Salmon and Steelhead
Habitat Limiting Factors Report

for the

CEDAR – SAMMAMISH BASIN
(Water Resource Inventory Area 8)

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"…salmon are among the oldest natives of the Pacific Northwest, and over millions of years they learned to inhabit and use nearly all the region's freshwater, estuarine and marine habitats. …From a mountaintop where an eagle carries a salmon carcass to feed its young, out to the distant oceanic waters of the California Current and the Alaska Gyre, the salmon have penetrated the Northwest to an extent unmatched by any other animal. They are like silver threads woven deep into the fabric of the Northwest Ecosystem. The decline of salmon to the brink of extinction is a clear sign of serious problems. The beautiful tapestry that the Northwesterners call home is unraveling; its silver threads are frayed and broken."

Excerpt from: Salmon Without Rivers: a History of the Pacific Salmon Crisis. By Jim Lichatowich, 1999. Island Press

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Fish Distribution Maps

The Fish Distribution Maps were initially developed through a workshop held in May 1999. Individuals from numerous governmental agencies, Indian tribes and non-profit organizations, and private citizens knowledgeable about salmonid utilization in the watershed participated. Information from databases, including StreamNet, SSHIAP and the WDFW Spawning Ground Survey Database were also utilized. The initial work product was further reviewed and refined during a workshops in 2000 and 2001.

Fish Barrier Map

The Fish Barrier Maps shown in this report were initially developed by using information from field notes and databases including StreamNet, SSHIAP, the WDFW Fish Barrier Database and the Washington Department of Transportation fish barrier database. The City of Bellevue provided GIS coverages for streams in their jurisdiction and the Adopt-A-Stream Foundation, under contract with King County, provided coverages for their work in north Sammamish River tributary streams.

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Executive Summary

I. Introduction

Many stocks of the wild salmonid populations in the Puget Sound ecoregion have declined. In March 1999, the National Marine Fisheries Service (NMFS) listed Puget Sound chinook salmon as a "Threatened" species under the Endangered Species Act (ESA). In November 1999, the U.S. Fish and Wildlife Service (USFWS) listed bull trout as a "Threatened" species under the ESA.

The Habitat Limiting Factors Report

As a first step in the long-term commitment to salmonid recovery in Water Resource Inventory Area 8 (WRIA 8), representatives from the Washington Conservation Commission and the WRIA 8 Technical Committee worked collectively to develop this Habitat Limiting Factors Report. The purpose of this report is to provide a current "snapshot in time" of the existing salmonid species and anthropogenic caused habitat conditions that limit the natural production of salmonids in the Cedar – Sammamish Watershed and the independent drainages to Puget Sound from Elliott Bay north to approximately the King County – Snohomish County line. This area is collectively termed WRIA 8 for the purposes of this report.

This report:

- Provides a summary of what is known about current and past salmonid species and habitat conditions in the WRIA for future reference;
- Provides baseline information for the WRIA (based on currently available data) for potential use in the implementation of an adaptive management program;
- Identifies limiting habitat factors in the WRIA, key findings, and associated data gaps that will be useful in building the WRIA 8 Salmonid Conservation Plan; and
- Provides guidance for policy makers to determine next steps and direct resources for the recovery process.

Focus on Limiting Habitat Factors

While the causes of declining salmonid populations can be attributed to many factors, this report focuses on human-controlled modification or destruction of saltwater nearshore and freshwater habitats and the changes to ecological processes that effect those habitats in WRIA 8.

