, pumpkinseed, largemouth bass, and oriental weatherfish (City of Seattle 2007, Tabor *et al.* 2010).

Based on carcass counts, coho salmon are the most numerous with an average of 33 carcasses per year (range 5 to 94). Chinook average four carcasses per year, sockeye seven, and only one chum carcass has been found between 2001 and 2008.

While fish passage barriers are not a problem on the mainstem of Thornton Creek, barriers are a problem on the North Branch and, to a lesser extent, the South Branch. On the North Branch, barriers are located just upstream of the confluence with Littlebrook Creek at NE 115th St and 35th Ave NE. On the South Branch, anadromous salmon have not passed a partial barrier located upstream of Lake City Way at NE 107th St. and 12 Ave. NE. Approximately 12 mi (19.3 km) of Thornton Creek is potentially fish-bearing, including both branches and lower segments of the larger tributaries.

Few anadromous smolts are caught in Thornton Creek. The low smolt numbers are a result of poor rearing habitat and lack of pools in the stream. High flows can also wash out juvenile fish.

6.1.7 Taylor Creek (South Lake Washington Action Area)

Taylor Creek, located in southeast Seattle in the South Lake Washington action area, receives runoff from a 629-acre (254.5 ha) watershed that includes parts of unincorporated King County (Figure 8). Taylor Creek has a total channel length of 2.8 mi (4.5 km), which includes two forks, the West and East Forks. Land use in the watershed is predominately residential (53%). While 18% is covered by roads, parking and right-of-way, 8% is used for commercial and industrial activities, and 21% is contained in parks or vacant land. About 60% of Taylor Creek flows through park or vacant land (mostly transmission line right-of-way).

6.1.7.1 Water and Sediment Quality

Twenty-one storm drains discharge to Taylor Creek (City of Seattle 2007). The West Fork of Taylor's Creek receives water from 8 storm drains. Two of these are relatively large draining 60 to 90 acres (24.3 to 36.4 ha). The East Fork receives water from 10 drains, two of which drain more than 30 acres (12.1 ha). No combined sewer overflow outfalls discharge to the watercourse.

Taylor Creek is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies. The 303(d) listings are summarized in Table 6-7.

Table 6-7
Summary of 303(d) listings for Taylor Creek

	Category	
Media	**2[1]**	**5[2]**
Water	Dissolved oxygen	
Other	Bioassessment	

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.
[2]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.
Source: Ecology 2008

6.1.7.2 Shoreline and Aquatic Habitat

The habitat of Taylor Creek is relatively good compared with other creeks in Seattle. Several factors contribute to this:

- Large extent of park and vacant land surrounding the creek
- Hard glacial substrates that resist erosion
- Presence of instream structures that help the channel to resist incision
- Minimal encroachment from development

Figure 8: Taylor Creek Watershed

Factors limiting aquatic habitat within Taylor Creek include altered hydrology and peak high flow events, limited access to upstream habitat, and lack of floodplain connectivity.

Within Lakeridge Park, habitat quality is relatively high. This portion of the creek maintains a floodplain connection and has high-quality riparian vegetation. Taylor Creek has a good amount of instream structure, especially in the Lakeridge Park areas, although it is not as dense as it would be in a forested system of similar size and gradient (Perkins 2002).

Outside of the park, Taylor Creek is comparable with other Seattle creeks, particularly in the East Fork and lower mainstem areas which lack land-water connectivity. The channel has been confined by armoring, lacks instream structure and channel complexity, and much of the riparian zone has been cleared, disturbed, or replaced by invasive species.

Development of the watershed, loss of forested wetlands and swales, and the presence of stormwater outfalls have increased runoff and high flows in the channel. The sections of creek that are located within the park and vacant areas appear to have sufficient floodplain connection and instream structure to handle increased stormwater runoff. The remaining sections of the creek, however, are impacted (*e.g.,* the East Fork and main channel downstream of Lakeridge Park). In addition, the West Fork wetland of Taylor Creek has a moderating effect on flood peaks by providing detention and storage.

The lower portion of Taylor Creek has been substantially changed due to residential development. The channel in this section is 80% armored and contains numerous bridge crossings and about one-third of the watercourse runs through culverts. Flooding is a major issue due to the undersized culverts. As the creek flows into Lake Washington, sediment deposition occurs and a new delta has formed which provides important habitat for fish rearing in the lake.

Fish Use

Fish species that can be found in Taylor Creek include coho and sockeye salmon, rainbow and cutthroat trout, three-spine stickleback, lamprey and prickly, torrent, and coast-range sculpin (City of Seattle 2007, Tabor *et al*. 2010). Chinook salmon are found in the lower portions of the creek (Tabor *et al* 2010). Access to Taylor Creek habitat is affected by two barriers that prevent anadromous fish from reaching most spawning and rearing habitat in the creek. The barriers are located approximately 600 feet (183 m) and 900 feet (274 m) upstream of the mouth of the creek. The barriers are the Rainier Avenue South culvert and a privately-owned concrete dam.

Taylor Creek contains 1.64 mi (2.6 km) of channel that supports fish, of which 774 feet (236 m) is culverted. Salmon (sockeye and coho) are restricted to the lower 600 feet (183 m) of Taylor Creek, between the mouth of Taylor Creek and the culvert under Rainier Avenue South.

Due to the limited access to the creek, few adult salmon spawn within Taylor Creek. On average, about 19 adult sockeye (range 0 to 32) and 1 adult coho (range 0 to 4) use the watercourse. Only 16% of potential suitable habitat is accessible and spawning occurs in the lower 250 to 300 feet (76.2 to 91.4 m) of the stream.

6.2 Lake Washington Ship Canal Action Area

The Ship Canal connects Lake Washington to Puget Sound. The Ship Canal action area, from upstream to downstream, is composed of Union Bay, Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and Salmon Bay. The Locks bisect Salmon Bay. Shilshole Bay is outside of Salmon Bay. There is confusion as to the exact locations of Salmon Bay and Shilshole Bay. Some documents show Salmon Bay on both sides of the Locks, and some show it as only on the upstream or east side of the Locks. This document refers to Salmon Bay on both sides of the Locks, bisected by the Locks, with Shilshole Bay part of the Salmon Bay and Shilshole Bay estuary between the Locks and the deeper waters of Puget Sound (see Figure 2).

Lake Washington Ship Canal Action Area

The Ship Canal receives runoff from approximately 5,500 acres (2,226 ha) in the Ballard, Fremont, Wallingford, and University areas north of the Ship Canal and a small primarily commercial area east of I-5 and south of Lake Union. Land use in the basin is evenly distributed between roadways (38%) and residential (32%), with lesser amounts of industrial (7%), commercial (14%), and open space/vacant land (6%). Drainage conveyance systems in the basin consist mostly of piped networks.

The Ship Canal is about 8 miles (12.8 m) long and is located entirely within the city limits of Seattle. The Montlake Cut connects Lake Washington to Portage Bay, which has a natural surface connection to Lake Union. Lake Union is linked to Salmon Bay through the Fremont Cut. Finally, the Locks form a dam at Salmon Bay, at the outlet of the Lake Washington basin.

The Locks structure and its operation influence the physical characteristics of the surrounding waterbodies. Operation of the navigational locks involves raising or lowering the water level so that vessels may pass between the two waterbodies. Other habitat modifications at the Locks include extensive shoreline hardening along both sides of the Locks and the armoring of Salmon Bay both upstream and downstream of the structure.

Due to the intensive industrial and commercial land use within the area, overall habitat conditions are more modified in the Ship Canal than in Lake Washington. The shoreline is heavily armored and the presence of bulkheads, docks, and overwater structures provide little natural shoreline within the system (Weitkamp *et al.* 2000). The south side of Portage Bay, portions of the Gas Works Park shoreline, and small areas at the south end of Lake Union are the only areas that have retained any seemingly natural shoreline characteristics (Weitkamp *et al*. 2000).

Four streams are located within the Lake Washington Ship Canal action area. Table 6-8 identifies the location of the streams and any fish species found within the creeks (Tabor *et al* 2006).

Table 6-8 Smaller streams and fish present within the Lake Washington Ship Canal action area.		
Stream	Action Area	Fish Species Present
Licton Spring Creek	Lake Washington Ship Canal	None
Mahteen Creek	Lake Washington Ship Canal	None
Lawton Creek	Lake Washington Ship Canal	None
Wolfe Creek	Lake Washington Ship Canal	None

6.2.1 Water Quality

Although water quality in the Ship Canal is generally good due to the high quality of inflowing water from the Lake Washington and Cedar River watersheds, the Ship Canal experiences seasonal temperature and dissolved oxygen problems, as well as occasional problems with fecal coliform bacteria levels. Water temperatures are often elevated during summer and frequently exceed the levels considered critical for salmon (64.4° F or 18° C). Water temperatures in surface samples (3.3 feet or 1 m depth) collected by King County between 2000 and 2005 from four stations along the Ship Canal and one station in south Lake Union generally ranged from 60.8° to 73.4° F (16-23° C) between June and September compared with 44.6° to 60.8° F (7-16° C) during other times of the year (King County undated). In addition, dissolved oxygen at the two stations where measurements are recorded at depth 29.5 to 32.8 feet (9-10 m), regularly dropped below 6 mg/L (2.8-9.8 mg/L), during the summer months when the water temperatures were above 68° to 69.8° F (20-21° C). Dissolved oxygen levels of 6 mg/L and above are optimal for salmon.

Water temperatures in the Ship Canal have been increasing steadily over the last 30 years, with an increase in the number of days that temperatures are greater than 68° F (20° C) (Weitkamp *et al*. 2000). The primary factor associated with these increases appears to be air temperature (Weatherbee and Houck 2000). The increased duration of warm water temperatures has a series of implications for salmon. Water temperatures increase the metabolism of fish and increase rates of predation, increasing the predation risks that juvenile salmon face in the Ship Canal. Water temperatures can also delay migrating adults near the Locks, or prevent their upstream movement all together (Fresh *et al*. 2000).

A particular water quality challenge for Lake Union has been caused by the introduction of saltwater through the Locks into the freshwater areas upstream. This saltwater intrusion is more of a problem in the summer when flows from the Cedar River and Lake Washington are lower, producing slower flushing rates of Lake Union. Because the density of saltwater is greater than freshwater, the saltwater intrusion forms a wedge that flows along the bottom of the Ship Canal and Lake Union. This salinity gradient combines with summer thermal stratification to cause the bottom layers of the water column (hypolimnion) to become anoxic (no oxygen). These anoxic conditions limit the areas of the Ship Canal that can be used for fish habitat (Weitkamp and Ruggerone 2000, King County 2012).

Fecal coliform bacteria numbers in the Ship Canal occasionally exceed the state water quality standards for lakes (geometric mean of 50 cfu/100 mL with no more than 10% of all samples exceeding 100 cfu/100 mL). Between 2000 and 2005, the annual geometric mean measured at 4 stations along the Ship Canal ranged from 7 to 132 cfu/100 mL (King County undated). Only one station, located near the Locks (King County Station 512), exceeded the state water quality standard (in 2000 and 2002). Between 2% and 31% of the 171 samples collected exceeded 100 cfu/100 mL; the 10% criterion was exceeded only at Station 512 (31%) and in Lake Union (11% at King County Station A522).

The Ship Canal is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies for water and sediment. The 303(d) listings are summarized in Table 6-9.

Table 6-9

Summary of 303(d) listings for Lake Washington Ship Canal and Lake Union

	Category		
Media	**2**[1]	**4C**[2]	**5**[3]
Water	pH Temperature Dissolved oxygen 4,4'-DDD 4,4'-DDE Zinc		Lead Aldrin Fecal coliform bacteria Total phosphorus
Habitat		Invasive exotic species	

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body is impaired by a non-pollutant that cannot be addressed through a water quality improvement project [total maximum daily load (TMDL) or pollution control program).

[3]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.

Source: Ecology 2008

6.2.2 Sediment Quality

Elevated concentrations of arsenic, copper, lead, mercury, and zinc have been observed in sediment throughout the Ship Canal (Cubbage 1992). PAHs and arsenic concentrations are highest along the northshore near Gas Works Park, although elevated concentrations of other metals (antimony, cadmium, copper, lead, mercury, nickel, silver, and zinc), as well as tributyltin, ethylbenzene, PCBs, phenol, and carbazole have also been reported in this area (Cubbage 1992, Floyd/Snider and MCS 2005). The City of Seattle and Puget Sound Energy are conducting remedial investigations/feasibility studies in the northshore area to assess the extent and severity of the contamination and to evaluate cleanup options.

Moshenberg (2004) also reported elevated concentrations of metals, tributyltin, PAH, and phthalates, and PCBs in sediment throughout the Ship Canal. With the exception of PCBs, concentrations of most contaminants were markedly higher in Lake Union compared to Lake Washington and Lake Sammamish. The nearshore areas in Lake Union exhibited the highest contaminant levels, particularly stations along the south and southwest shorelines, and along the western edge of the lake (Moshenberg 2004).

6.2.3 Shoreline and Aquatic Habitat

The Ship Canal extends from the locks eastward through Union Bay and terminates at Webster Point beyond which is the main body of Lake Washington. The Ship Canal shorelines are largely modified. Seventy-five percent of the shoreline is retained by bulkheads or riprap. There is an average of 32.6 docks per mile, and 17.3% of the shoreline is shaded (Toft *et al.* 2003).

The authorized depth of Salmon Bay, just upstream of the Locks, is 30 feet (9.1 m), with a variable width ranging from 100 to 200 feet (31 to 61 m). Before construction of the Locks, this area was tidally influenced and navigable only by shallow-draft vessels at high tide. Historically, Salmon Bay was a saltwater inlet (at least during high tide). At low tide, it was almost dry, with the water level dropping nearly 20 feet (6.1 m) between extreme high and low tides (Williams 2000). Construction of the Locks raised and stabilized the water level in this section of the canal converting it from an estuarine to freshwater/pseudo-estuarine environment.

The Fremont Cut is about 5,800 feet (1,767.8 m) long and connects Salmon Bay and Lake Union. The Fremont Cut was dredged to an authorized depth of 30 feet (9.1 m) and has a channel width of 350 feet (106.7 m). Concrete sills, bolstered by riprap, line both sides of the channel. Upland of the concrete revetments, the riparian zone consists of a row of Lombardy poplars and other landscaped vegetation.

Lake Union is about 581 acres (235 ha) in area. The mean water level in Lake Union was not changed by construction of the Ship Canal, but the range of water level has been reduced. The elevation at the Locks only ranges 2 feet (0.6 m) from 20 to 22 feet (6.1 to 6.7 m). Overwater coverage, bulkheads, and shoreline armoring are extensive.

Relatively little shallow water habitat either natural or altered is left along Lake Union shorelines, including riparian zone vegetation. Lake Union is lined with a large variety of commercial and industrial facilities, including ship repair and scrapping yards, marinas, and office buildings. More than 80% of the shoreline has been modified by bulkheads or other forms of bank stabilization (City of Seattle 2000). Eurasian water-milfoil is a problem in the lake. The species contributes a large amount of organic material to the lake, which affects dissolved oxygen levels (WDNR 1999).

Lake Union has an arm extending eastward known as Portage Bay. Portage Bay is lined by University of Washington facilities, commercial facilities, and houseboats. The southeastern portion of Portage Bay has an area of shallow, freshwater, and marsh habitat. The remainder of the shoreline has been developed, and several marinas are located in the bay.

The Montlake Cut is about 2,500 feet long (762 m) and connects Portage Bay and Union Bay, which is part of Lake Washington. The Montlake Cut was dredged to an authorized depth of 30 feet (9.1 m) and has a channel width of 350 feet (106.7 m). Similar to the Fremont Cut, the Montlake Cut has concrete revetments that line both sides of the channel. The tops of the revetments are used as waterside walks. The Montlake Cut is characterized by steep side slopes, planted with a combination of English ivy, deciduous and evergreen trees, and native shrubs and grasses.

Before construction of the Ship Canal, Union Bay consisted of open water with the shoreline extending north to 45th Street. After construction, Union Bay was lowered by 9 feet (2.7 m) and a marsh was created on fill placed in the northern portion of the bay. The southern limits of the marsh consist of remnant cattail marshes that still exist at the southern edge of the Montlake fill. Much of the marsh that was created after construction has since been filled, leaving only the fringe marsh on the southern end (Jones and Jones 1975).