II. Watershed Overview

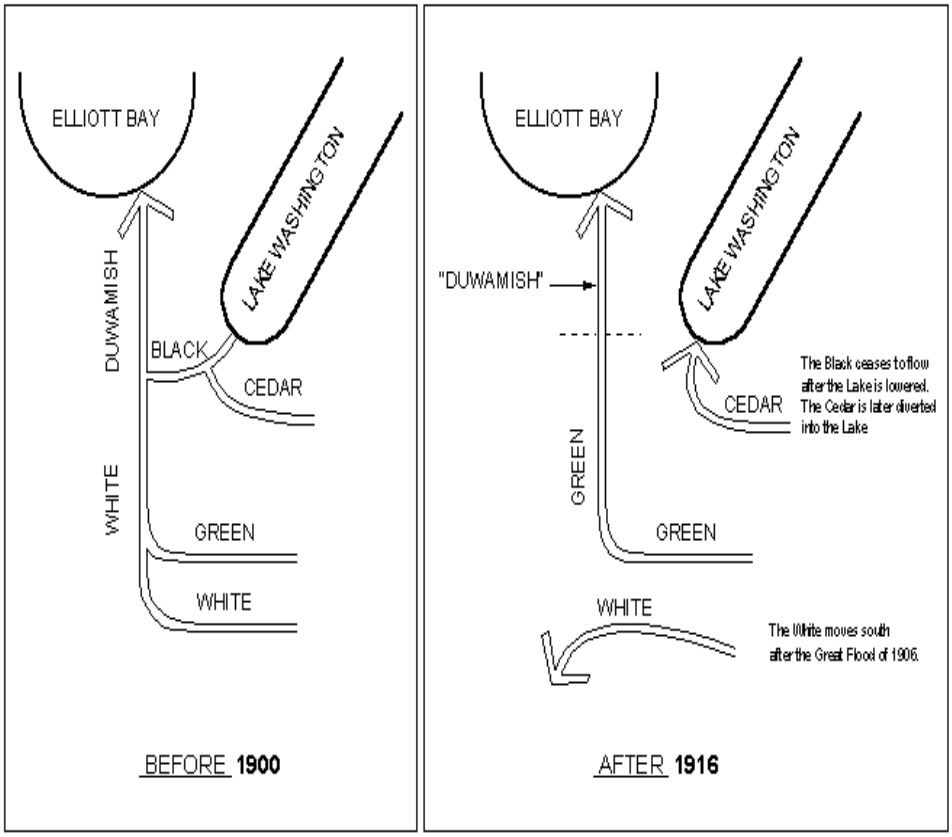
Physical Description

Out of the 692 square miles in WRIA 8, 607 are in the Cedar - Sammamish watershed, which contains two major river systems, the Cedar and the Sammamish, and three large lakes, Union, Washington and Sammamish. The remainder of the WRIA consists of numerous small watersheds that drain directly to Puget Sound between Elliott Bay and Mukilteo. Lake Washington is the second largest natural lake in the state, with about 80 miles of shoreline (including about 30 miles along the shore of Mercer Island) and a surface area of about 35.6 square miles. Arguably, Lake Washington has the most highly altered watershed on the West Coast. Despite such heavy alteration, it continues to support numerous salmon runs.

WRIA 8 is located predominantly within the borders of King County, but 15 percent of it extends northward into Snohomish County. To the west it is bounded by Puget Sound, while to the east the headwaters of the Cedar River reach the crest of the Cascade Range near Stampede Pass. The northern and southern boundaries follow hilltops, ridges and plateaus that define the drainage divides between the Snohomish/Snoqualmie (WRIA 7) and Green/Duwamish (WRIA 9) watersheds, respectively.

The Lake Washington watershed has been dramatically altered in the 150 years since the first Euro-American settlers arrived in the Seattle area. This started with heavy logging of old growth forest in the 19th Century. It expanded at the turn of the 20th Century, when Seattle tapped the Cedar River as its main source of water supply. A major alteration of the watershed occurred in the decade of 1910-20, when the Lake Washington Ship Canal and Hiram M. Chittenden Locks were completed (Figure 1). The ecological consequences of this last alteration were profound: the outlet of Lake Washington was redirected from its south end, at the Black River; the new outlet at the Locks and Salmon Bay had almost no features of a natural estuary and presented migrating salmonids an abrupt transition from freshwater to saltwater (and saltwater to freshwater); and the level of Lake Washington was dropped about nine feet, which drained wetlands along much of its shoreline and dramatically changed the confluences with its tributaries. In a separate but related action in the same decade, the Cedar River was redirected from its normal connection with the Black River, which had fed the Duwamish, and was channelized to flow into Lake Washington, with the initial hope of creating a major freshwater industrial port at Renton. The lowering the water surface level of Lake Washington also lowered the water surface of Lake Sammamish and drained the vast wetland complex that had made up the Sammamish River Corridor between the two lakes. This provided the basis for a major expansion of farming in that corridor, which led to channelization of the Sammamish River in the early 1920's to nearly its present course. Thus, by the 1920's the general hydrogeography of the present watershed was established.

Figure 1. Configuration of the Duwamish drainage prior to 1900 and after 1916 (Source: Dunne and Dietrich 1978)



In the ensuing years, the most important cause of physical change to the watershed has been the expansion of urban and suburban development. In particular, this has altered the hydrology of the watershed; both through changes in land cover and through increased water withdrawals. Changes in land cover due to urbanization have been extensively shown to relate to degradations in salmon habitat, mostly due to changes in flows but also because of degraded riparian areas. The removal of forest cover for urban and suburban development dramatically increases the size and frequency of high flows from stormwater in lowland creeks. It typically reduces low flows in the summer and early fall, because cleared land and impervious surfaces dramatically reduces groundwater recharge. As to increased water withdrawals, through the 1940s these were primarily from Seattle's Cedar River Watershed, but total withdrawals from the watershed have been relatively stable since then, as Seattle and the region have developed other supplies. Major groundwater withdrawals in the watershed since then have been from below the lower Cedar River, lower Issaquah Creek, lower Bear Creek and Rock Creek (a tributary to the Cedar River). Following significant floods in the 1950s, countywide flood control efforts in the 1960s led to a dramatic expansion of levees on

the Cedar River and local sponsorship of major dredging and levee construction on the Sammamish River by the Corps of Engineers. This in turn supported the greater development of the floodplains of both rivers. Meanwhile, expanding urbanization led to heavy residential development of the shorelines of Lake Washington and Lake Sammamish. Residential development has also expanded along the bluffs above Puget Sound and along parts of its shoreline. The marine nearshore of WRIA 8 was even more dramatically affected by the construction of a railroad line along most of its length early in the 20th Century. Bulkheads and other protections for the railroad line and developments have significantly curtailed natural, beach-forming ecological processes along the Puget Sound nearshore.