Union Bay has several areas of freshwater marsh, milfoil, and associated fauna. The south side of the bay is bordered by the University of Washington's Arboretum and traversed by the Evergreen Point Floating Bridge, creating a network of smaller embayments and canals with marsh habitats. The north side of Union Bay contains the marshy fill area and numerous private residences with landscaped waterfronts, and dock facilities dominate the remainder of the shoreline.

Important shallow-water habitat has declined for juvenile salmon as a result of development (Toft 2001, Piaskowski and Tabor 2001, Tabor and Piaskowsi 2002). Development of lakefront property has armored about 70% of the shoreline (Toft 2001). The banks along the Ship Canal are about 96% armored (Weitkamp *et al.* 2000). These bank conditions are coupled with overwater structures such as docks and piers. As of 2000, 2,737 docks lined the lake shoreline covering about 4% of the lake's surface area within about 100 feet (30 m) of shore (Fresh and Lucchetti 2000, Weitkamp *et al.* 2000, Toft 2001, R. Malcolm and E. Warner, Muckleshoot Indian Tribe, unpub. data). These overwater docks and piers have increased shading and segmented the Ship Canal shorelines. Bank armoring, overwater structures, and accompanying homes, decks, and yards, have reduced native riparian vegetation and woody debris. Cumulatively, such alterations influence juvenile salmonid migration movements, prey availability, and predator behavior and distribution (Warner and Fresh 1998, Kahler *et al.* 2000, Koehler 2002, Fresh *et al.* 2003).

Important impacts on habitat include reduced amounts of woody debris in littoral areas (Christensen *et al.* 1996), reduced shallow-water refuge area, reduced riparian cover, decreased sockeye beach spawning areas through aquatic macrophyte growth, and elimination of beach spawning habitat through altered substrate composition and water circulation patterns (Fresh and Lucchetti 2000).

Within the Ship Canal, the only fragments of Lake Union that retain some natural shoreline are along the south side of Portage Bay, portions of the Gas Works Park and a few small areas at the south and east sides of Lake Union. The specific impact these conditions have on migrating juvenile and adult salmon is unknown but of concern. The bank armoring and bulkheads and docks along most of this shoreline severely limit the amount of desirable habitat and cover available to rearing and migrating juvenile salmon. For returning adult Chinook salmon, the Ship Canal is primarily a passageway that is traversed in a few days (Fresh *et al.* 2000).

6.2.4 Habitat Access: Barriers

The Locks provide a barrier for salmonid migration in both directions. Passage is possible through the Locks *via* the fish ladder, large lock, small lock, the saltwater drain, and the smolt passage flumes. Adult salmonids migrating to freshwater primarily pass via the fish ladder and the two lock chambers. Juveniles are thought to primarily pass *via* the smolt passage flumes, but also use the large lock miter gates and the filling culverts.

The fish ladder allows upstream migration of anadromous fishes. The ladder is located on the south side of the spillway. The ladder is 8 feet (2.4 m) wide, with three adjustable weirs at the upper end fish exit, 18 fixed weirs with submerged orifices, one adjustable and one fixed slot in the entrance. The lower six weirs are designed with diffusers that provide transportation and attraction water (Corps 1992). Flow through the fish ladder includes 23 cubic feet/sec (0.65 cu m/sec) freshwater from the surface of the Ship Canal, as well as 160 cubic feet/sec (4.5 cu m/sec) attraction water into the diffusers from the saltwater drain. The attraction water was provided in 1976 when the original 1917 fish ladder was rehabilitated to allow saltwater to be mixed with freshwater as a means to attract more fish and to facilitate upstream migration. This additional water was provided *via* a ‘Y’ valve from the saltwater drain pipe. Water is released through the fish ladder year-round, except during ladder maintenance periods (typically one week in late May or early June).

The saltwater drain system allows upstream migration of adult fish via the drain outlet. However, in the late 1970s at the request of WDF (now WDFW) the Corps began operating the system to exclude adult salmonids from using this route. This was done because it was determined that adults are able to migrate through the saltwater drain system in the Ship Canal, or follow the ‘Y’ to the diffuser well in the fish ladder, where they may become trapped. The Corps operates the saltwater drain when tide elevation is less than or equal to 6.5 feet (2 m) MHHW. Fish can access the saltwater drain system when tides are higher than 7 feet (2.1 m) MHHW. In 2008, a 50 x 60 foot screen structure was placed over the upstream end of the saltwater drain system. The screen was installed to prevent adult salmon from entering the saltwater drain and getting caught in the diffuser wells of the fish ladder. The screen has hinged doors that are closed during the adult migration period (June through mid-September).

Adults also migrate to freshwater through the large and/or small locks. Adult anadromous fish enter the large and small locks when the lower gates (west end) are open to allow boats to leave or enter the locks.

In early to mid-April, four flumes are installed in spillway gates 4 and 5 of the Locks to improve smolt passage through the Locks. Before 1995, little or no water was spilled over the spillway during most days in June and July. In 1995, at the request of the WDFW and NMFS, the Corps built and installed a prototype low-flow smolt bypass system. The smolt passage flume used 20% to 25% of the water volume of a 1-foot (0.3 m) spillway gate opening. The prototype flume was installed each year by mid-April and operated for as long as water was available during 1995 through 1999. In 2000, together with funding from the City of Seattle and King County, the prototype flume was replaced with four smolt passage flumes.

Each flume can be opened or closed independently, allowing a large range of available flow conditions, ranging from 50 to 400 cubic feet/sec (1.4-11.3 cu m/sec). Installation of these flumes has allowed the Corps to increase their operational flexibility and to use water more efficiently for safe smolt passage within a wider range of available flows. The primary concern with the smolt passage flumes is the potential lack of available water to allow operation of the flumes during the later part of June and July when most juvenile Chinook salmon are migrating through, or rearing below, the Locks. When water isn’t available, Chinook salmon and other smolts are forced to select other routes (fish friendly or not) to exit the Locks.

Tagging studies have indicated that significant numbers of Chinook migrating upstream through the Locks hold for an extended period in the area just above the saltwater intake drain in the area known as the coolwater refuge before moving into the watershed (Fresh et al. 1999; Corps 2001). An acoustic tagging study funded by King County and the Corps tracked 45 adult Chinook migrating upstream in and around the Locks between July and October 2000 (Corps 2001). The study found the following:

1. The average residence time of tagged fish within the hydrophone array immediately upstream of the Locks was 19 days.
2. The earlier a fish entered the system, the longer it remained before moving upstream with all tagged fish exiting the system (the monitored area) between August 10 and October 2, with a mean departure date of September 4
3. Prominent holding or residence areas were located in front of the saltwater drain intake, in the small lock, and in the large lock

Tagging studies also showed that annually 30% to 40% of the acoustic tagged adults fell back below the Locks one or more times (Fresh *et al.* 2000). Fallback fish may move back and forth through the Locks (presumably the large locks) up to four times. This may be due to the abrupt changes in salinity or because of the high temperature gradient between the freshwater and the saltwater.

Smolt and juvenile migratory behavior through the Locks is based on four years of monitoring smolt passage at the Locks and information from other water control projects in the Pacific Northwest (Corps 1999, Williams 2000). Juvenile salmonids encounter complex water currents above and below the Locks, but currents are negligible until fish are within several hundred feet of the Locks. In contrast to the constraints imposed on juvenile salmonid movements near the Locks, juveniles in a natural estuary would be free to move up and down the channel selecting preferable temperature and salinity and habitat rearing areas.

In studying PIT-tagged juvenile Chinook after passage through the Locks, it was found that some juveniles pass through the Locks more than once (DeVries 2005). Of 1,990 detected PIT-tagged Chinook, 32 passed through the flumes twice. Juvenile Chinook salmon were passed back up into the Ship Canal through either the large or small locks before passing through the flumes a second time. The time from the first to the second flume detection (recycling time) ranged from five to 40 days. It was also thought that smaller fish were more likely to rear for longer periods at the Locks which increased the probability they would be passed through the Locks more than once. There was no relation between the recycling time and fish size (at the time the fish were tagged). Little information is available to determine the importance of a freshwater lens below the Locks (for rearing or migratory juvenile Chinook salmon) although it is believed that some portion of the juveniles can make the transition faster than others. A large fraction of PIT-tagged fish caught by beach seine below the Locks made the transition to saltwater (>20%) in less than two days.

In late spring/early summer, the smolt flumes are used to control lake elevations. In most years, by late spring, the flow volume into the Ship Canal is usually reduced such that the spillway gates cannot be opened wide enough to allow safe passage of smolts. Lake elevations below acceptable levels, continued dry weather forecasts, and inflows below normal trigger conservation measures at the Locks. Conservation measures begin with closing the saltwater drain, decreasing hours of operation for the flumes, and initiating lockage restrictions. Reduced inflow requires conservation of water to maintain elevations of Lake Washington and results in modifications to Locks operation. The first conservation measure is closing all spillway gates. Secondary measures include reducing lockages and altering saltwater management practices. However, if inflows to Lake Washington and therefore the Ship Canal increase, the spillways may have to be used. In this case, the spillways are opened at least 0.5 foot (0.15 m) for safe fish passage.

The fish ladder passes a small number of migrating juvenile salmon. In 1994, before the prototype flume installation in 1995, the estimate of outmigrants using the fish ladder was about 40,000 fish out of an expected 3 to 5 million smolts or about 1% of all smolts (Kerwin 2001). All juvenile fish passing through the fish ladder from the exit (top pool) to the entrance (bottom pool) are presumed to be uninjured. It is unlikely that juvenile Chinook would pass back upstream through the fish ladder.

Historical fish protection measures to the saltwater drain have included screening the intake and the outlet so adult salmon would not enter the culvert. During rehabilitation of the fish ladder in 1976 to1977, a fiberglass mesh screen was installed across the entrance of the saltwater drain intake (freshwater side) to exclude fish from entering the intake and becoming entrained into the culvert. This screen was removed by 1980 as large volumes of debris became impinged on the screen reducing the volume and efficiency of the drain. From 1980 to 1994, a screen to exclude adults covered the outlet of the saltwater drain (marine side), but the screen was removed in 1994 after the WDFW observed smolts impinged on the upstream surface of the screen.

The saltwater drain cannot be eliminated as a pathway for juvenile salmon under current operating conditions. Even during periods of little or no spill, however, the saltwater drain intake is less likely to be a major pathway for juvenile fish than the large lock culvert intakes for several reasons:

1. The drain intake is at a greater depth (50 feet (15 m) average vs. 33 feet (10 m) for Lock culvert intake)
2. Velocities into the intake (0.5-1.0 feet/sec [0.15-0.3m/sec) are much lower than velocities typically encountered and selected by smolts that passed through either the flumes or the culvert intakes (3-5 feet /sec [0.9-1.5m/sec)
3. Poor water quality conditions (low dissolved oxygen) may exist for sustained periods

No direct monitoring of juvenile salmon passage has been conducted in the small lock, although anecdotal information indicates few fish use this pathway (Kerwin 2001). Previous observations of smolt use of the small locks and direct monitoring of the large lock suggest that few, if any, fish would use the small lock when there is enough available water to run three or more flumes. Even if fish were to use this pathway, attributes of the small lock suggest few fish would be injured because the small lock, unlike the large lock, is not lined with barnacles, and conduits in the small lock operate under lower head and velocity than the large lock.

6.2.5 Non-Native and Predator Fish in Ship Canal

The primary freshwater predators in the Ship Canal include the non-native smallmouth and largemouth bass and the native northern pikeminnow. The northern pikeminnow appears to be an important predator but little data are available on their abundance. There are an estimated 3,400 smallmouth and 2,500 largemouth bass in the Ship Canal (Tabor et al. 2000).

Six anadromous salmonid species pass through the Locks and Ship Canal:

1. Chinook salmon
2. Coho salmon
3. Sockeye salmon
4. Coastal cutthroat
5. Steelhead
6. Bull trout

Since the separation of the Lake Washington drainage basin from the Green/Duwamish drainage basin, at least two stocks of anadromous salmon may have been extirpated from the Lake Washington system: chum and pink salmon, possibly native to the Cedar River. Since 1936, at least eight stocks have been introduced and are maintained either as hatchery stocks (*e.g.*, Chinook, coho) or have established naturally reproducing, self-sustaining populations (*e.g.*, sockeye).

Predation of salmonids is often greatest at bottleneck areas where fish aggregate. Within the Ship Canal, juveniles may be vulnerable to predation as they migrate from Lake Washington to the Locks, pass through the Locks, aggregate below the Locks, and as they rear in the relatively small estuary.

Several species of marine organisms exist in the lower portion of the Ship Canal up to and including the Locks (Table 6-10). Some marine and estuarine species migrate through the Locks or live in the transition zone immediately below the Locks. For example, starry flounder occur in the lower Ship Canal while shiner surfperch are found above the Locks through much of the summer, and Pacific herring and longfin smelt move above and below the Locks during up-lockage, the period when the Locks are used to pass boats upstream.

Table 6-10

Aquatic species inhabiting or migrating through Hiram M. Chittenden Locks

Common name	**Genus**	**Species**	**Resident or migratory**
Marine/Estuarine Fish			
Starry flounder	*Platichthys*	*stellatus*	R
Wolfeel	*Anarrhichthys*	*ocellatus*	R
Shiner surfperch	*Cymatogaster*	*aggregata*	R
Striped surfperch	*Embiotoca*	*lateralis*	R
Pacific herring	*Clupea*	*pallasi*	R
Anadromous Fish			
Chinook salmon	*Oncorhynchus*	*tshawytscha*	M

Common name	Genus	Species	Resident or migratory
Coho salmon	*Oncorhynchus*	*kisutch*	M
Sockeye salmon	*Oncorhynchus*	*nerka*	M
Chum salmon	*Oncorhynchus*	*keta*	M
Steelhead trout	*Oncorhynchus*	*mykiss*	M
Cutthroat trout	*Oncorhynchus*	*clarki clarki*	M
Bull trout	*Salvelinus*	*confluentus*	M
Dolly Varden	*Salvelinus*	*malma*	M
Atlantic salmon	*Salmo*	*trutta*	M
Pacific lamprey	*Lampetra*	*tridentatus*	M
River lamprey	*Lampetra*	*ayresi*	M
American shad	*Alosa*	*sapidissima*	M
Longfin smelt	*Spirincus*	*thaleichthys*	M
Freshwater Fish			
Yellow perch	*Perca*	*flavescens*	R
Black Crappie	*Pomoxis*	*nigromaculatus*	R
Peamouth Chub	*Mylocheilus*	*caurinus*	R
Smallmouth bass	*Micropterus*	*salmoides*	R
Marine Invertebrates			
Barnacles	*Balanus*	*crenatus*	R
Barnacles	*Balanus*	*cariosus*	R
Blue mussel	*Mytilus*	*edulis*	R
Amphipods			R
Isopods			R
Annelids			R
Scallop	*Pododesmus*	Sp.	R
Sea cucumber	*Eupentacta*	Sp.	R
Sea urchin	*Strongylocentrotus*	Sp.	R
Starfish	*Pycnopodia*	Sp.	R

Common name	Genus	Species	Resident or migratory
Tunicates (Sea squirts)	*Chelyosoma*	Sp.	R
Anemome	*Tealia*	Sp.	R
Other Marine Organisms			
Sponge			R
Algae	*Fucus*	Sp.	R
Algae	*Amphora and Synedra*		R
Bryozoans	***Crisia***	**Sp.**	R

In 2000, the Muckleshoot Indian Tribe conducted pilot studies of predation of juvenile Chinook salmon below the Locks (Footen 2000). The most abundant predators in the inner bay were sea-run cutthroat trout and staghorn sculpin and in the outer bay the key predators were staghorn sculpin and resident Chinook (blackmouth). Bull trout were another important predator on juvenile Chinook salmon. Chinook salmon made up 12% of the cutthroat trout diet; 34% were other smolts, mostly chum. Bull trout diet consisted of 27% Chinook salmon and 12% other salmonids. Fifty percent of the sculpin diet was Chinook salmon, but this estimate was influenced by a single sample.

Most of the consumed juvenile salmon within the Ship Canal appear to be subyearling fish (Tabor *et al.* 2004c). Tabor noted that preliminary research done by the Muckleshoot Indian Tribe, USFWS, and University of Washington in 1995 and 1997 indicated that smallmouth bass may be an important predator of salmonid smolts in the Ship Canal. Subsequent sampling of stomach contents of over 900 predators from the end of April to the end of July indicated that both bass species and northern pikeminnow consumed smolts from mid-May to the end of July. Lowest densities of predators appeared to occur in Salmon Bay, in fact few freshwater piscivorous fish have been found there (Tabor *et al.* 2004c). Smallmouth bass of all size categories consumed salmonids, with greatest predation rate occurring in June when salmonids made up about 50% of their diet. Largemouth bass consumed salmon at a generally low rate and only by bass 5.8 to 9.8 inches (148-249 mm) long. Largemouth bass appeared to eat more coho and fewer Chinook and sockeye. About 45% of the diet of northern pikeminnow consisted of salmon, of which 45% were Chinook smolts, 40% were coho and 15% were sockeye.

Tabor *et al.* (2004c) estimated that about 3,400 smallmouth bass and 2,500 largemouth bass longer than 5 inches (130 mm) fork length reside in the Ship Canal. They used bioenergetics and direct meal-turnover models to estimate total consumption of smolts. The bioenergetics model predicted smallmouth bass consumed 27,300 salmonids and largemouth bass consumed 8,700. The direct meal-turnover model predicted smallmouth bass consumed 41,100 salmonids and largemouth bass consumed 4,600. The highest predicted consumption occurred in age 2 fish because of their large population size and high growth rates. The overall mortality rate was on the order of 1% for Chinook smolts passing through the Ship Canal and being consumed by small- and largemouth bass. Tabor could not derive a population estimate for northern pikeminnow, but reasoned that because salmonids made up a substantial portion of their diet, this species had the potential to be a significant predator if their population size in the Ship Canal is large.

Largemouth bass are more common in vegetated areas with gentle slopes and fine substrates such as south Portage Bay, Lake Union, and Salmon Bay, whereas smallmouth bass tended to use areas with steeper slopes. Tabor *et al.* (2004c) found smolts tended to be less concentrated in largemouth bass habitat than in smallmouth bass habitat. However, estimated smallmouth bass predation rates on Chinook smolts were relatively low, ranging between 0.4% and 3.0% (Tabor *et al*. 2004c). Most consumed Chinook were small and likely to use similar habitats to smallmouth bass more frequently than larger Chinook smolts during the warmer part of outmigration season when bass consumption rates were higher. Northern pikeminnow were thought to be less selective feeders than bass, but were nonetheless an important predator. The extent to which habitat overlap and temperature affect predation rates is unknown, however, in part because of the difficulty in catching them (Tabor *et al.* 2004c). Based on other systems, it is possible that northern pikeminnow could congregate in areas where smolt numbers are high in the Ship Canal, and could be present in deeper water where smolts are thought to become more concentrated as water temperatures warm.

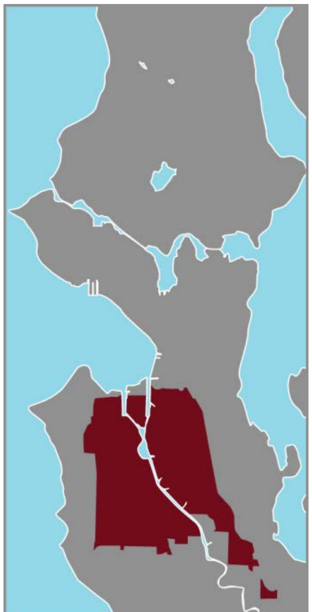
Tabor *et al.* (2004c) also noted that catch rates of predators were generally lower in Salmon Bay than elsewhere in the Ship Canal. The lower catch rates may have reflected differences in habitat structure and water quality including the effects of saltwater intrusion, sampling difficulties, and possibly the effect of sediment contamination in Salmon Bay on piscivorous predator survival.

Acoustic tracking studies were conducted from 2006 through 2009 of smallmouth bass, largemouth bass, and northern pikeminnow (Tabor *et al* 2010). Smallmouth bass commonly used overwater structures, areas of sparse vegetation, vegetation edges, and areas with gravel and sand substrate. Smallmouth bass primarily used 6.5 to 13.1 feet (2 to 4 m) deep water and were rarely in water that was more than 39.4 feet (12 m) deep. A large portion of the smallmouth bass migrates out of the Ship Canal into Lake Washington between June and October and remain there until early spring.

Northern pikeminnow usually inhabited Lake Washington, but from May through August some of the tagged northern pikeminnow moved into the Ship Canal (Tabor *et al.* 2010). Here, they were concentrated close to shore during the day and were often associated with vegetation. At night, northern pikeminnow occupy a wide range of depths.

6.3 Lower Green/Duwamish Action Area

The Duwamish River estuary is located at the lowermost extent of the Green/Duwamish River system (WRIA 9), a 93-mile-long (149.6 km) river system that originates in the Cascade Mountains near Stampede Pass and flows generally west and northwest toward the City of Seattle. Currently, the Green/Duwamish River basin drains 483 square miles (1,251 sq/km) (Weitkamp and Ruggerone 2000). Tidal influences on river height are observed upstream to about RM 15 (T. Nelson, King County, pers. comm. 2005). The saltwater wedge typically extends along the channel bottom up to a small rapid near Boeing Bridge at RM 7; saltwater may move farther upstream during extreme high tides. This reach is an important transitional area for both juvenile and adult salmon that acclimate to changes in salinity during their migration. The last 4.6 miles (7.4 km) of the watershed are located within Seattle. The lower portion of the Duwamish River, called the Duwamish Waterway, splits into East and West Waterways as it moves north and enters Elliott Bay.



Lower Green/Duwamish Action Area

Circulation of water within a stratified estuary comprises a net upstream movement of water within a lowermost saltwater wedge and a net downstream movement of fresher water in the layer overriding the wedge (Pritchard 1955). The saline wedge water, which has its source in Elliott Bay, oscillates upstream and downstream with the tide. During periods of low freshwater inflow and high tide stage, the saltwater wedge has extended as far upstream as the Foster Bridge, 10.2 miles (16.4 km) above the mouth. At freshwater inflow greater than 1,000 cubic feet/sec (28 cu m/sec), the saltwater wedge does not extend upstream beyond the East Marginal Way Bridge (RM 7.8) regardless of the tide height (Stoner 1967).

The Duwamish River transports fine material in a freshwater plume emptying into Elliott Bay. Sediments return from Elliott Bay to the Duwamish as a near-bottom sediment load contained in the saltwater wedge (GeoSea Consulting 1994).

The waterway receives runoff from approximately 11,600 acres (4,694 ha) of land in south Seattle. The waterway has been developed mainly for industrial uses, including a large shipping port. As such, the majority of the tidelands, tidal swamps, and tidal marshes have been filled. The channel has been straightened and is maintained for navigation through dredging (Blomberg *et al.* 1988). The banks of the river have been heavily armored and contain many overwater structures to support the operation of shipping-related businesses. Land use in the basin is evenly distributed between roadways (27%), residential (22%), and industrial (28%) uses, with lesser amounts of commercial (6%) and open space/vacant land (14%).

A recent survey of outfalls in the river identified over 200 outfalls discharging to the river between the turning basin near the south end of Seattle City limits and the south end of Harbor Island, near the mouth of the river. About 40 of these outfalls are publicly-owned storm drains (Seattle, King County, Port of Seattle, Washington Department of Transportation, City of Tukwila), ten are combined sewer overflows (2 City of Seattle and 8 King County overflows), five are emergency overflows from city/county sewer pump stations, and the remainder are either private storm drains or other outfalls of unknown origin/ownership (Herrera 2004). Additionally, approximately 40 storm drains, seven pump station emergency overflows, and six combined sewer overflows discharge into the East and West waterways.

Six streams are located within the Lower Green/Duwamish action area. Longfellow Creek is described below. Table 6-11 identifies the location of the other streams and any fish species found within the creek (Tabor *et al* 2006).

Table 6-11

Smaller streams and fish present within the Lower Green/Duwamish action area.

Stream	Action Area	Fish Species Present
Puget Creek	Lower Green/Duwamish	Rainbow Trout
Unnamed DW01	Lower Green/Duwamish	Dry
Durham Creek	Lower Green/Duwamish	Threespine stickleback, Coho salmon
Unnamed DW02	Lower Green/Duwamish	None
Hamm Creek – North Fork	Lower Green/Duwamish	None

6.3.1 Water Quality

Water quality in the Duwamish River has been adversely affected by discharges from public and private storm drains, combined sewer overflows, industrial and municipal wastewater discharges, contaminated groundwater, and spills and leaks that discharge directly to the river from waterfront or overwater activities. Since the 1980s, industrial and municipal wastewater inputs have been significantly reduced as a result of increased surveillance monitoring and the construction of the wastewater effluent transfer line which diverted Renton Treatment Plant effluent from the Duwamish River to Puget Sound. Removal of the South (Renton) Treatment Plant outfall led to significant decreases in the ammonia and phosphorus concentrations in the Green River (Kerwin and Nelson 2000).

Monthly monitoring conducted in the lower Duwamish Waterway at three stations between the East Marginal Way S bridge near S 115th St and the south end of Harbor Island show that maximum water temperatures have increased by about 3.6° F (2° C) since 1970 (Kerwin and Nelson 2000). Likewise, the number of times state freshwater quality standards for temperature have been exceeded has increased from one in 1970 to three in the 1980s to seven between 1990 and 1998. Between 1996 and 1999, two of the three stations (at the 16th Ave S bridge and at the East Marginal Way S bridge near S 115th St) exceeded the salmon migration blockage threshold 69.8° F (21° C) and/or the Class B marine standard 66.2° F (19° C).

Dissolved oxygen levels in the lower Duwamish River have improved since the diversion of the South Treatment Plant discharge, although occasionally state water quality standards continue to be exceeded. For example, between 1996 and 1999, fewer than 1% of the samples collected (2 out of 783) did not meet the Class B marine standard (5 mg/L). Both excursions occurred at the S Spokane Street Bridge. In addition, mortalities or delays in Chinook salmon migration—which used to occur frequently—have not been observed since the diversion (Kerwin and Nelson 2000).

Based on King County samples collected from five to nine sites along the Lower Duwamish River between 1996 and 1999, toxic pollutants such as metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc), ammonia, and pentachlorophenol do not appear to be a problem for water quality (Kerwin and Nelson 2000). However, data are lacking for organic compounds.

The Duwamish River/Duwamish Waterway is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies for water, sediment, and fish tissue. The 303(d) listings are summarized in Table 6-12.

Table 6-12

Summary of 303(d) listings for the Duwamish River/Duwamish Waterway

	Category			
Media	**2**[1]	**4A**[2]	**4B**[3]	**5**[4]
Water	Bis (2-ethylhexyl)-phthalate Dissolved oxygen pH Temperature	Ammonia-N		Dissolved oxygen Fecal coliform bacteria pH
Tissue	4,4'-DDE Bis (2-ethylhexyl) phthalate Chlordane Dieldrin			4,4'-DDD 4,4'-DDE 4,4'-DDT Alpha-BHC High molecular weight polycyclic aromatic hydrocarbons (HPAH) Total PCBs
Sedi-ment	1,2,4-Trichlorobenzene 1,2,4-Trichlorobenzene 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dimethylphenol 2-Methylnaphthalene 2-Methylphenol 4-Methylphenol Acenaphthene Acenaphthylene		1,2,4-Trichlorobenzene 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dimethylphenol 2-Methylnaphthalene 2-Methylphenol 4-Methylphenol Acenaphthene Acenaphthylene Anthracene	1,2,4-Trichlorobenzene 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dimethylphenol 2-Methylnaphthalene 2-Methylphenol 4-Methylphenol Acenaphthene Acenaphthylene Anthracene

	Benzo[ghi]perylene Benzo[ghi]perylene Bis (2-ethylhexyl) phthalate Butylbenzylphthalate Butylbenzylphthalate Cadmium Dibenzo[a,h]anthracene Dibenzofuran Diethyl phthalate Dimethyl phthalate Hexachlorobenzene Hexachlorobenzene Hexachlorobutadiene Indeno (1,2,3-cd) pyrene Naphthalene N-Nitrosodiphenylamine Pentachlorophenol Phenanthrene Phenol Total PCBs		Arsenic Benzo[a]anthracene Benzo[a]pyrene Benzo[ghi]perylene Benzofluoranthenes Total (b+k+j) Bis (2-ethylhexyl) phthalate Butylbenzylphthalate Cadmium Chromium Chrysene Copper Dibenzo[a,h]anthracene Dibenzofuran Dibutyl phthalate Diethyl phthalate Dimethyl phthalate Di-N-Octyl Phthalate Fluoranthene Fluorene Hexachlorobenzene Hexachlorobutadiene High molecular weight polycyclic aromatic hydrocarbons (HPAH) Indeno(1,2,3-cd) pyrene Lead Low molecular weight polycyclic aromatic hydrocarbons (LPAH) Mercury Naphthalene N-Nitrosodiphenylamine Pentachlorophenol Phenanthrene	Arsenic Benzo[a]anthracene Benzo[a]pyrene Benzo[ghi]perylene Benzofluoranthenes Total (b+k+j) Benzoic Acid Benzyl Alcohol Bis (2-ethylhexyl) phthalate Butylbenzylphthalate Cadmium Chromium Chrysene Copper Dibenzo[a,h]anthracene Dibenzofuran Dibutyl phthalate Diethyl phthalate Dimethyl phthalate Di-N-Octyl Phthalate Fluoranthene Fluorene Hexachlorobenzene Hexachlorobutadiene High molecular weight polycyclic aromatic hydrocarbons (HPAH) Indeno (1,2,3-cd) pyrene Lead Low molecular weight polycyclic aromatic hydrocarbons (LPAH) Mercury Naphthalene N-Nitrosodiphenylamine

			Phenol Pyrene Sediment Bioassay Silver Total PCBs Zinc	Pentachlorophenol Phenanthrene Phenol Pyrene Sediment Bioassay Silver Total PCBs Zinc

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body has an approved TMDL in place and is actively being implemented.

[3]Water body has a pollution control program in place that is expected to solve the pollution problem. The water body is still impaired, but the pollutant is being addressed.

[4]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.

Source: Ecology 2008

6.3.2 Sediment Quality

In 2001, the U.S. EPA listed about 5 miles (8 km) of the Lower Duwamish Waterway, extending from near the turning basin at the south end of the Seattle City limits to the south end of Harbor Island, as a Superfund site due to elevated concentrations of contaminants in the waterway sediments. The contaminants in the waterway sediments include PCBs, PAHs, metals (arsenic, cadmium, copper, lead, mercury, and zinc), and phthalates. The U.S. EPA, the Washington State Department of Ecology, and other partners are investigating and cleaning up sediment contamination under Superfund and other programs.

A remedial investigation/feasibility study is being prepared by the members of the Lower Duwamish Waterway Group (City of Seattle, Port of Seattle, King County, and The Boeing Company). Based on a preliminary risk assessment, seven areas have been identified as candidates for early action cleanup. The following cleanup activities have occurred or are scheduled to occur:

- Norfolk dredge/cap completed by King County in 1999
- Diagonal/Duwamish dredge/cap completed by King County in 2004
- Terminal 117 waterway and upland cleanup being conducted. Cleanup has been occurring since 1999 and future alternatives to continue to address contaminants is ongoing. The Port of Seattle is responsible for cleanup of the sediments and upland property and the City of Seattle is responsible for cleanup of streets and yards.
- Slip 4 cleanup has been occurring since 2003, but was put on hold in 2007 when it was discovered that PCBs were still discharging from outfalls. In

February 2010, the City of Seattle and Boeing have agreed to share future cleanup expenses in Slip 4 (City of Seattle 2010).

Due to rising concentrations of PCBs in tissue samples, the Washington State Department of Health has issued advisories against the consumption of any resident fish, shellfish, or crab that come from the Duwamish River (WDOH 2005).