Beside these changes in physical habitat, the introduction of non-native fauna and flora have significantly changed the biology of the Lake Washington ecosystem. There have been upwards of 40 non-native fish introduced into the watershed. Some of these introduced species did not persist and today, there are 24 known non-native fish species in the watershed, including notably smallmouth and largemouth bass, which can be significant predators of juvenile salmonids. Sockeye salmon in the lake system are believed to be primarily the descendants of fry transplanted from Baker Lake in the 1930s. Since juvenile sockeye require a lake for a year or more of rearing, the Cedar River supported few if any sockeye prior to its connection with Lake Washington (in years of heavy floods, the historic Cedar River flowed into Lake Washington for short periods of time, but the connection was not lasting nor regular). However, the Cedar did support runs of pink and chum salmon prior to being redirected into Lake Washington; these are now extinct. As to non-native flora, Eurasian watermilfoil now dominates much of the shorelines of Lakes Washington and Sammamish. Himalayan blackberry is common in riparian areas throughout the watershed, and Japanese knotweed and reed canary grass are spreading.

The Cedar - Sammamish Watershed is comprised of two major physiographic areas. The eastern portion of the watershed (about 14% of its total area) lies in the Cascade Range while the western portion (the remaining 86%) occupies the Puget Sound Lowland. Largely because of its elevation, the eastern portion (the upper Cedar River and parts of upper Issaquah Creek) receives much more precipitation, up to 102 inches annually, compared to an average of 38 inches in the western portion. The three basins in the watershed with the largest salmonid populations--the Cedar River, Bear Creek and Issaquah Creek--are distinctly different based on geology, hydrology and topography. Only the Cedar River, which originates in relatively high mountain country in the Cascade Range, develops a large annual snowpack. Issaquah Creek originates at the foot of the Cascades, in bedrock hills that are too low to hold snow for sustained spring or summer runoff. Bear Creek is entirely a lowland stream system, originating in a large area of forests and wetlands in south Snohomish and north King counties. Beside the Cedar River, all of the watershed streams must rely primarily on groundwater to sustain baseflows in the summer and early fall.

The division of the watershed by its topography and its three major lakes gives it ecological complexities not found in watersheds based on major river systems. Stream habitat issues for salmon in the Cedar River, Issaquah Creek and Bear Creek are largely unique to each system; actions to address them can be largely independent of one another. The geographic distribution of these systems, and the physical differences between them, has helped create

genetic differences among their salmon populations. All of these differences contribute to the likelihood that recovery goals for salmon in the watershed will be based not just on production, but also on distribution and genetic diversity within the watershed. The lakes have their own complex ecologies, which are not especially well understood but which make salmonids from the Cedar - Sammamish Watershed unusual within Puget Sound. Native salmon from Bear Creek and other tributaries of the original Cedar - Sammamish Watershed basin would have co-evolved with lake habitats. However, the native salmon of the Cedar River would have evolved primarily in stream conditions. The effect of native salmon from the Cedar River migrating and rearing in Lake Washington rather than in the historic Cedar, Black and Green/Duwamish river complex is not known.

WRIA 8 has the largest human population in the state, with approximately 1.4 million people, more than twice the human population of any other WRIA despite its being geographically smaller than most. Based on projections by the Puget Sound Regional Council, this population is expected to increase more than 10 percent in each of the next two decades, bringing it to more than 1.7 million in 2020.

Most of WRIA 8 lies within the Urban Growth Area boundaries. However, nearly all of its most productive salmon spawning habitats are not within that area. Beside the lower Cedar River and Bear and Issaquah creeks, only Little Bear and May creeks have upper basins that are largely outside of the urban area. The official life of the current boundary of the Urban Growth Area in King County is through 2014. A long-term challenge for salmon recovery throughout Puget Sound is to preserve and enhance habitat in the face of effects of increasing human population pressures.

To help us better understand the Cedar - Sammamish Watershed and WRIA 8, we have divided it into ten geographic areas as shown in the corresponding map (Map 1):

- Tributaries draining directly to Puget Sound;
- Nearshore (marine waters and habitats);
- Hiram M. Chittenden Locks and Salmon Bay
- Lake Union
- Lake Washington
- Lake Washington tributaries (except the Cedar River)
- Cedar River
- Sammamish River and its tributaries
- Lake Sammamish
- Lake Sammamish tributaries

These divisions make sense because of natural and/or anthropogenic landscape features. However, they are all linked together as part of the larger ecosystem and by the processes necessary to support naturally produced salmonids.

Land Uses and History

Land uses differ considerably across the watershed and there are few watersheds in the Puget Sound basin that matches the extremes evident in WRIA 8. In the upper Cedar River, land is devoted almost entirely to preservation of forests. A mix of residential, commercial forestry generally characterizes the smaller streams, and agricultural land uses. Residential, industrial, and commercial uses prevail in the lower reaches of virtually all the streams. The Puget Sound drainages are primarily residential in nature.