The East and West waterways adjacent to Harbor Island are also the subject of remedial investigations because of contaminated sediment. Contaminants include arsenic, copper, lead, mercury, zinc, tributyltin, PCBs and PAHs, (USEPA 2005). Between 2004 and 2005, the Port of Seattle dredged a 20-acre (8-ha) area in the East Waterway to remove PCB-contaminated sediment. A remedial investigation/feasibility study will be conducted to determine the need for additional cleanup in the East Waterway. Several contaminated areas in the West Waterway were dredged and capped by Lockheed Martin and Todd Shipyards between 2003 and 2005. EPA has determined that no additional cleanup is necessary in the West Waterway (USEPA 2005).

6.3.3 Shoreline and Aquatic Habitat

Lingering effects of more than a century of development combined with ongoing activities have affected the aquatic habitat of the Lower Green/Duwamish action area. The ongoing activities include expanding urbanization, railroads, shipping, logging, agriculture, and other industries. The effects of those activities are industrial waste discharge, stormwater runoff from impervious surfaces, freshwater diversions for industrial and domestic use, and flood control (Howard Hanson Dam, RM 64, and numerous levees).

Development began to affect the Lower Duwamish River in the early 1900s. The Cedar River historically flowed into the Black River, then into the Duwamish River and into Elliott Bay. In 1916, the Cedar River was diverted into Lake Washington and the Black River ceased to exist (except as a small tributary to the Duwamish River). The White River, which historically flowed into the Green River, was diverted into the Puyallup River in 1906. The diversion of these rivers reduced the Duwamish/Green drainage basin by 75% and its average flow up to 81%. At about the same time, the lower river was dredged to create the Duwamish Waterway, replacing 9 meandering miles (14.4 km) of river with a straight, deep, 5.3-mile-long (8.5 km) navigation channel (City of Seattle 2003).

The Duwamish estuary is characterized by industrial development (43%) and residential development (39%). In the lower portion of the estuary, the loss of estuarine and riparian habitat has been extensive (Kerwin and Nelson 2000). The estuary shoreline has been dramatically altered: 21,000 feet (6,400 m) have been lost due to straightening of the channel and 53,000 feet (16,154 m) have been filled and developed. Only 19,000 feet (5,791 m) of vegetated riparian shoreline remain. The once extensive 3,850 acres (1,558 ha) of tidal mudflats, marshes, and swamps have been reduced to only 45 acres (18 ha). Ninety-seven percent of the estuary has been filled.

Between the mouth and RM 6.0 (just upstream from Turning Basin No. 3 at the south end of the Duwamish Waterway), 55% of the shoreline is riprapped with asphalt, boulders, or cobbles; 20% is bulkheads, and 7% is faced with vertical sheet piling (TerraLogic and Landau 2004). Furthermore, a considerable portion of the remaining intertidal and shallow subtidal portions of the lower Duwamish Waterway is covered by barges (Muckleshoot Indian Tribe Fisheries Division [MITFD] unpub. data). The effects of eliminating natural shorelines were compounded by the filling of marshes and mudflats, the creation of steep bulkhead and riprap banks, the removal of vegetation, and the construction of buildings, piers, and impervious pavement. Altogether, these actions eliminated about 98% of the Lower Duwamish River's emergent marshes and intertidal mudflats and 100% of its tidal swamps (Blomberg *et al.* 1988). The surviving highly modified habitats generally provide poor habitat for juvenile salmon (Spence *et al.* 1996).

Estuaries provide essential habitat where salmon undergo osmoregulatory transitions when initially entering saltwater as juveniles and entering freshwater as adults. Estuaries also provide important foraging areas where growth may be rapid before entering the ocean and encountering new and abundant predators. In estuaries, juveniles typically utilize low velocity habitats, such as braided channels and tidal sloughs. In the Duwamish estuary, the historical migration routes of anadromous salmonids into off-channel distributary channels and sloughs have largely been eliminated.

Evidence indicates that the primary area used by juvenile salmon in the Duwamish for transitioning from freshwater to saltwater has shifted upstream (in response to dredging and channel modifications) to approximately RM 4.7 to RM 6.5. This is the primary reach where freshwater initially mixes with saltwater and where eddies provide low velocity rearing habitats. Salmon densities (all species) are relatively high in this area (Nelson et al. 2004, Ruggerone *et al.* 2006).

In the Lower Duwamish estuary, the banks have been straightened, steepened, hardened, and denuded of riparian vegetation. Warner and Fritz (1995) found the greatest abundance of juvenile salmon using shallow, sloping, soft mud beaches compared with sites having sand, gravel, or cobble substrates. The Kellogg Island area, located one mile upstream of the river mouth, has remnant intertidal shallows (Terminal 107 and Kellogg Island Reserve), restored upper intertidal habitats (Herring House Park), and relatively large riparian zones that provide insect prey for juvenile salmon. This area provides the majority of the remaining intertidal wetlands in the Duwamish estuary (Simenstad *et al.* 1991).

Research indicates that densities of juvenile Chinook salmon are lower at Kellogg Island compared with those near RM 4.7 to RM 6.5. Although restored habitats near Kellogg Island provide important salmon habitat, it appears salmon spend less time in this area compared with areas near Turning Basin No. 3. It is probable the high densities of juvenile salmon shifted upstream to the new freshwater/saltwater transition zone after initial dredging of the Duwamish Waterway. Mark and recapture studies in restored off-channel habitats, such as Herrings House near Kellogg Island, indicated only a small fraction of the Chinook population utilized these habitats because the areas are small and because fish entered the habitat for only one high tide, on average (Ruggerone and Jeanes 2004).

Chemical contamination of sediments in certain areas of the Duwamish River has compromised the effectiveness of the small amount of remaining habitat (USEPA 2002). Chemicals of concern found at elevated concentrations included PAHs, PCBs, metals (arsenic, mercury and zinc), phthalates, phenols, and pesticides (DDT, DDE, DDD). Varanasi et al. (1993) found juvenile Chinook salmon from the Duwamish Waterway displayed a lower immune system response compared with juvenile Chinook salmon from the Nisqually River, a comparable estuary without significant industrial contaminants. However, other studies suggested PCBs and PAHs in diets likely to occur in the Duwamish may not adversely affect the immune system of Chinook salmon (Powell *et al.* 2003, Palm et al. 2003). In 2002, residence time of natural Chinook salmon in the Duwamish estuary declined steadily from approximately 28 ± 7 days in late May to 20 ± 7 days in early June to 15 ± 3 days in late June (Ruggerone and Volk 2004). Residence time data provide new information on the potential exposure of juvenile salmon to contaminated prey. There is concern that contaminants could bioaccumulate to levels that may affect the ability of the individual salmon to grow and mature properly (NOAA Fisheries 2002).

6.3.4 Habitat Access: Barriers

There are no barriers that block the migration of salmonids in the Duwamish estuary. Large docks and other large overwater structures may inhibit juvenile salmonids migrating along shallow-water habitats of Puget Sound. Changes in the migration route of salmonids in response to overwater structures may increase their susceptibility to predation if the new pathway leads the salmonids to areas frequented by predators (Simenstad *et al.* 1982).

6.3.5 Non-Native and Predator Fish

Most of the fish predators (smallmouth and largemouth bass) found in freshwater systems such as Lake Washington are not present in the Duwamish estuary. Predators in the Duwamish estuary may include river lamprey, juvenile coho salmon, yearling and older Chinook salmon, bull trout, sculpins, and avian species including great blue heron, western grebe, merganser, cormorant, pigeon guillemot, and kingfisher. River lamprey may be a significant predator on juvenile Chinook salmon with 7% of juveniles observed showing lamprey marks (Salo 1969). Lamprey marks have also been observed on salmon in recent years (Ruggerone et al. 2004). Specific studies of river lamprey predation on juvenile Chinook have not been conducted in the Duwamish estuary, but Beamish and Neville (1995) estimated that lamprey were killing 25% to 65% of the young Chinook and coho migrating out of the Fraser River.

Although the Duwamish estuary contains many overwater structures and piers, fish predators are rarely present under these piers (Weitkamp and Farley 1976, Weitkamp and Katz 1976, Weitkamp 1982, Ratte 1985, Williams and Weitkamp 1991). Insufficient information is available to determine what effect other predators may have on juvenile salmonid survival in the estuary (Weitkamp *et al.* 2000). However, few salmon predators have been captured by beach seine in the estuary during winter through summer and by purse seine during winter (Nelson et al. 2004, SAIC *et al.* 2005, Ruggerone *et al.* 2006).

6.3.6 Longfellow Creek (Lower Green/Duwamish Action Area)

Seattle's second largest creek, Longfellow, is located in the Delridge Valley in West Seattle (Figure 9). It is a tributary of the West Waterway of the Duwamish River and drains about 1,667 acres (679 ha) of mainly residential property (31%) and roadways (22%), with small amounts of commercial (13%) and industrial (8%) property. About 16% of the watershed is contained in parks and open space. Overall, 52% of the watershed is covered by impervious surfaces. Almost the entire Longfellow Creek watershed (99%) drains to a formal drainage system.

Longfellow creek is about 4.7 miles (7.6 km) long from the headwaters and consists of roughly 3 miles (4.7 km) of open channel, although the lower 0.6 mile (1 km) of the creek is piped. The headwaters of the creek originate at underground springs and travel 1 mile (1.6 km) before reaching the open channel of the creek. The headwaters were once a natural wetland and peat bog at the southern city limits, and are now contained in Roxhill Park and the adjacent retail development. Over 40% of the open channel portion of Longfellow Creek is located on park property, most of which is occupied by the West Seattle Golf Course. The remaining 60% flows through private property. Much of the riparian corridor has been developed. As a result, little of the native vegetation remains along a significant portion of the creek.

Figure 9. Longfellow Creek Watershed

6.3.6.1 Water Quality

Sixty-four storm drains discharge stormwater runoff directly to Longfellow Creek. Three other outfalls infrequently deliver combined sewer overflows to the watercourse. On average four CSO events occur per year (range 0 to 11).

Longfellow Creek is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies. The 303(d) listings are summarized in Table 6-13.

Table 6-13

Summary of 303(d) listings for Longfellow Creek

	Category	
Media	**2**[1]	**5**[2]
Water	Temperature Dissolved oxygen	Fecal coliform bacteria Dissolved oxygen

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant.

Source: Ecology 2008

King County has been collecting monthly samples in Longfellow Creek (at SW Yancy St and SW Brandon St) since about 1979. Samples are analyzed for conventional water quality indicators (temperature, dissolved oxygen, fecal coliform bacteria, pH, total suspended solids, and turbidity), metals, and nutrients. Summary statistics for conventional water quality parameters from monthly samples collected by King County (undated) between 1979 and 2005 are presented in Table 6-14. As shown in Figure 10, dissolved oxygen and temperature typically exhibit a seasonal trend with higher temperatures and lower dissolved oxygen concentrations in the warm summer months. Longfellow Creek frequently does not meet state water quality standards for temperature and dissolved oxygen during the summer months. Temperature and dissolved oxygen excursions are probably related to the lack of riparian vegetation throughout most its length. Large sections of Longfellow Creek pass through private property; consequently the riparian zones are largely unprotected.

Longfellow Creek also frequently exceeds state water quality standards for fecal coliform throughout the year. Over the past ten years, annual geometric mean levels (98 to 1,124 cfu/100 mL) exceeded the standard for primary contact recreation (100 cfu/100 mL) in all but 2005 at SW Yancy St, and 8% to 92% of the samples exceeded 200 cfu/100 mL. The 200 cfu/100 mL standard, which is allowed in no more than 10% of the samples, was met only once, at SW Yancy St in 2005. Seattle Public Utilities has been collecting two to three stormwater samples per year from Longfellow Creek since 1999. Stormwater samples generally contain higher levels of fecal coliform bacteria than do non-stormwater samples. The geometric mean for non-storm samples ranged from 100 to 1,100 cfu/100 mL compared with 2,900 to 5,200 cfu/100 mL in the stormwater samples.

Table 6-14

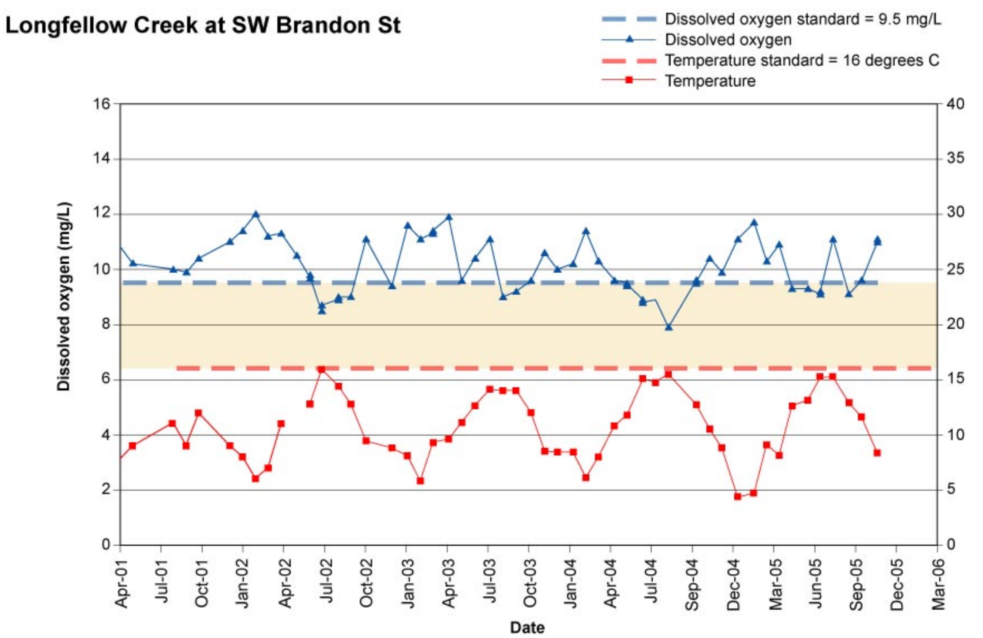
Summary statistics for conventional water quality parameters in Longfellow Creek

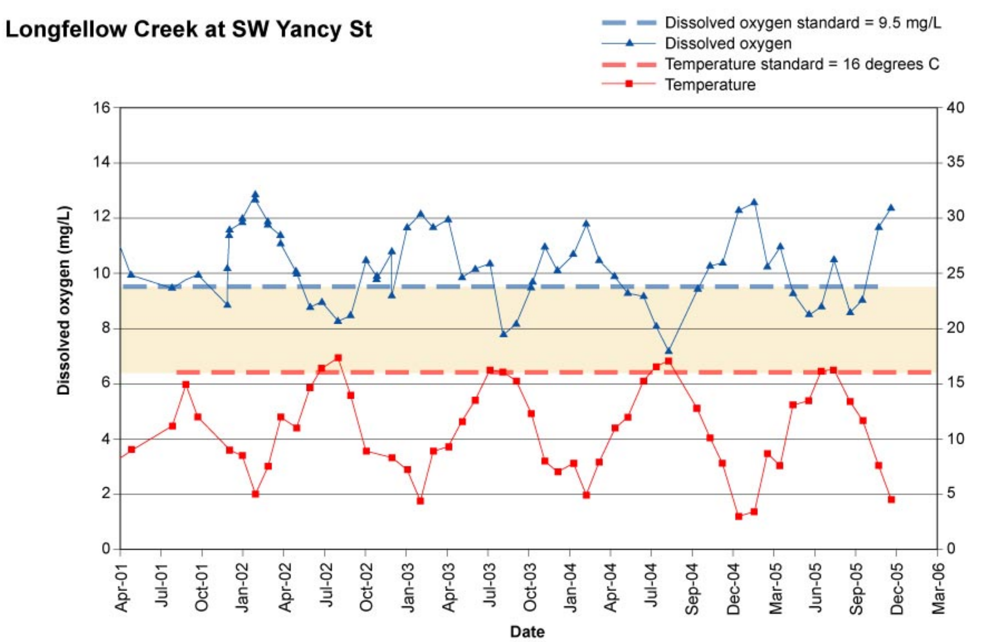
	DO (mg/L)	Temp. (degrees C)	Fecal coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
Longfellow Creek at SW Yancy St (C370)						
No. of samples	217	197	214	215	182	221
Minimum	7.1	1.2	9	6.3	0.3	0.5
Maximum	15.0	20.2	25,000	9.4	463	160
Median	10.6	11.0	350	7.8	3.5	3.8
Mean	10.6	11.1	1,258	7.7	12.5	9.8
5th percentile	8.6	5.0	46	7.0	1.1	1.5
95th percentile	13.0	17.0	6,000	8.5	33.8	41
Longfellow Creek at SW Brandon St (J370)						
No. of samples	168	158	168	165	139	170
Minimum	6.5	3.0	10	5.2	0.5	0.5
Maximum	14	19.2	39,000	8.9	203	93
Median	10.2	10.9	410	7.7	2.1	2.5
Mean	10.2	11.0	1,346	7.6	7.2	5.7
5th percentile	8.7	6.0	59.05	6.9	0.8	1.0
95th percentile	12	16.0	6,000	8.2	20.1	20

Source: Reference Stations C370 and J370. King County (undated)

Figure 10

Dissolved oxygen and temperature in Longfellow Creek





Reference: Stations C370 and J370. King County (undated).
Note: The areas between the two dashed lines show the samples that do not meet state water quality standards.