These land uses have emerged over the last 150 years, which have seen a number of other fundamental changes to the WRIA. Some of these major changes include:

- 1840's and 1850's European settlement begins
- 1880-1910 Logging across much of the watershed
- 1901 City of Seattle begins water diversions out of Cedar River
- 1916 Cedar River diverted into Lake Washington, Hiram M. Chittenden Locks finished changing the outlet of Lake Washington to Salmon Bay
- 1945-2000 Residential, commercial, and industrial uses replacing largely farmlands and forests in western half of WRIA

CURRENT FISH STATUS

Chinook, sockeye, coho, kokanee, steelhead, rainbow and coastal cutthroat trout as well as native char (Bull trout), and one non-native salmonid (Atlantic salmon) have been recently found in the Cedar – Sammamish Watershed. Additionally, at least 40 non-native fish species (of which approximately 24 persist) have been introduced into the Lake Washington watershed creating numerous new trophic interactions with the native species.

Chinook

The Cedar - Sammamish Watershed supported an average yearly total run (fish returning to the river and those caught in the fisheries) of about of approximately 9,600 adult chinook salmon (hatchery and naturally produced) during the period 1968-1997. However, in the past nine years the naturally produced run size has averaged less than 550 adult fish. Returns of naturally produced chinook to the Cedar – Sammamish Watershed have experienced the same decline that has occurred in many of the other Puget Sound drainage basins. Research is needed to better understand the contribution of hatchery "strays" to the naturally produced "wild" chinook stocks in the Cedar - Sammamish Watershed.

Coho

Coho escapement estimates for the tributaries of Lakes Washington and Sammamish from 1980 to 1999 averaged 8,058 and ranged from 399 to 20,002. However, escapement estimates are not always indicative overall habitat productivity because they do not necessarily reflect the harvest of Cedar - Sammamish Watershed basin origin subadult and adult coho.

The Cedar River coho stock was identified as unique based on its spawn timing and its geographic isolation. However, the status of this stock appears to be on a downward trend in escapement. Between 1980 and 1999 the average escapement was 3,710. While there has been insufficient or no escapement data collected in four of the ensuing 10 years, the most recent two years indicate extremely poor returns. Since 1991, where data is available, the average coho escapement has been 697 fish.

Winter Steelhead

The Cedar - Sammamish Watershed winter steelhead stock has been characterized as "Depressed". This winter steelhead population began a steady decrease in the mid-1980's, similar to those of many other regional stream systems. Recently, escapement estimates of this stock has shown a slight upward trend but preliminary numbers from the 2000/01 run year indicate a poor return.

Sockeye

The Cedar River sockeye salmon stock makes up the largest production unit of the aggregate Lake Washington sockeye salmon run. The long-term trend for this stock is negative and the stock status is depressed. Lake Washington tributary sockeye spawners make up the second production unit of this stock and the long-term status is also depressed. The smallest production unit of this sockeye stock is Lake Washington beach spawners and the status of this stock is also depressed. This last stock has seen a larger decrease in percentage of population that the first two and the reasons are unclear. It has been hypothesized that the construction of docks and/or the introduction and explosive distribution of Eurasian watermilfoil may be partially to blame.

Kokanee

Cedar - Sammamish Watershed kokanee (*O. nerka*), the resident form of sockeye salmon, have been separated into two distinct stocks based on a number of key characteristics, the most important being run timing and unique genetic traits (Young et. al. 2001). The early run stock of kokanee that return to Issaquah Creek are considered native to the Lake Sammamish drainage.

Another stock of kokanee salmon enters east and south Lake Sammamish tributaries (e.g.: Laughing Jacobs, Ebright and Lewis creeks) from October through early January. These adult kokanee are morphologically distinct from the kokanee mentioned above with a heavy spotting pattern along their entire dorsal surface and both caudal lobes along with varying degrees of red coloration laterally.

Finally, what has been thought to be a separate kokanee stock present in Bear Creek (sometimes referred to as Big Bear Creek) and Swamp Creek is now believed to be genetically closer to sockeye salmon and has been called a residualized sockeye stock (Young et al 2001). However, if the definition of a kokanee is landlocked or residualized sockeye then this stock would be managed as a kokanee stock

Rainbow Trout

The rainbow trout found in Lake Washington are believed to be from one of two origins. They are growing juvenile steelhead trout that will ultimately smolt and migrate to the marine waters of Puget Sound and beyond or the from non-native stocks of hatchery origin rainbow trout reared fish released into WRIA 8 and intended for a "put-grow and take" or "put and take" recreational fisheries. The hatchery produced fish are not believed to be a self-sustaining population as there is no evidence of natural reproduction and the recreational harvest is quite high.

Coastal Cutthroat Trout

Assessing populations of coastal cutthroat trout in the Cedar - Sammamish Watershed Basin is particularly difficult. Ludwa et al. (1997) estimated the abundance of coastal cutthroat trout in McAleer Creek at 8 fish per 50 meters of stream. In that same study, the number of coastal cutthroat trout in Lyons Creek was estimated at 30 fish per 50 meters of stream. Scott et al. (1986) examined Kelsey Creek in 1979 and found 4 to 5 fish per 50 meters but that was increased to 23 fish per 50 meters in 1996 (Ludwa et al 1997).

Data for trends in coastal cutthroat trout abundance in Cedar - Sammamish Basin streams is not available at the time of this report. With a paucity of specific coastal cutthroat data, it is not within the scope of this report to determine population abundance for these fish. However, observations by local fisheries biologist indicate that coastal cutthroat populations in the Cedar Lake Sammamish Basin are increasing.

NMFS found the scarcity of available information made a risk assessment extremely difficult for coastal cutthroat trout. In their final conclusion a majority of the Biological Review Team (BRT) members believed the Puget Sound ESU coastal cutthroat is not presently in danger of extinction, nor is it likely to become so in the foreseeable future. A minority believed that the ESU is likely to become endangered in the foreseeable future (Johnson 1999).

Native Char (Bull Trout)

The stock status for bull trout in the basin is unknown. Information on the presence, abundance, distribution, utilization and life history of bull trout in the Cedar - Sammamish Watershed Basin is either unavailable or extremely limited. There are reproducing populations of native char in the upper Cedar River subbasin, principally associated with Chester Morse Lake. Reproducing populations of char in the lower Cedar River, Lake Washington or Lake Sammamish or their tributaries have not been confirmed.

Presently, only one life history form, adfluvial, of bull trout is known to be present in Chester Morse Reservoir. Resident forms may be present in the upper headwaters of the Cedar or Rex Rivers or within some of their tributaries. Quantitative information concerning life history and abundance of these fish in WRIA 8 is sparse. Redd counts conducted during the from 1992 to 2000 inclusive range from 6 to 236 (Kurko pers comm) but viewing conditions during some years likely caused an underestimation of the actual number of redds.

III. Individual Sub-Watershed Synopsis

a. Streams Draining Directly to Puget Sound

Primary designated land uses: residential, commercial, and industrial

Recently documented salmonid species present: chinook (rare), coho (sparse), chum (sparse) and coastal cutthroat trout.

A number of independent streams in WRIA 8 drain directly into Puget Sound. Among the largest are Pipers Creek, Boeing Creek and Picnic Point Creek. All have correspondingly small drainage basins, are heavily impacted by urbanization and no longer function properly in supporting naturally reproducing salmonid populations.

Limiting Habitat Factors and Impacts:

Urban, commercial and industrial use that are:

- Creating fish passage barriers;
- Altered stream hydrology;
- Reduction in channel complexity;
- Reduction in LWD recruitment; and
- Generally non-functional riparian habitats

b. Marine Nearshore

Primary designated land uses: railroad, residential, commercial and industrial

Recently documented salmonid species present: All species of juvenile and adult anadromous salmonids (chinook, coho, sockeye, winter steelhead, and coastal cutthroat trout) from WRIA 8 utilize this subarea. Anadromous salmonids and additional anadromous salmonid species (e.g.: chum and pink) from other WRIAs also utilize this subarea. .

The Marine Nearshore (Nearshore) is, by definition those habitats that lie between the lower limit of the photic zone (approximately at minus 30 meters MLLW) and the upland–aquatic interface. It provides a critical link in the life history of all anadromous salmonids for physiological transition, feeding, refuge and as a migration route to and from the ocean. Most anadromous salmonid species utilize the Nearshore for juvenile rearing.

The overwhelming majority of the marine shoreline of WRIA 8 has been adversely impacted by the placement of a railroad line along 87% of the shoreline. This eliminated the supply of beach sediments that were the source of most of the sands and gravels to the beaches. The placement of the railroad line also eliminated the marine riparian vegetation that would have historically been present. These impacts not only adversely impact anadromous salmonids originating from WRIA 8 but other WRIAs as well that utilize the shorelines for support during migration.

All migratory juvenile anadromous salmonids are dependent on healthy and functioning estuarine and nearshore environments. Some species, such as chinook and chum salmon, are more dependent on healthy estuarine habitats for physiological transition and rearing prior to their ocean migration. Nearshore habitats also produce important prey items for anadromous salmonids including vertebrate and invertebrate species utilized by juveniles and forage fish (e.g.: herring, sandlance, and surf smelt) utilized by subadult and adult salmonids.

Limiting Habitat Factors and Impacts:

Industrial, urban, and commercial use that are:

- Interrupting ecosystem processes such as beach sediment recruitment;
- Alterations to water quality;
- Reduction in LWD recruitment; and
- Generally non-functional riparian habitats.

c. Hiram M. Chittenden Locks and Salmon Bay

Primary designated land uses: commercial and recreational boat traffic and surface water elevation (level) control structure for Lakes Union and Washington

Recently documented salmonid species present: chinook, coho, sockeye, steelhead, chum, pink salmon and coastal cutthroat trout.

Physical Changes: In 1916 the Ship Canal was completed, resulting in the rerouting of the outlet of Cedar - Sammamish Watershed from the Black River through the Lake Washington Ship Canal (Ship Canal) and the Hiram M. Chittenden Locks (Locks). One of the results of this project was the lowering of the surface of Lake Washington an average of 9 feet. The completion resulted in moving the estuary outlet for Lake Washington from the Duwamish River to the Ship Canal and into Salmon Bay.

The Locks were constructed as a navigation project, with a small and large lock, to provide commercial boat traffic from the marine waters of Puget Sound to the protected freshwater waters of the Ship Canal and Salmon Bay. The original project purpose and design did not include specific features to pass downstream migrating salmon and steelhead smolts.