Nutrient levels in Longfellow Creek are generally high and exceed recommended water quality criteria. For example, total phosphorus concentrations in Longfellow Creek (5 to 970 µg/L in non-storm samples and 91 to 670 µg/L in stormwater samples) frequently exceed the U.S. EPA water quality criterion (100 µg/L), which establishes a desired goal for the prevention of nuisance plant/algal growth in streams or other flowing waters not discharging directly to lakes or impoundments (USEPA 1976). In addition, total nitrogen concentrations in Longfellow Creek (170-3,250 µg/L) frequently exceed U.S. EPA (2000) recommended criterion for streams in the western United States (340 µg/L for Ecoregion II). These criteria represent conditions in surface waters that are minimally impacted by human activities and are designed to prevent eutrophication and water quality problems associated with nutrient enrichment.

Concentrations of toxic materials in Longfellow Creek are generally low. Ammonia-nitrogen levels exceeded state water quality standards in only 1% of the samples collected since 1979. For metals, only dissolved copper exceeded the state water quality standards (in two stormwater samples collected by Seattle Public Utilities in 2004).

The USGS has also found low levels of some pesticides in stormwater collected from Longfellow Creek during a May 14, 1998 storm (Voss and Embrey 2000). Three stormwater samples collected during the rising limb of the storm contained detectable levels (0.03-0.35 µg/L) of several herbicides and their metabolites (2,4-D, acetochlor, dicamba, dichlobenil, dichlorprop, MCPA [4-chloro-2-methylphenoxyacetic acid.], mecoprop, pentachlorophenol, prometon, and trichlorpyr) and 1 insecticide (diazinon at 0.046 µg/L) and 1 insecticide metabolite (4-nitrophenol at 0.05-0.12 µg/L). With the exception of diazinon, concentrations were below reported toxic effects levels for aquatic organisms.

To support an ongoing NOAA coho prespawn mortality investigation, the USGS and Seattle Public Utilities collected time-weighted composites (1-hour composites composed of 15-minute grab samples) from Longfellow Creek (between SW Alaska St and SW Genesee St) during three storms in October and November 2003 (SPU unpub. data). A total of 16 stormwater samples were analyzed for semi-volatile organic compounds. In addition, one sample was analyzed for pesticides and PCBs. Bis(2-ethylhexyl)phthalate—a plasticizer used in polyvinyl chloride (PVC) resins to fabricate flexible vinyl products such as upholstery, tubing, and gloves, as well as paper and paperboard, defoaming agents, adhesives, and lubricants—was detected most frequently (100% of the samples), followed by pentachlorophenol (88%), phenol (88%), benzyl alcohol (75%), benzoic acid (62%), and PAHs (6-50%).

Water quality is being investigated as a potential contributor to the unusually high rates of coho salmon pre-spawn mortalities reported in urban creeks in the Puget Sound since 1999 (Reed et al. 2003). Between 1999 and 2005, pre-spawning mortality rates in Longfellow Creek averaged 71% (McMillan 2006, SPU unpub. data). Water and sediment quality is still being investigated as a potential factor related to this pre-spawning mortality. Conventional water quality parameters (e.g., temperature and dissolved oxygen) and disease do not appear to be causal. Rather, the weight of evidence suggests that adult coho—which enter small urban streams following fall storm events—are acutely sensitive to non-point source stormwater runoff (Scholtz 2006, S. McCarthy, NMFS, pers. comm. 2006). No sediment quality data have been collected at this time. Pre-spawn mortality surveys were stopped in 2010 to analyze and publish the data and to define a path to move forward with the pre-spawn mortality issue and to pinpoint the causal factors (Davis, J. USFWS pers. comm. 2011).

6.3.6.2 Shoreline and Aquatic Habitat

Factors limiting aquatic habitat within Longfellow Creek include alterations to the stream hydrology, reduced floodplain connectivity, lack of longitudinal connectivity, lack of gravel recruitment and retention, abundance of fine sediment, lack of channel complexity, and reduced riparian vegetation.

Longfellow Creek habitat is severely degraded by substantial hydrological alterations. The narrow, straight, elongated shape of the basin requires much of the Longfellow Creek's flow energy to be dissipated within the channel. Creek conditions are also affected by reduced connectivity between the stream and its floodplain. Encroachment and confinement of the channel migration zone through armoring is a major change in the Longfellow watershed. More than 40% of the channel has been piped including the lower 3,258 feet (993 m), and the upper mile of former plateau wetlands. Buildings, roads, yards, and armoring (23% of open channel) confine much of the remaining open channel. In contrast to stream widths that average 12 feet (3.6 m), unconfined sections in the golf course canyon reach an average of 19 feet (5.8 m) and are as wide as 30 feet (9.1 m) within the channel. When in-channel wetlands are included, these areas can have channel widths up to 100 feet (30 m).

Longfellow Creek largely contains poor habitat. In most areas, the creek channel is incised, riprapped, concrete, and featureless, with a plane-bed channel dominated by glide habitat. The creek has bank and streambed erosion problems especially in the upper reaches. As a result of the lack of land-water connectivity, Longfellow Creek does not contain much instream structure. The limited pool habitat (18% of open channel length) and pockets of gravel are usually associated with structures placed in the creek during improvement projects. Most of the confined, incised sections of Longfellow Creek do not have sufficient channel capacity to add structure due to flooding and bank erosion problems. Many of the confined incised sections have been restored and improvements have been made to sections along the golf course.

The lack of floodplain connectivity also limits gravel recruitment and retention. As a result, the creek has thin to nonexistent channel substrates throughout most of the open channel area. Isolated pockets of gravel-dominated substrate are found primarily in the golf course and in restored areas. While coarse sediment is typically supplied by erosion of the bed and banks, floodplain sources have been cut off from Longfellow Creek channel by armoring and encroachment. In addition, the Longfellow Creek channel is dominated by loose sand and silt. This is mostly due to bank erosion and limited landslides in areas with fine sediment (sand and silt).

Development near the stream has degraded the riparian zone around Longfellow Creek. Only a few short reaches of the stream, outside of the golf course, have good riparian areas. These areas are located in parks. The golf course has the best riparian corridor along the stream averaging 100 feet in width. Two fairways crossing the creek break-up the continuous riparian corridor. Yard encroachment in some areas has reduced canopy cover, allowing creek temperatures to increase. Invasive species can also be found along sizeable portions of the creek. There have been some restored areas where planting has occurred and although the vegetation is becoming established, monitoring and maintenance would be useful. Sections of the creek in the golf course offer good canopy cover (shade), but lack diversity, especially mature native conifers.

Fish Use

Historically, Longfellow Creek contained coho salmon, sea-run cutthroat trout and steelhead. Both cutthroat and steelhead are now absent from the creek. A variety of fish continue to use the creek, most commonly coho and chum salmon and resident rainbow trout. Prickly sculpin, Pacific staghorn sculpin, and three-spine stickleback are also found in the creek. Chinook salmon have been found in Longfellow Creek in 2001 and 2003 (Shapiro 2001; City of Seattle 2007, Tabor *et al* 2010).

Longfellow Creek has the largest coho salmon run in the city. On average, 141 coho carcasses (range 32 – 277) have been found in Longfellow Creek between 1999 and 2005 (City of Seattle 2007). It is estimated that over 400 adult coho may use Longfellow Creek. An average of 17 chum carcasses (range 0 -67) have been found. Smolt traps within Longfellow Creek show indicate low production of coho salmon possibly due to poor rearing habitat, lack of pools, low spawning success as a result of redd superimposition, or coho prespawn mortality.

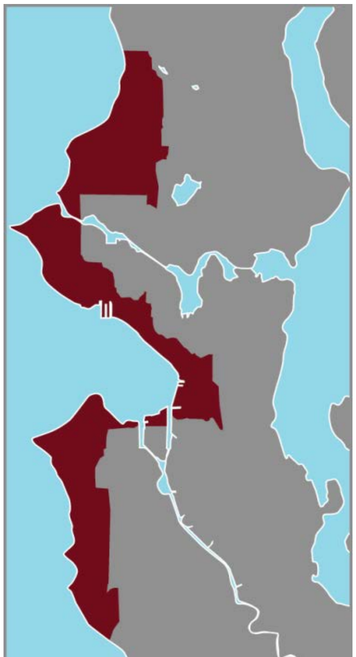
Spawning for anadromous salmon is limited to 15% of the open-channel due to manmade barriers. The lowest downstream barrier is located at a dam and culvert at the 12th fairway of the West Seattle golf course. Approximately 1,900 feet of open channel is available for spawning and rearing. Barriers within Longfellow Creek may also limit resident rainbow trout distribution. The farthest upstream point at which rainbow trout have been recorded is at 25th Ave SW.

6.3.6.3 Habitat Access Barriers

Longfellow Creek has substantial fish passage barriers. The downstream-most fish passage barrier, located in the golf course at the 12th Fairway culvert, restricts anadromous fish to the lower 2,400 feet (731 m) of open channel. The need for additional habitat is indicated by both adult and juvenile salmon use of the stream. Superimposition of salmon redds suggests that there may not be sufficient spawning habitat (< 800 feet [243 m]) available for the existing fish (maximum entry was an estimated 600 coho and 90 chum in 2001), despite an average 71% pre-spawning mortality of coho (McMillan 2006, SPU unpub. data). Low numbers of outmigrating coho smolts (fewer than 1 fish/day) and the absence of juvenile salmonids (coho, rainbow trout) recorded during surveys may indicate a lack of adequate rearing habitat, as well as the effects of pre-spawning mortality. Barriers at the upstream end of the golf course and at Juneau Street are the remaining barriers blocking most of the remaining open channel habitat in Longfellow Creek.

6.4 North Seattle/Puget Sound, Elliott Bay, and South Seattle/Puget Sound Action Areas

Seattle's marine nearshore area extends from North 145th Street south to Seola Creek in West Seattle and includes 29.5 miles (47.5 km) of Puget Sound shoreline. This section of the Puget Sound shoreline has been grouped for this document as the North Seattle Puget Sound, Elliott Bay, and South Seattle Puget Sound action areas.



North Seattle/Puget Sound, Elliot Bay, and South Seattle/ Puget Sound Action Areas

The nearshore environment in Seattle includes areas within both WRIA 8 and WRIA 9. About 8 miles (12.8 km) of shoreline is within Elliott Bay and 2.5 (4 km) miles of shoreline is within Shilshole Bay. The nearshore has one of the highest degrees of shoreline modification in Puget Sound at over 80% (Kerwin and Nelson 2000). Most shoreline modification such as seawalls and bulkheads were placed to protect residential development from erosion or to support the railroad.

The mile-long, 300-feet-wide (91-m) estuary west of the Locks serves as the 'estuarine' area with the Locks creating an abrupt transition between fresh and saltwater (Kerwin 2001). The estuarine area of the canal downstream of the Locks is dredged to an authorized depth of 34 feet (10.3 m) MLLW and has a maximum tidal range of 19.3 feet (5.8 m). This area lacks the diversity of habitats and brackish water refuges characteristic of estuarine habitat. This area has experienced substantial bank armoring, which has reduced the quantity and quality of shallow intertidal habitat. A marina was constructed by the Port of Seattle, just north of Shilshole Bay and south of Golden Gardens Park. Construction of the marina, known as the Shilshole Bay Marina, consisted of a large breakwater jetty, dredging, and shoreline filling/armoring, which has resulted in the loss of both subtidal and intertidal habitats. The most 'natural' shoreline areas are found adjacent to the cliffs and bluffs in Discovery Park and within the sand beach areas of Golden Gardens Park (Williams *et al.* 2001).

The nearshore environment in Puget Sound possesses an extremely productive and dynamic ecosystem. Tides, currents, wave action, and intermixing of saltwater with freshwater create a complex physical environment situated at the juncture between land and water. The marine nearshore environment encompasses the area from upland bluffs, banks, and beaches, and the lower limit of the photic (light penetration) zone, which varies with season and climatic conditions. Some define the lower limit of the photic zone at about 100 feet (30 m) below the MLLW line. The nearshore area includes a wide variety of upland, marine, and estuary habitats including marine riparian areas, backshore areas, beaches, tidal marshes, tidal flats, eelgrass meadows, kelp forests, and exposed habitats. Terrestrial habitats along the shoreline such as bluffs, sand spits, and coastal wetlands are also included within the nearshore environment, as well as the tidally-influenced region found within the lower sections of mainstem rivers and coastal streams.

The Puget Sound marine waters offshore of Seattle receive runoff from about 9,900 acres (4006 ha) in north, central, and south Seattle. Land use in the basin is primarily residential (50%) and roadways (22%), with lesser amounts of industrial (6%), commercial (4%), and open space/vacant land (17%). Drainage conveyance systems in the basin consist mostly of piped networks. Piper's Creek and Fauntleroy Creek (discussed below) are the only significant open channel systems in the basin.

Twenty-five streams are located within the North Seattle/Puget Sound (12 streams), Elliott Bay (7 streams) and South Seattle/Puget Sound (6 streams) action areas. Piper's Creek (North Seattle/Puget Sound) and Fauntleroy Creek (South Seattle/Puget Sound) are described below. Table 6-15 identifies the location of the other streams and any fish species found within the creek (Tabor *et al* 2006).

Table 6-15
Smaller streams and fish present within the North Seattle/Puget Sound, Elliott Bay, and South Seattle/Puget Sound action areas.

Stream	Action Area	Fish Species Present
Unnamed PS01	North Seattle/Puget Sound	None
Unnamed PS02	North Seattle/Puget Sound	Not accessible
Unnamed PS03	North Seattle/Puget Sound	Not accessible
Broadview Creek	North Seattle/Puget Sound	None
Unnamed PS04	North Seattle/Puget Sound	Not accessible
Unnamed PS05	North Seattle/Puget Sound	Not accessible
Unnamed PS06	North Seattle/Puget Sound	None
Unnamed PS07	North Seattle/Puget Sound	None
Unnamed PS08	North Seattle/Puget Sound	None
Unnamed PS09	North Seattle/Puget Sound	Not accessible
Unnamed PS10, 11, 13, 14	North Seattle/Puget Sound	None
Scheuerman Creek	Elliott Bay	Threespine stickleback
Owls Creek	Elliott Bay	None
Unnamed PS18	Elliott Bay	Not accessible
Unnamed PS19	Elliott Bay	Not accessible
Unnamed PS20	Elliott Bay	Not accessible
Unnamed PS21	Elliott Bay	None
Fairmont Creek	Elliott Bay	None
Schmitz Creek	Elliott Bay	None
Mee-kwa-mooks Creek	South Seattle/Puget Sound	None
Pelly Creek	South Seattle/Puget Sound	None
Unnamed PS22	South Seattle/Puget Sound	Dry
Seola Creek	South Seattle/Puget Sound	Dry

6.4.1 Water Quality

Water quality in Puget Sound is affected by many factors, including human activities and ocean currents, as well as physical, chemical, and biological processes. The average tidal range in Puget Sound is 12 to 14 feet (3.7-4.3 m), with an average volume exchange of 8 billion cubic meters per tidal cycle (King County 1994). This relatively high water exchange is a key factor in maintaining good water quality conditions in the offshore areas (Stark et al. 2005). However, nearshore conditions are affected by human activities such as land use, municipal wastewater discharges, combined sewer overflows, storm drain discharges, and shoreline erosion. Because many contaminants present in these discharges tend to adsorb particulate material, the sediment deposited in nearshore areas tends to accumulate contaminants.

Between 1994 and 2003, water temperatures in offshore areas ranged from about 44.6° to 61.8° F (7.0-16.6° C) (as measured at mid-sound stations KSBP01 and LSNT01, located near the northern border of King County and offshore of the Fauntleroy area in Seattle, Stark *et al.* 2005). Average temperatures ranged from 49.6° to 53.8° F (9.8-11.6° C). In general, the offshore areas are well mixed throughout most of the year, with a thermocline developing during the summer months. Higher temperatures generally occur during the summer season along the shallow beach areas. Temperatures at beach stations between 2001 and 2003 ranged from 43.7° to 67.1° F (6.5-19.5° C) (King County 2002, Stark *et al.* 2005).

Salinity varies seasonally, with the lowest measurements generally occurring during the winter and spring months due to contributions from freshwater sources and the highest levels occurring from August to December, which is believed to result from upwelling of saltier deep Pacific water along the outer coast (Stark *et al.* 2005). Salinity ranged from about 22 to 32 on the practical salinity scale (PSS) at the two offshore stations, KSBPO1 and LSNT01 between 1994 and 2003. Lower surface salinities have been recorded in Elliott Bay due to the large freshwater contributions from the Duwamish River (Stark *et al.* 2005).

Dissolved oxygen levels in Puget Sound have remained fairly consistent (Stark *et al.* 2005). Concentrations at all offshore stations and depths ranged from 4.5 to 14.1 mg/L between 2001 and 2003. Dissolved oxygen generally declines with depth up to about 164 feet (50 m) and then remains relatively constant. Average concentrations range from 8.7 to 9.07 mg/L in surface samples and from 6.57 to 6.95 mg/L at a depth of 656 feet (200 m) (Stark et al. 2005, King County 2002). Dissolved oxygen drops below the state water quality standard for marine waters (7 mg/L) in deep water during the late summer and fall due to seasonal influx of deep oceanic water, which contains lower oxygen. Water column stratification, which impedes vertical mixing with oxygenated water from the surface, helps to sustain the low dissolved oxygen concentrations at depth (Stark et al. 2005). Between 2001 and 2003, dissolved oxygen concentrations rarely fell below 5.0 mg/L, the upper limit for biological stress (NOAA 1998). Concentrations below 5.0 mg/L occurred at both outfall and mid-sound stations and occurred at depths greater than 164 feet (50 m) (Stark *et al.* 2005).

Offshore sampling stations generally meet the state water quality standards for fecal coliform bacteria. However, nearshore samples collected along the shoreline frequently exceed the standards. The marine standard for primary contact recreation allows a geometric mean number of no more than 14 cfu/100 mL, with no more than 10% of the samples exceeding 43 cfu/100 mL (Ecology 2004). In 2002 to 2003, all offshore stations met the standard (Stark et al. 2005). However, in 2001, two of three stations located in Elliott Bay met the geometric standard, but did not meet the peak standard (in 4 of 30 samples) and one station exceeded both the geometric mean and the peak standard (in 9 of 30 samples) (King County 2002). Samples collected at the following stations consistently fail the fecal coliform standards:

- Carkeek Park and mouth of Piper's Creek
- Shilshole Bay
- Magnolia beach
- Near the mouth of the Lake Washington Ship Canal
- Inner Elliott Bay
- Fauntleroy Cove.

Fecal coliform data collected by King County from 2001 to 2003 are summarized in Table 6-16 (King County 2002, Stark *et al.* 2005).

Table 6-16

Summary of compliance with state marine water quality standards for fecal coliform bacteria at beach stations

		2001		**2002**		**2003**	
Location	Station No.	Geomean	Peak	Geomean	Peak	Geomean	Peak
Piper's Creek	KTHA01	No	No	Yes	No	Yes	No
Golden Gardens	KSLU03	No	No	No 7/12	No	Yes	Yes
Shilshole Bay	KSQU01	No	No	No 12/12	No	No 12/12	No
Magnolia	KSYV02	No	No	No 5/12	No	No 4/12	No
Inner Elliott Bay	LTEH02	No	No	No 12/12	No	No 12/12	No
Inner Elliott Bay	LTAB01	Yes	No	Yes	Yes	Yes	No
Seacrest	LSFX01	Yes	Yes	Yes	Yes	Yes	Yes

		2001		2002		2003	
Duwamish Head	LSGY01	Yes	Yes	Yes	Yes	Yes	Yes
West Seattle	LSHV01	Yes	Yes	Yes	Yes	Yes	Yes
Lincoln Park	LSTU01	Yes	Yes	Yes	Yes	Yes	Yes
Fauntleroy Cover	LSVW01	No	No	No 12/12	No	No 7/12	No

Yes = Samples meet state water quality standards

No = Samples exceed state water quality standards

For non-compliance, ratio indicates the numbers of exceedances

Metals—both dissolved and total forms—are frequently detected in Puget Sound water samples, but concentrations are generally low. All of the samples collected by King County in 2001 and 2002 from seven Seattle area beach sites (Carkeek Park, Golden Gardens, Shilshole Bay, West Point—north and south beach, Alki Point, and Normandy Park) were below the acute and chronic toxicity criteria for dissolved metals (Stark *et al.* 2005, King County 2002). King County stopped sampling for metals after 2002.

Puget Sound/Elliott Bay is on the 2004 Ecology 303(d) list of threatened and impaired waterbodies for water and sediment. The 303(d) listings are summarized in Table 6-17.

Table 6-17

Summary of 303(d) listings for Puget Sound/Elliott Bay

	Category		
Media	2[1]	4B[2]	5[3]
Water	Fecal Coliform Bacteria Endosulfan Dissolved Oxygen		Fecal Coliform Bacteria
Sediment	1,2,4-Trichlorobenzene 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dimethylphenol 2-Methylphenol	1,2,4-Trichlorobenzene 1,2-Dichlorobenzene 1,4-Dichlorobenzene 2,4-Dimethylphenol 2-Methylnaphthalene	Sediment Bioassay

	4-Methylphenol Acenaphthylene Benzo[ghi]perylene Benzyl Alcohol Bis(2-ethylhexyl) phthalate Butylbenzylphthalate Butylbenzylphthalate Dibenzo[a,h]anthracene Diethyl phthalate Dimethyl phthalate Hexachlorobenzene Hexachlorobutadiene Mercury N-Nitrosodiphenylamine Pentachlorophenol Sediment Bioassay	2-Methylphenol Acenaphthene Acenaphthylene Anthracene Arsenic Benzo[a]anthracene Benzo[a]pyrene Benzo[ghi]perylene Benzofluoranthenes Total (b+k+j) Bis(2-ethylhexyl) phthalate Butylbenzylphthalate Cadmium Chromium Chrysene Copper Dibenzo[a,h]anthracene Dibenzofuran Dibutyl phthalate Diethyl phthalate Di-N-Octyl Phthalate Fluoranthene Fluorene Hexachlorobenzene Hexachlorobutadiene High molecular weight polycyclic aromatic hydrocarbons (HPAH) Indeno(1,2,3-cd)pyrene Lead Low molecular weight polycyclic aromatic hydrocarbons (LPAH) Mercury Naphthalene N-Nitrosodiphenylamine	

		Pentachlorophenol Phenanthrene Phenol Pyrene Silver Total PCBs Zinc	
[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired. [2]Water body has a pollution control program in place that is expected to solve the pollution problem. The water body is still impaired, but the pollutant is being addressed. [3]Water body has violated water quality standards and no TMDL or pollution control program has been developed for the pollutant. Source: Ecology 2008			

6.4.2 Sediment Quality

Sediment contamination in Puget Sound offshore of Seattle appears to be limited to a few hotspot areas associated with waterfront activities and/or site-specific discharges, such as combined sewer overflows and/or stormdrain outfalls. Data from King County's marine monitoring program for 2001 to 2003 indicate that concentrations of metals and organic contaminants were well below the Washington state sediment management standards at all stations. Sample locations are summarized in Table 6-18.

Specific areas where sediment contamination has been reported include the sediment offshore of the northwest corner of Harbor Island and at various locations along the Seattle waterfront (PTI and Tetra Tech 1989, USEPA 2005). In 1983, the EPA listed the marine sediments offshore of Harbor Island as part of a Superfund site, due to elevated concentrations of arsenic, copper, lead, mercury, zinc, tributyltin, PCBs, and PAHs (USEPA 2005). Todd Shipyard dredged and capped an area of about 38.9 acres (15.7 ha) on the north side of Harbor Island, removing about 166,000 cubic yards of sediment and 2,700 creosote-treated timber piles. Work was completed in 2005.

Table 6-18

King County marine sediment monitoring locations in Puget Sound offshore of Seattle

Location	2001	2002	2003
West Point—north beach	√		
Alki beach near CSO storage and treatment facility	√		
Alki offshore of CSO storage and treatment facility	√		
Magnolia beach		√	
Elliott Bay—offshore of Denny Way CSO		√	
Elliott Bay—outer		√	
Shilshole Bay		√	
West Seattle		√	
Golden Gardens beach			√
Normandy Park beach		√	√

King County dredged and capped a 3-acre (1.2 ha) site offshore of the Denny Way combined sewer overflow in 1990 to test the feasibility of capping contaminated sediments in Elliott Bay with clean dredged material from the Duwamish River (Brown and Caldwell 1999). Sediments offshore of the Denny Way combined sewer overflow are contaminated with mercury, silver, PAHs, and bis(2-ethylhexyl)phthalate. King County recently completed the Denny combined sewer overflow control project, which includes a large tunnel to store wastewater during large events, a combined sewer overflow treatment facility along Puget Sound, and a new outfall for the Denny Way combined sewer overflow (King County undated). The project is designed to reduce overflows to Puget Sound from 50 events per year to 4 to 20 treated overflows and one untreated overflow per year, which should greatly reduce the potential for sediment offshore of the outfall to become recontaminated.

In 1992, the Corps capped a 4.5-acre (1.8 ha) site offshore of Pier 53-55 along the Seattle waterfront to contain elevated levels of cadmium, mercury, silver, and organic compounds (Wilson and Romberg 1997). Post-cap monitoring has found that the 3-foot (0.9-m) cap is stable and contaminants are not migrating upwards from the underlying sediments, but elevated concentrations of 4-methylphenol and phenol were found on the surface of the cap in 1996 (Wilson and Romberg 1997).

6.4.3 Shoreline and Aquatic Habitat

The marine nearshore region within central Puget Sound includes several types of distinct habitat areas, including eelgrass meadows, kelp forests, tidal flats, tidal marshes, river and stream mouths and deltas, sand spits, beaches and backshores, high-bank bluffs, and marine riparian zones (Williams *et al.* 2001).

Land use within the nearshore environment in the City of Seattle has greatly modified the aquatic habitat in these action areas (PSWQAT 2000). More than 50% of tidal flats and intertidal areas in major embayments of Puget Sound have been lost since 1850 (PSWQAT 2000). Many estuarine and nearshore areas of Puget Sound have been filled or have had overwater structures installed to provide upland development sites for commercial/industrial and to some extent residential development. Significant portions of nearshore and shoreline habitats have also been altered with vertical or steeply sloping bulkheads and revetments to protect various developments and structures (*e.g.*, railroads, piers) from wave-induced erosion, stabilize banks and bluffs, to retain fill, and to create moorage for vessels (BMSL *et al.* 2001).

It has been estimated that 33% of Puget Sound's shoreline has been modified, with 50% of the main basin of Puget Sound having been altered (PSWQAT 2000). In areas where nearshore habitats currently remain intact or only partially modified, development continues to threaten habitat (WSCC 1999, BMSL *et al.* 2001). Construction of bulkheads and other structures has resulted in habitat loss that has directly affected forage fish for bull trout, salmon, and other piscivorous fish inhabiting Puget Sound.

Bank armoring and inwater structures such as rock jetties and gabions can reduce the mobilization and transport of sediments along the shoreline. The lack of sediment recruitment, and reduced mobilization and deposition along the shore, can result in substantial changes to substrate composition in many marine nearshore and estuary areas. These substrate changes can in turn reduce or eliminate intertidal and subtidal vegetation, including eelgrass beds and kelp forests. However, northern Elliott Bay contains a few areas of intact feeder bluffs that supply sediment to Puget Sound beaches (*e.g.*, Discovery Park). There are additional feeder bluffs near the marina at the south side of Magnolia and along Perkins Lane. These feeder bluffs provide sediment for intertidal and subtidal vegetation including eelgrass beds and kelp forests (City of Seattle 2003). This vegetation provides critical refuge and forage habitat areas for juvenile salmonids, as well as baitfish spawning areas

Factors that have affected the functions of the marine nearshore environment include the loss of habitat within the migratory corridor, degradation of water and sediment quality, alteration of physical processes including bank erosion and alongshore sediment transport and accretion, loss of riparian functions, and introduction of non-native species. Human activities have disrupted the natural processes that create habitat within the nearshore environment. Bank armoring, dredging, filling, and the construction of overwater structures have resulted in direct modification to the nearshore habitat within the Seattle shoreline area.

Although much is known about the importance of riparian areas (transition zones between aquatic habitats and upland areas, such as banks and bluffs) in freshwater systems, relatively little research has been conducted on the functions and values of riparian vegetation in marine systems. Brennan and Culverwell (2004) hypothesize that marine riparian areas provide functions similar to freshwater riparian areas and may provide additional roles unique to marine systems. Riparian corridors provide habitat complexity, predator refuge habitat, food sources in the form of insects dropping into the water and also provide shade to smelt (forage fish) spawning beaches. A loss of riparian vegetation results in a reduction in food resources for salmonids in the nearshore environment. Loss of riparian vegetation along the shoreline may decrease the productivity of deeper water habitats by decreasing detrital inputs. Functional riparian vegetation on Elliott Bay is limited to Magnolia Bluff along the northern shore and represents less than 14% of the bay shoreline. About 3,870 feet (1,179 m) of undeveloped bluff is vegetated with deciduous trees and shrubs. The marine riparian vegetation along the Seattle shoreline consists of 39.5% grass or landscaped areas, 29.1% open area, and 26.5% trees and shrubs. Little marsh habitat exists along the shoreline with only 2.7% of the 29.5 miles (47.4 km) of shoreline having dune grass and other salt-tolerant marsh habitat. Eighty-nine percent of the shoreline is armored, and there are 5.4 million square feet (501,676 sq m) of overwater structures (Anchor Environmental 2004).

Puget Sound nearshore habitats are important for rearing, migration, and growth of juvenile salmon, especially among fish that recently emigrated from rivers (Brennan and Higgins 2004). Juvenile salmonids may be present in nearshore habitats throughout much of the year, although highest densities are likely during late winter to early summer when many juveniles initially enter Puget Sound. Recoveries of coded-wire-tagged salmon demonstrated that salmon from many Puget Sound watersheds utilize nearshore waters adjacent to Seattle (Nelson et al. 2004, Brennan and Higgins 2004). Nearshore habitats provide spawning habitat for forage fish, which are important prey for Chinook salmon and bull trout.

Eelgrass (*Zostera marina L.*) and bull kelp (*Nerocystis luetkeana)* are important in the nearshore ecosystem and provide numerous critical functions including primary production, wave and current energy buffering, and habitat for fish and invertebrates (Williams *et al.* 2001). Studies of primary production indicate that eelgrass productivity can equal or exceed the productivity rates of most other aquatic plants (Thom 1984, Kentula and McIntire 1986, Thom 1990). Limited data show that once eelgrass is established in an area, fish and shellfish increase in the area (Thom *et al.* 1999).

Eelgrass occurs from about +3.28 feet (1 m) to 16.4 feet (5 m) MLLW in the central Puget Sound area (Bulthuis 1994, Thom *et al.* 1998). Kelp grows attached to bedrock or pebble and gravel size substrate in the very low intertidal and shallow subtidal zones. An important factor controlling the distribution of both eelgrass and kelp is desiccation stress (Thom 1978, Thom *et al.* 1998). Eelgrass is found throughout the Seattle shoreline north of the Ship Canal in dense to moderate concentrations. However, eelgrass is not found along the shoreline near Shilshole Marina (King County 2003). Eelgrass along the nearshore of the South Seattle Puget Sound action area is patchy with most eelgrass found around Alki Point and along the northwest shore of the Duwamish Head and categorized as moderately dense to dense (Williams *et al.* 2001). In the North Seattle/Puget Sound action area, kelp occurs along the breakwater of Shilshole Marina and on the north side of West Point. In Elliot Bay, kelp forests are found along 5,577 feet (1,700 m) of shoreline. Kelp was found near the Duwamish Head, along the lower end of Magnolia Bluff, and in patchy locations between Pier 91 and Alki Point (Williams *et al.* 2001).