The physical separation of the freshwater in Lake Washington and the marine waters of Puget Sound has resulted in one of the most modified estuary systems on the West Coast of North America.

Historically, Salmon Bay was a long, shallow, tidally inundated, saltwater bay that opened to Puget Sound and had tidal elevations equal with Puget Sound. At low tide, it was practically dry, the water level dropping as much as 20 feet (6.1 m) between extreme high and low tides (Williams 2000), but averaging 8 foot (2.4 m) fluctuations between high and low tide. Salmon Bay connected to Shilshole Bay through, The Narrows, where the Locks were

eventually placed. Early maps indicate a small stream (Ross Creek) drained from Lake Union into Salmon Bay. In the late 1800's, this original stream had been dredged, straightened and widened to allow for the transport of logs between Salmon Bay and Lake Union. With completion of the Lake Washington Ship Canal, the Fremont Cut, and Salmon Bay waterway, a navigable connection between Lake Union and Salmon Bay was established.

Currently, the mile-long Salmon Bay waterway between the Locks and Shilshole Bay serves as the "estuarine" area with the Locks creating for migrating adult and juvenile salmon an abrupt transition between fresh and marine waters. This area is not an estuary formed by river action and associated deposition, but was historically influenced by tidal action up to the Fremont Cut. As a result, this area lacks the diversity of habitats and brackish water refuges characteristic of other (unaltered) river estuaries and over 1,300 acres of shallow water and wetland habitat were lost from the implementation of the Locks and Ship Canal.

Limiting Habitat Factors and Impacts:

The Locks are a unique feature that:

- Caused fish passage delays and mortalities;
- Created a highly altered estuary;
- Thru dredging, filling and bank hardening created a loss of over 1,300 acres of shallow water and wetland habitats;
- Simplified the remaining channel; and
- Adversely impacted water quality.

d. Lake Union and Ship Canal

Primary designated land uses: commercial and recreational boat traffic, water dependent industrial and commercial use with upland areas primarily in residential, commercial and industrial uses.

Recently documented salmonid species present: chinook, coho, sockeye, steelhead, rainbow and coastal cutthroat trout.

Physical Changes: The construction of the Lake Washington Ship Canal (completed in 1916) created a connection between Lake Washington, Lake Union, and Puget Sound where previously there had been none. Lake Union and what is now known as Portage Bay were originally separated from Lake Washington and Union Bay by a natural ridge. Historically, Lake Union is believed to have been a separate drainage basin fed by underground springs and intermittent creeks. By 1885, a narrow canal, which served as a log chute, had been excavated between Lake Washington and Lake Union. As part of construction of the Ship Canal, a minimum 100 foot-wide navigable passage was constructed between the two lakes and between Lake Union and the original Salmon Bay.

The overwater coverage, bulkheads, and shoreline armoring associated with land uses is extensive. As a result, there is relatively little shallow water habitat (natural or altered) along

the Lake Union shorelines. Portage Bay, however, has retained shallow water habitat. 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.

Limiting Habitat Factors and Impacts:

Lake Union and the Ship Canal are unique features in WRIA 8 that:

- Degraded water quality through an increase in water temperature;
- The riparian shoreline of Lake Union is highly altered from its historic state;
- Historic practices and discharges into Lake Union and the Lake Washington Ship Canal have contributed to the contamination of bottom sediments;
- Thru dredging, filing and bank hardening simplified the historic channel;
- Thru dredging, filling and bank hardening simplified the historic stream channel; and
- Non-functional riparian habitats.

e. Lake Washington

Primary designated land uses: recreational boat traffic, water dependent commercial use, shorelines primarily single and multi family residential structures with upland areas primarily in residential, commercial and industrial uses.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout.

Physical Changes: Lake Washington is the second largest natural lake in Washington State with a surface area of 22,138 acres. The lake drains to Puget Sound via the Lake Washington Ship Canal, an artificial waterway 8.6 miles long. The main inflow to the system is the Cedar River, which contributes about 55 percent of the mean annual inflow. The Sammamish River contributes approximately 27 percent of the surface flow to the lake.

Lake Washington has experienced a series of physical and limnological changes that began in 1916 when the natural outlet of the lake, the Black River, was blocked, and the outlet was changed to the Ballard Locks. At the same time, the Cedar River was redirected to increase the amount of flow into Lake Washington. These actions lowered the lake's level by about 10 feet, exposed 5.4 km2 of previously shallow water habitat, reduced the lake's surface area 7.0 percent, decreased the shoreline length by about 12.8 percent, and eliminated much of the lake's wetlands. Historically, the lake level varied by up to 6.5 feet during flood events. Currently the level of Lake Washington is not allowed to fluctuate more than 2 feet.

The shoreline of the lake has been extensively altered. Historically, more commercial development was located on the lakeshore, but as the population in the watershed has grown, the demand for residential waterfront property increased significantly. The majority of the shoreline is now urban, residential, with the exception of a few commercial and industrial developments. Thirteen incorporated cities now border the lake.

As the watershed has developed, dredging, filling, bulkheading, and the construction of piers, docks, and floats have occurred in shoreline areas. An estimated 82 percent of the Lake Washington shoreline has been bulkheaded. There is 33.2 miles of Lake Washington shoreline within the Seattle city limits of which 31.5 miles (or 95 percent) was classified as unretained (i.e., not hardened) in 1999 (Weitkamp et al. 2000). Overall, 70.65 percent of the Lake Washington shoreline is retained by either rip-rap or bulkheads, while 29.35 percent of the shoreline is unretained and is either beach, naturally vegetated, or landscaped.

In 1999, there were an estimated 2,737 piers and docks along the shore of the lake that collectively covered about 4 percent of the lake's surface within 100 feet of shore (Toft in prep). This estimate did not include marinas, moored vessels, commercial developments and bridges. This represents an overall frequency of 36 docks per mile. In 1942 there were an estimated 1,122 docks (Hockett 1976). The 1999 counts represent an increase of 1615 docks from 1942. The annual percent increase in new docks has been steadily decreasing from 5.7 % in the 1940's, to 1.8 % in the 1960's and 0.5 % during the 1990's. The annual percent of recreational docks has been increasing at about the same rate as the total dock count but the annual percent increase of large marina dock complexes increased during the late 1970's and 1908's, leading to a doubling in the number since 1960 to an overall count of 111 (Toft in prep). These figures do not account for increases or decreases in the size of the docks.

Much of the large woody debris that was likely associated with the lake's shore has been eliminated. The only "natural" shoreline remaining in Lake Washington is in the vicinity of St. Edwards Park, which represents less then 5 percent of the lake's shoreline. A recent survey of the lake's shoreline under the City of Seattle's jurisdiction indicated that "natural vegetation" was present along only 22 percent of the northern shoreline and 11 percent of the southern shoreline.

The limnological characteristics of Lake Washington have undergone dramatic changes during the last 50 years. Except for combined sewer overflows, sewage effluent was completely diverted from the lake by 1968 and the lake subsequently reverted to a mesotrophic state. The major sources of phosphorus inputs to the lake are now from tributary streams. As a result of the diversion of sewage, several major changes in the zooplankton community occurred. Most notably, beginning in 1976, *Daphnia* became the dominant pelagic zooplankton taxa.

Cleanup of the lake resulted from the formation of METRO in the 1950's, which rerouted sewage discharges to Puget Sound. The cleanup of Lake Washington due to the rerouting of sewage effluent provides one of the best examples anywhere of a successful, large-scale, regional restoration program.

In addition to changes in the lake's littoral zone and limnology, exotic plants and animals (i.e., non-native) have impacted the Lake Washington ecosystem. Twenty-four non-native fish species have been identified in Lake Washington. Some of these species are known to prey on juvenile salmon (e.g., smallmouth bass) while others are potential competitors with juvenile salmonids for food.

Nine introduced, non-native plant species are currently present in Cedar - Sammamish Watershed. Certainly one of the most visible, and also likely the most significant is Eurasian watermilfoil, an exotic aquatic plant, which was introduced into Lake Washington in the 1970's.

Limiting Habitat Factors and Impacts on Lake Washington:

- The riparian shoreline of Lake Washington is highly altered from its historic state. Current and future land use practices all but eliminate the possibility of the shoreline to function as a natural shoreline to benefit salmonids;
- Introduced plant and animal species have altered trophic interactions between native animal species;
- The known historic practices and discharges into Lake Washington have contributed to the contamination of bottom sediments at specific locations;
- The presence of extensive numbers of docks, piers and bulkheads have highly altered the shoreline; and
- Riparian habitats are generally non-functional.

f. Lake Washington tributaries (except the Cedar River)

Primary designated land uses: primarily residential, commercial and industrial.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout.

The tributaries of Lake Washington are among some of the most altered hydrological streams in the Puget Sound Region. They low gradient streams, have a hydrology pattern generally dependent on rainfall and groundwater and not snowpack, and exist in heavily urbanized settings and are subjected to the adverse habitat impacts that accompany this setting. These drainage basins generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems.

Limiting Habitat Factors and Impacts on Lake Washington tributaries

Land use practices have resulted in:

- Numerous known and unknown blockages;
- Pool habitat is limited with very few deep pools, off-channel habitat, instream complexity, riparian cover and refugia habitat is lacking and little LWD is available;
- The hydrologic connectivity to the floodplain has been degraded due to streambank hardening;
- The riparian buffers typically are inadequate and often fragmented;
- Changes to the natural hydrologic regime; and
- There are high levels of impervious surfaces.

g. Cedar River (lower and upper) and its tributaries

Primary designated land uses: In the lower Cedar River reaches a combination of industrial, commercial, residential use transitioning into agricultural and forestry as one moves upstream outside of urban growth boundaries. In the upper Cedar River the predominant land use is transitioning from commercial forestry to preservation of forests inside the City of Seattle municipal watershed.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout. In the upper watershed native char (Bull trout) have been documented.

The lower Cedar River tributaries are low to moderate gradient streams, have their origins in rain-on-rain elevations, and exist in urbanized settings with the adverse habitat impacts that accompany this setting. The downstream reaches generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems. As one moves upstream, habitat conditions show improvement but in many instances do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival. The Cedar River is also the largest (by volume) input of water into Lake Washington.