6.4.3.1 Underwater Sound

High underwater sound levels can have negative physiological and neurological effects on a wide variety of vertebrate species including fishes and birds (Cudahy and Ellison 2002; Fothergill *et al.* 2001; Steevens *et al.* 1999; U.S. Department of Defense 2002; Yelverton and Richmond 1981; Yelverton *et al* 1973). High sound levels can injure or kill fishes, while lower sound levels can cause behavioral changes (Hastings and Popper 2005; Popper 2003; Turnpenny and Nedwell 1994; Turnpenny *et al.* 1994).

Sound pressure levels greater than 180 dB_{peak} can cause injury and mortality to murrelets and listed fish species. Behavioral changes that can affect feeding and migration can occur at sound pressure levels of 150 dB_{rms}. Many factors, such as duration of the exposure, species life history, timing, and ambient levels can all influence potential behavioral changes to fishes and birds.

Elliott Bay is highly urbanized with numerous transportation corridors for ferries, barges, and recreational vessels. Ambient underwater noise levels have been measured in Elliott Bay at Piers 56 and 70. Ambient noise levels were 156 dB_{peak} and 154 dB_{rms} at Pier 56 and 147 dB_{peak} and 132 dB_{rms} at Pier 70 (Laughlin 2006). Ambient noise levels were higher at Pier 56 because the pier is closer to many anthropogenic activities.

6.4.4 Predators in Shilshole Bay

The primary known avian and mammalian predators on juvenile Chinook are glaucous-winged gulls (*Larus glaucescens* and others), harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*). Gull predation in the lock chamber has virtually been eliminated since implementation of the slow fill procedures in 1999. Before 1999, gulls ate up to one of every eight smolts entrained in the large lock conduits (WDFW 1996). In 2000, anecdotal information has indicated there were only isolated periods when gulls may be preying on sockeye salmon smolts passed over the smolt flumes. One or two noted periods of predation included extreme low tides during the highest smolt passage days.

The abundance of harbor seals and California sea lions in Puget Sound has increased significantly in recent decades. Between 1985 and 1995, significant numbers of adult steelhead were consumed by sea lions. In 1996, NMFS authorized removal of several ‘nuisance’ sea lions and subsequent sea lion predation rates declined to 2% of the adult steelhead run. Concurrent with removal of the ‘nuisance’ animals, NMFS has been running an acoustic deterrent device (ADD) or acoustic harassment device (AHD) in areas near the Locks. The ADD acts as a behavioral barrier to sea lions, emitting sounds in the range of 10 to 15 kHz, a frequency range that appears to exclude most animals from the area below the Locks (Fox *et al.* 1996). Sea lions have not been observed preying on juvenile salmonids near the Locks since 1999. The ADD has been tested on Chinook salmon as they migrate through the fish ladder. No difference was observed in their behavior as they migrated through the fish ladder (B. Norberg, NMFS, pers. comm. 2005).

Harbor seals are present in Puget Sound year-round and are more abundant than sea lions. They commonly prey on salmon, but predation by harbor seals at the Locks has been infrequently observed. Although one or more adults can be seen on an irregular basis by the fish ladder, the number of juvenile Chinook salmon taken by harbor seals is believed to be a very small percentage of the run (Corps 2001).

6.4.5 Fish Present in Elliott Bay

The nearshore waters of Elliott Bay provide habitat for various species of marine fish (Table 6-19). The most abundant fish just north of the Elliott Bay Seawall in the shallow waters include shiner perch, pile perch, striped seaperch, Pacific sand lance, and Pacific herring. Common species in deeper water include English sole, rock sole, starry flounder, and various rockfish and smelt.

Eight species of native anadromous salmonids occur in Elliott Bay. These include Chinook salmon, chum salmon, pink salmon, sockeye salmon, coho salmon, steelhead trout, bull trout, and sea-run coastal cutthroat trout. The emigration and residence timing of juvenile salmonids varies for each species. Very little information is available on the distribution of salmonids immediately adjacent to the seawall.

Table 6-19 **Fish present in the nearshore of Elliott Bay**		
Common Name	**Scientific Name**	**Occurrence**
Pacific lamprey	*Entosphenus tridenatus*	Occasional
Spiny dogfish	*Squalus acanthias*	Common
Brown cat shark	*Apristurus brunneus*	Occasional
Sixgill shark	*Hexanchus griseus*	Occasional
Big skate	*Raja binoculata*	Rare
Longnose skate	*R. rhina*	Occasional
Ratfish	*Hydrolagus colliei*	Common
Pacific herring	*Clupea harengus pallasi*	Rare
Northern anchovy	*Engraulis mordax*	Rare
Chinook salmon	*Oncorhynchus tshawytscha*	Common
Chum salmon	*O. keta*	Common
Pink salmon	*O. gorbuscha*	Occasional
Sockeye salmon	*O. nerka*	occasional
Coho salmon	*O. kisutch*	Common
Rainbow trout/steelhead	*O. mykiss*	Common
Sea-run coastal cutthroat trout	*O. clarki*	Occasional
Bull trout/Dolly Varden	*Salvelinus confluentus/S. malma*	Rare
Surf smelt	*Hypomesus pretiousus*	Common
Longfin smelt	*Spirinchus thaleichthys*	Occasional
Lingcod	*Ophiodon elongates*	Occasional
Cabezon	*Scorpaenichthys marmoratus*	Occasional
Kelp greenling	*Hexagrammos decagrammus*	Common
Pacific cod	*Gadus macrocephalus*	Occasional
Pacific hake	*Merluccius productus*	Common
Pacific tomcod	*Microadus proximus*	Common
Walleye Pollock	*Theragra chalcogramma*	Common
Blackbelly eelpout	*Lycodopsis pacifica*	Common
Tube-snout	*Aulorhynchus flavidus*	Common

Common Name	Scientific Name	Occurrence
Threespine stickleback	*Gasterosteus aculeatus*	Occasional
Bay pipefish	*Syngnathus leptorhynchus*	Common
Penpoint gunnel	*Apodichthys flavidus*	Rare
Shiner perch	*Cymatogaster aggregate*	Common
Striped perch	*Embiotoca lateralis*	Common
Pile perch	*Rhacochilus vacca*	Common
Kelp perch	*Brachyistius frenatus*	Rare
Snake prickleback	*Lumpenus sagitta*	Common
Pacific sandlance	*Ammodytes hexapterus*	Common
Brown rockfish	*Sebastes auriculatus*	Occasional
Quillback rockfish	*S. maliger*	Common
China rockfish	*S. nebulosus*	Occasional
Copper rockfish	*S. caurinus*	Common
Yellowtail rockfish	*S. flavidus*	Rare
Black rockfish	*S. mulonops*	Common
Bocaccio	*S. paucispinis*	Rare
Canary rockfish	*S. pinniger*	Rare
Yelloweye rockfish	*S. ruberrimus*	Rare
Prickly sculpin	*Cottus asper*	Occasional
Buffalo sculpin	*Enophrys bison*	Occasional
Pacific staghorn sculpin	*Leptocottus armatus*	Common
Dover sole	*Microstomus pacificus*	Common
English sole	*Parophrys vetulus*	Common
Flathead sole	*Hippoglossoides elassodon*	Occasional
Pacific sanddab	*Citharichthys sordidus*	Occasional
Petrale sole	*Eopsetta jordani*	Occasional
Rex sole	*Glyptocephalus zachirus*	Occasional
Rock sole	*Lepidopsetta bilineata*	Occasional
C-O sole	*Pleuronichthys coenosus*	Common
Sand sole	*Psettichthys melanostictus*	Occasional
Starry flounder	*Platichthys stellatus*	Occasional

6.4.6 Fauntleroy Creek (South Seattle/Puget Sound Action Area)

Fauntleroy Creek receives runoff from a 149-acre (60.23 ha) watershed in the southwestern portion of Seattle (Figure 11). About 23% of the watershed area and 75% of the creek channel length (upper mainstem and tributaries) are in parks and open space. The land use in the watershed is 57% residential and 17% commercial and transportation (roads, parking lots and rights-of-way). The total channel length is about 1.6 miles (2.6 km) long, including six small tributaries, which are fed by numerous groundwater seeps in Fauntleroy Park. The mainstem length is about 0.9 miles (1.4 km) long. The park area surrounding the upper portions of the creek contains wetlands and forest cover. Downstream of the park, Fauntleroy Creek passes through residential areas in open channels and culverts, before reaching Puget Sound near the Fauntleroy Ferry Terminal. Fauntleroy Creek flows year-round with an average estimate of 0.9 to1.3 cubic feet/sec (0.25-0.4 cu m/sec) at the mouth, a two-year storm peak flow estimate of 9.0 cubic feet/sec (0.2 cu m/sec), and a 100-year storm peak flow estimate of 39.8 cubic feet/sec (1.12 cu m/sec) at the Fauntleroy Way Southwest culvert (Hartley and Greve 2005).

6.4.6.1 Water Quality

Nine storm drains discharge stormwater to the upper reaches of Fauntleroy Creek and its tributaries (City of Seattle 2007). No combined sewer overflow outfalls discharge into the stream. In the lower reaches of the creek stormwater enters through surface runoff and through groundwater recharge.

Fauntleroy Creek is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies. The 303(d) listings are summarized in Table 6-20.

Table 6-20

Summary of 303(d) listings for Fauntleroy Creek

	Category	
Media	**2[1]**	**4A[2]**
Water	Mercury	Fecal coliform bacteria

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body has an approved TMDL in place and is actively being implemented.

Source: Ecology 2008

Ecology included Fauntleroy Creek on the 2004 303(d) list of threatened and impaired waterbodies as a category 5 waterbody (total maximum daily load required due to demonstrated exceedances of state water quality standards) for fecal coliform bacteria (Ecology 2004). This listing is based on samples collected on June 15 and August 29, 1988, at four sites along Fauntleroy Creek (Kendra 1989) and earlier sampling conducted by King County (formerly Metro). Fecal coliform bacteria in 13 samples collected by Ecology in 1988 ranged from 590 to 2,700 cfu/100 mL, with a geometric mean of 1,300 cfu/100 mL.

Ecology began monitoring water quality near the mouth of Fauntleroy Creek in October 2004. Summary statistics from the preliminary results for conventional water quality parameters are presented in Table 6-21.

Table 6-21

Summary of conventional water quality parameters in Fauntleroy Creek near mouth*

	DO (mg/L)	Temp. (degrees C)	Fecal coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
Minimum	9.8	6.5	23	8.0	3	1.5
Maximum	12.4	15.4	390	8.3	33	19
Median	11.1	10.6	87	8.2	10	5.2
Mean	11.1	10.8	145	8.2	13	6.2
5th percentile	9.8	6.9	27	8.0	3	1.5
95th percentile	12.2	15.1	341	8.3	33	13

*15 samples collected between October 2004 and December 2005. Source: Preliminary data Ecology (undated)

Although fecal coliform levels in the creek have declined since 1988 (590-2,700 cfu/100 mL), Fauntleroy Creek (annual geometric mean of 130 cfu/100 mL in 2004-2005) continues to exceed the water quality standard for extraordinary primary contact recreation (50 cfu/100 mL).

In addition to elevated fecal coliform levels, the area offshore of Fauntleroy Creek frequently experiences odor problems during the summer. Studies have found that the odor problems are caused by hydrogen sulfide generated by decaying seaweed that builds up along the beach from offshore algal beds (WDOH 1991). Seaweed growth is normally limited by the availability of nitrogen, and by mid-summer there is usually insufficient nitrogen to support large growth. However, input from Fauntleroy Creek is believed to support seaweed.

Dissolved oxygen and temperature conditions in Fauntleroy Creek are good. Samples collected between October 2004 and December 2005 consistently met state water quality standards.

Although data are limited, concentrations of toxic materials in Fauntleroy Creek are generally low. Between October 2004 and December 2005, ammonia-nitrogen levels were consistently below toxic levels. Dissolved metals concentrations in Fauntleroy Creek were also low; none of the samples exceeded state water quality standards. Copper and lead levels were either undetected or detected at levels below the acute and chronic toxicity criteria for aquatic resources.

Figure 11. Fauntleroy Creek Watershed

Nutrient levels in Fauntleroy Creek are relatively low. Only one sample (864 µg/L in August 2005) of 15 exceeded the U.S. EPA (1976) water quality criterion (100 µg/L), which establishes a desired goal for the prevention of nuisance plant/algal growth in streams or other flowing waters not discharging directly to lakes or impoundments.

No sediment quality data have been collected for Fauntleroy Creek.

Prespawn mortality rates in Fauntleroy Creek average about 39 percent. This average is lower than rates in other Seattle watercourses (City of Seattle 2007).

6.4.6.2 Shoreline and Aquatic Habitat

Factors limiting aquatic habitat within Fauntleroy Creek include alterations to stream hydrology, reduced floodplain connectivity, restricted habitat access, sedimentation, and lack of channel complexity.

Habitat in Fauntleroy Creek varies in quality between the upstream areas in the park and downstream areas in residential neighborhoods. The channel condition within the park is naturally confined by the ravine and the creek is slightly incised and widening, likely in response to increased streamflows by altered hydrology from urban and residential development. Incision and channel widening are a concern because they make the upper valley walls unstable and erode sand. Erosion of the upper valley walls produces a high volume of sand in Fauntleroy Creek, which can cover spawning areas. Fine sediment sources and a naturally low coarse sediment supply limit potential spawning use of habitat upstream of California Avenue. However, the export of sediment from Fauntleroy Creek benefits the marine environment by the creation and maintenance of shoreline habitat.

The stream within the park has low bank heights, an active floodplain connection and good instream structure (wood and cascade-step pools). These structures help dissipate energy from higher flows. Instream habitat within the park includes long riffles punctuated with short cascade step pools, which have been formed by instream logs. The riparian corridor is continuous and varies in width from 100 to 200 feet (30.5 to 61 m).

The lowermost reaches of the creek, below California Ave., are characterized by a straightened, narrow channel averaging 4.5 feet (1.4 m) wide, with a plane-bed channel type and 35% glide habitat. This section of the creek has been degraded by artificial confinement resulting from extensive fill for roads and culverts and bank armoring. Riparian vegetation downstream of the park is of poor quality dominated by landscaping and invasive species. The lower reaches lack instream habitat structure and as a result of the confinement and heavily armored banks, there is insufficient room to safely add structure.

Fish Use

Coho salmon, Pacific staghorn sculpin, rainbow trout, and an occasional chum are found within Fauntleroy Creek (City of Seattle 2007, Tabor *et al* 2010). Coho spawn in the lower 1,000 feet (305 m) of stream because of the 45th Avenue Southwest culvert, the most downstream fish passage barrier. The culvert prevents salmon use of high quality habitat upstream in Fauntleroy Park. Pacific sandlance were captured in the intertidal area of the creek (Tabor *et al.* 2010).

An average of 26 coho adults enter the watercourse to spawn each fall, although the numbers vary widely (0 to 63 carcasses). Forty percent of the adults are hatchery fish that are either released into the watercourse by Seattle's Salmon-in-the-Classroom program or are strays from nearby hatcheries. Approximately 1,100 coho fry are released into Fauntleroy Creek each year, but juvenile survival is extremely low. Between 37 and 721 fry have been caught in the smolt traps from 2003 to 2006.

Only 400 feet of good spawning habitat is available in Fauntleroy Creek just upstream of Fauntleroy Way SW. Pool habitat is also limited.

6.4.7 Piper's Creek

The Piper's Creek watershed is in the North Seattle/Puget Sound Action Area and covers 1,604 acres (649 ha) of northwest Seattle along north Puget Sound (Figure 12). Only 11% of the watershed is located in parks/open space, and the remaining land use is mostly residential (59%) and roads/commercial/industrial (29%). The total channel length is 4.9 miles (7.9 km), with 2 miles (3.2 km) of mainstem and 2.9 miles (4.7 km) of tributary channel. Most of the creek channel is open (90%) and the remaining area is contained in culverts. The creek has 14 tributaries, including a major tributary system that consists of Venema and Mohlendorph creeks. Piper's Creek and its tributaries originate on a residentially-developed plateau. Piper's Creek drains the central and southern portion of the watershed, while Venema and Mohlendorph creeks drain northern areas. From the plateau, the creeks pass into a ravine located mainly within the boundaries of Carkeek Park. The mainstem of Piper's Creek is located almost entirely within Carkeek Park, except for the most upstream sections of the mainstem and some of the tributaries.

Figure 12. Piper's Creek Watershed

6.4.7.1 Water Quality

Twenty-nine storm drains discharge into Piper's Creek and its tributaries (City of Seattle 2007). No combined sewer overflow outfalls discharge into the stream. Sixteen storm drains discharge into upper Piper's Creek. There are eight outfalls on Venema and Mohlendorph creeks. Two outfalls drain relatively large areas in the watershed: one in the upper reach of Mohlendorph Creek drains an area of 290 acres (18% of watershed), and one drains nearly 575 acres (35% of watershed).

Piper's Creek is on the 2008 Ecology 303(d) list of threatened and impaired waterbodies. The 303(d) listings are summarized in Table 6-22.

Table 6-22

Summary of 303(d) listings for Piper's Creek

	Category	
Media	**2[1]**	**4A[2]**
Water	Dissolved Oxygen pH	Fecal coliform bacteria

[1]Water of concern – water body shows evidence of a water quality problem, but pollution level is not high enough to violate the water quality standard, or there may not be enough violations to categorize it as impaired.

[2]Water body has an approved TMDL in place and is actively being implemented.

Source: Ecology 2008

With the exception of fecal coliform bacteria, which frequently exceeds state water quality standards, during non-stormflow conditions water quality in Piper's Creek is generally good. The creek does experience occasional problems with total suspended solids and turbidity. Ecology included Piper's Creek on the 303(d) list of threatened and impaired waterbodies as a water of concern (*i.e.*, category 2) for turbidity in Venema Creek, a tributary creek to Piper's Creek (Ecology 2004). Increases in turbidity and suspended solids downstream typically result from larger storm flows associated with urbanization in the watershed. Urban stream banks typically erode more easily as riparian vegetation is removed or modified. Upland construction activities and ground disturbances also result in high inputs of turbid water.

Piper's Creek frequently exceeds state water quality standards for fecal coliform throughout the year. Over the past ten years, the annual geometric mean fecal coliform level exceeded the state standard for extraordinary primary contact recreation (50 cfu/100 mL) every year in Piper's Creek (both upstream and downstream of Venema Creek) and in nine of the ten years at the Venema Creek station. Fecal coliform levels in Venema Creek (43-210 cfu/100 mL geometric mean) were generally lower than the levels measured in Piper's Creek (76-630 cfu/100 mL). In addition, the 100 cfu/100 mL limit was exceeded in 15% to 94% of the samples. Under the state water quality standards, no more than 10% of all samples are permitted to exceed 100 cfu/100mL.

Stormwater samples generally contain higher levels of fecal coliform bacteria than non-storm samples. The annual geometric mean for non-storm samples ranged from 43 to 210 cfu/100 mL and from 76 to 630 cfu/100mL in Venema Creek and Piper's Creek respectively, compared with 2,200 cfu/100 mL and 3,800 to 4,100 cfu/100 mL in the stormwater samples.

In 1992, EPA issued a programmatic total maximum daily load for fecal coliform bacteria in the creek based on the 1990 Watershed Action Plan and 1999 update (Piper's Creek Watershed Management Committee 1990, 1999). The Watershed Action Plan recommended specific actions including public education, inspection/enforcement, utility operations and maintenance, and monitoring that should be implemented to reduce nonpoint pollution in the Piper's Creek watershed. Although many of the actions recommended in the 1990 plan have been implemented, recent data (King County undated, SPU undated, and Onwumere 2003), indicate that elevated levels of fecal coliform persist in many locations within the basin.

King County has been collecting monthly samples in Piper's Creek (above Venema Creek, below Venema Creek, and Venema Creek) since about 1988. Samples are analyzed for conventional water quality indicators (temperature, dissolved oxygen, fecal coliform bacteria, pH, total suspended solids, and turbidity), metals, and nutrients. Seattle Public Utilities has also been collecting two to three stormwater samples each year in the creek since about 1999. Conventional water quality parameters from monthly samples collected by King County (undated) between 1979 and 2005 are shown in Table 6-23.

As shown on Figure 13, dissolved oxygen and temperature typically exhibit a seasonal trend with higher temperatures and lower dissolved oxygen concentrations in the warm summer months. Over the 18-year period of record, Piper's Creek downstream of Venema Creek exceeded the temperature standard in one sample and no exceedances occurred in Venema Creek or in Piper's upstream of Venema Creek. Between 1988 and 2005, dissolved oxygen concentrations in Piper's and Venema Creeks exceeded the standard in only 1% to 2% of the samples.

Table 6-23

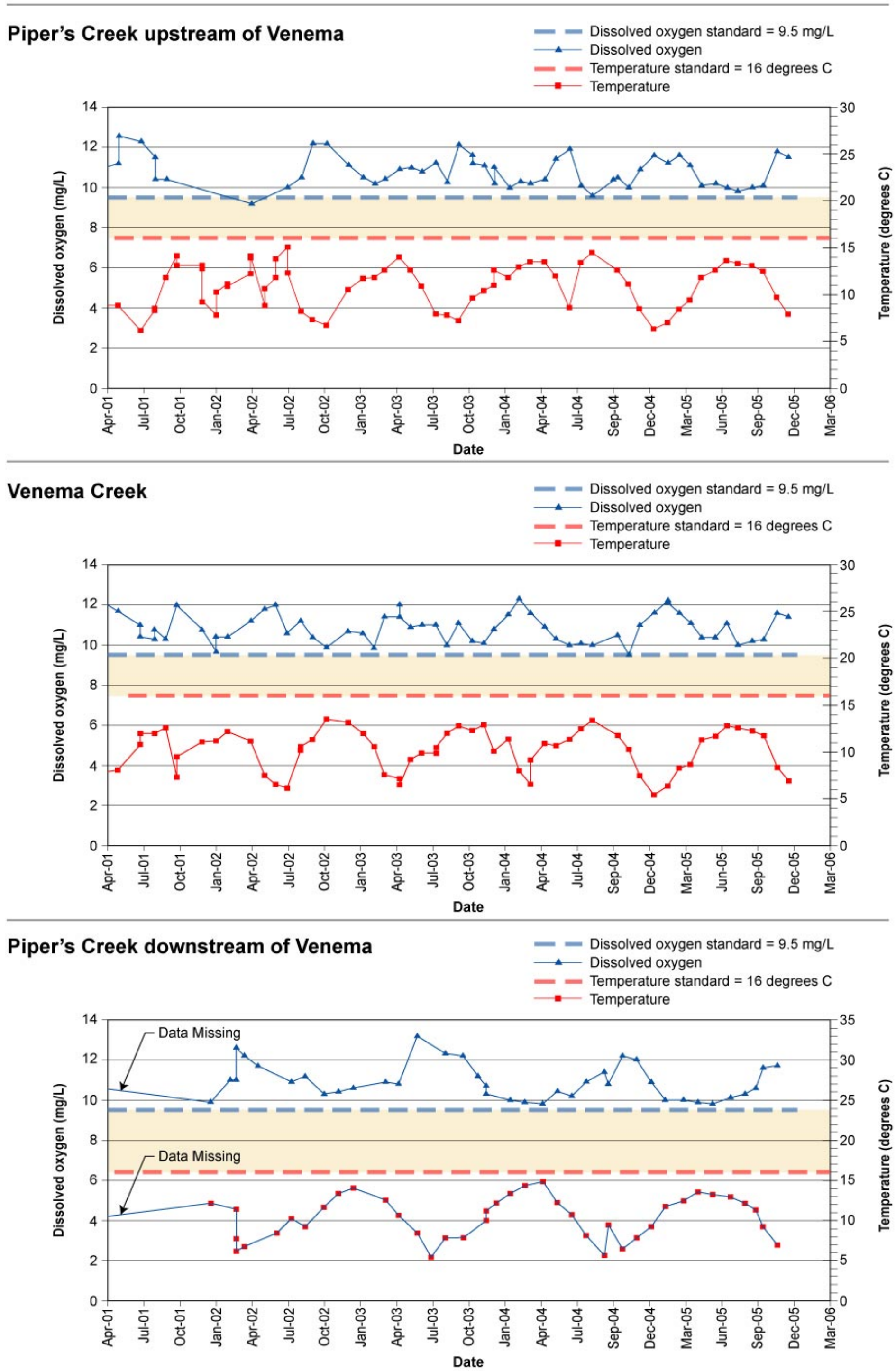
Summary statistics for conventional water quality parameters in Piper's Creek*

	DO (mg/L)	Temp. (degrees C)	Fecal coliform (cfu/100 mL)	pH	TSS (mg/L)	Turbidity (NTU)
Piper's Creek upstream of Venema Creek (Station KTAH03)						
No. of samples	209	398	412	206	204	203
Minimum	6.6	2.0	1	6.0	0.5	0.2
Maximum	13.1	16.1	37,000	8.4	223	70
Median	10.7	11.4	200	7.9	3.3	1.7
Mean	10.8	10.8	762	7.8	9.7	4.3
5th percentile	9.7	6.0	24	7.1	1.1	0.7
95th percentile	12.2	14.4	3,760	8.2	35.7	15.0
Venema Creek (Station KTAH02)						
No. of samples	210	211	218	207	205	205
Minimum	6.3	2.0	4	6.1	0.01	0.1
Maximum	13.1	14.5	9,700	8.4	166	73
Median	11.0	10.2	70	7.9	3.0	1.3
Mean	11.1	9.7	258	7.8	8.3	3.2
5th percentile	10.0	5.1	12	7.3	0.9	0.5
95th percentile	12.6	13.3	602	8.2	29	9.8
Piper's Creek downstream of Venema Creek (Station KHSZ06)						
No. of samples	254	259	264	251	249	249
Minimum	6.0	1.5	11	6.0	0.5	0.1
Maximum	14.0	16.0	40,000	10.0	425	180
Median	10.9	10.2	250	7.7	3.7	2.0
Mean	10.9	10.0	1,201	7.7	22.4	8.8
5th percentile	9.8	5.0	31	7.0	1.1	0.7
95th percentile	12.7	14.0	5,825	8.2	94.2	37

Source: King County (undated)

Figure 13

Dissolved oxygen and temperature in Piper's Creek



Reference: Stations KTAH02, KTAH03, and KSHZ06, King County (undated).
Note: The areas between the two dashed lines show the samples that do not meet state water quality standards.

Nutrient levels in Piper's Creek are generally high and exceed recommended water quality criteria. For example, total phosphorus concentrations in Piper's Creek (18 to 720 µg/L in non-storm samples and 3-990 µg/L in stormwater samples) frequently exceed the U.S. EPA water quality criterion (100 µg/L), which establishes a desired goal for the prevention of nuisance plant/algal growth in streams or other flowing waters not discharging directly to lakes or impoundments (USEPA 1976). In addition, total nitrogen concentrations in Piper's Creek (180 to 3,470 µg/L) frequently exceed the U.S. EPA (2000) recommended criterion for streams in the western United States. (340 µg/L for Ecoregion II). These criteria represent conditions in surface waters that are minimally impacted by human activities and are designed to prevent eutrophication and water quality problems associated with nutrient enrichment.

Concentrations of toxic materials in Piper's Creek are generally low. Ammonia-nitrogen levels were consistently below toxic levels. For metals, only dissolved lead exceeded the state water quality standard (in one non-storm sample collected in 2001 downstream of Venema Creek). During storm events, seven of 27 samples exceeded chronic toxicity criterion for dissolved copper, and two samples exceeded the acute toxicity criterion. Water quality is being investigated as a potential contributor to the unusually high rates of coho salmon pre-spawn mortalities reported in urban creeks in the Puget Sound since 1999 (Reed et al. 2003). Between 1999 and 2005, pre-spawn mortality rates in Piper's Creek averaged 58% (McMillan 2006, SPU unpub. data).

6.4.7.2 Shoreline and Aquatic Habitat

Factors limiting aquatic habitat within Piper's Creek include alterations to the stream hydrology, reduced floodplain connectivity, restricted habitat access, sedimentation, and lack of channel complexity.

Habitat in Piper's Creek has the similar degradation patterns as that of other Seattle creeks, although not as severe as those for Thornton and Longfellow creeks. Piper's Creek has been incising and widening (eroding) in response to increased stormwater runoff. Much of the creek carries a large amount of fine sediment (mostly sand). Not surprisingly, the upland developed portions of the watershed have the most degraded channel and riparian conditions, while areas within Carkeek Park contain relatively good habitat. Older grade control structures located in Piper's Creek mainstem, upstream of the King County/Metro sewage pumping station, have helped the channel to restabilize and to reconnect with the floodplain.

The changes in the drainage patterns in the Piper's Creek system resulting from watershed development have an effect on the amount of fine sediment in the system. Steep, eroding tributaries and landslides from upper valley walls supply large amounts of sand and gravel to the channel in mainstem Piper's Creek, and extensive erosion of canyon walls are a major source of sand to Venema Creek. Although tightlining outfalls— by placing pipe from the top of the valley walls directly into the channel—in 1999 to 2000 greatly reduced delivery of sand to Piper's Creek, mass wasting and channel erosion in Venema and upper Piper's channels are the largest components of the existing sediment supply. Upper Piper's Creek produces about 57% of the total mass wasting (sediment) supply while the Venema creek system produces about 29% of the sand in the channel.

The lack of connectivity between the land and stream through bank armoring, particularly in the lower reaches of Venema (35% to 40% armored) and Piper's creeks (26% of the channel), prevents the channel from widening and connecting to the floodplain. Placement of weirs in mainstem Piper's Creek, upstream of the pump station, has resulted in restabilizing portions of the channel, through widening the channel and reconnecting it to the floodplain (Perkins 2002). Both Venema and Mohlendorph creeks are incising in response to higher storm flows (Perkins 2002). The Piper's Creek watershed does contain relatively good riparian vegetation especially in the lower reaches. Much of Piper's Creek is in Carkeek Park and has good cover for shade. However, much of the vegetation is mature alder with few mature conifers. The upper watershed contains fragmented riparian habitat composed mainly of lawns, landscaping, and invasive Himalayan blackberry.

Due to changes in hydrology patterns and lack of connectivity, the Piper's Creek system lacks habitat complexity. In Venema and Mohlendorph creeks, wood and large substrate are insufficient for forming and maintaining habitat. Bank armoring exacerbates these conditions. In Piper's Creek, in-channel refuge habitat is restricted to plunge pools associated with weirs, which composes only about 15% of available habitat.

Fish Use

Piper's Creek is used by cutthroat and rainbow trout, coho and chum salmon and coastrange, prickly, staghorn, and shortnose sculpin (City of Seattle 2007, Tabor *et al* 2010). Of the estimated 2.7 miles (4.3 km) of potentially fish-bearing channel, anadromous fish have access to about 0.6 miles (1 km) including lower Venema and Mohlendorph creeks and Piper's Creek below the pump station. Juvenile use has not been well studied. Pre-spawning mortality averages 58% in the creek.

Barriers to fish passage limit access to upstream areas. The Metro pump station culvert and bypass are the most significant barriers. Returning adult salmon access to the lower river is limited to high tides that connect Puget Sound to the creek channel.

Adult chum salmon numbers ranged between 16 and 398 fish per year (carcass counts) between 1999 and 2005. Coho salmon numbers range between 5 and 122. With the limited access to the stream, redd superimposition is a concern in the creek. The amount of spawning habitat, number of adult salmon, and small amount of habitat accessible contributes to the red superimposition. Coho production is thought to be limited by the more abundant chum population.

Coho prespawn mortality averages about 58% in Piper's Creek, ranging from 18 to 100%. Piper's Creek has the most variable prespawn mortality rate in Seattle watercourses. Chum salmon are also affected, but their mortality rate is only 2 to 4%.