The City of Seattle began to divert water out of the upper Cedar River in 1901 and access for anadromous fish has been denied since that time. The reintroduction of anadromous fish is scheduled to occur by 2003(?). Land use of the upper watershed has historically been a mixture of commercial timber harvest and preservation for the City of Seattle water supply. In 1995 the City of Seattle, who owns 99.4% of the upper watershed, placed a moratorium on timber harvest and in its place initiated an emphasis on protection and restoration of lands in the watershed.

Limiting Habitat Factors and Impacts on Lake Washington tributaries

Land use practices have resulted in lower Cedar River and its tributaries:

- Numerous known and unknown blockages;
- Bank hardening features (e.g.: levees) that have caused scouring, reduced side channel and off-channel habitats;
- Pool habitat is limited with very few deep pools, instream complexity, and refugia habitat is lacking and little LWD is available;
- The hydrologic connectivity to the floodplain has been degraded due to streambank hardening;
- A reduction in forest cover and increasing impervious surfaces;
- Rechanneling of specific stream reaches that limits lateral stream migration to facilitate roads and protect property;
- The riparian buffers typically are inadequate and often fragmented; and
- Some streams have high levels of impervious surfaces.

Land use practices have resulted in upper Cedar River and its tributaries:

Generally speaking, these lands are in a state of protection and in recovery from recent logging in some areas;
The Landsburg Diversion Dam is still a blockage to anadromous fish but anadromous fish are scheduled to be allowed upstream with the construction of passage facilities in 2003

h. Sammamish River and its tributaries

Primary designated land uses: Residential, open space and recreational areas, urban commercial, residential and agriculture.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout.

The Sammamish River corridor is a distinct, regional landscape feature, which originates at the north end of Lake Sammamish and ends at the river mouth at the northern tip of Lake Washington. The river itself drains a watershed of about 240 square miles, of which 97 square miles are in the Lake Sammamish basin, 50 are in the Bear Creek basin, 67 are in the combined basins of Little Bear, Swamp and North creeks, and the remaining 26 in small sidewall streams and the valley floor comprise this subarea. The current river channel is 13.8 miles long.

The Sammamish River corridor can be divided into two reaches, based on topography and, to a lesser extent, land use. The lower corridor extends from R.M. 4.5 to R.M. 0.0 on Lake Washington. It has a much narrower, topographically constrained drainage area, which includes the downtown cores of the cities of Bothell and Kenmore but also some open space areas. The lower reach includes two large salmon-bearing streams, Swamp Creek and North Creek. A major King County sewer line runs underneath the Sammamish River Trail, which is adjacent to most of the river. The sewer line and the trail create potential constraints for restoration projects on their side of the river (mostly the right bank). From the standpoint of planning, the trail is also important for the recreational use it receives and the public ownership it provides.

The upper river corridor extends from the head at river mile (R.M.) 13.8 north to R.M. 4.5 through a floodplain valley that is more than one-mile wide in places. Two salmon-bearing streams are located in the upper reach: Bear Creek and Little Bear Creek.
Prior to Euro-American settlement, the Sammamish River had a complex, highly sinuous, meandering channel and abundant "swampy" areas that were filled with peat and diatomaceous earth.

Prior to the lowering of Lake Washington, there was generally about an 8.4-foot elevation difference between Lake Sammamish and Lake Washington. The river lost most of this elevation in its upper reach; backwater effects from Lake Washington appear to have extended beyond the confluence with Little Bear Creek. This backwatered area included extensive forested wetlands, especially at the mouth of North Creek. The Sammamish River was historically approximately twice as long as it is today, and overflowed its banks regularly. Its

corridor was densely forested with cedar, hemlock and Douglas fir, with willows and deciduous vegetation dominating close to the river banks.

The river corridor was heavily logged from the 1870s through the early 20th Century, by which time it had been essentially cleared of its old growth forest. Farming was attempted in the floodplain, but became feasible on a much larger scale after the opening of the Chittenden Locks in 1916, which lowered Lake Washington about nine feet, effectively draining most of the sloughs and wetland habitats along much of the corridor, especially in the lower reach. Lake Sammamish was lowered by this action as well, which decreased the elevation difference between the lakes to approximately twelve feet, reducing the river current somewhat. Around this same time, farmers in the Sammamish Valley formed a drainage district, which began to straighten the upper reach of the river to improve farmlands. By the mid-1920s, the river had largely been placed in its current location, though not at its current depth. The lowering of the lake, the channelization of the river and the construction of drainage ditches in the river valley eliminated much of the complexity of the floodplain, including wetlands, side-channels and many spring-fed streams that had flowed into the river from neighboring hillsides. Beginning in 1962, the U.S. Army Corps of Engineers systematically dredged and channelized the mainstem Sammamish River into its current conformation, primarily as a flood control project to prevent flooding of adjacent farmland during high spring flows. This action deepened the river by five feet throughout the valley and hardened the river's banks throughout most of its length, dramatically decreasing its remaining connection with the floodplain and cutting off most of the smaller streams to the river as resulting in a loss of salmonid refugia and/or forage areas

The Bear Creek subbasin represents the most important salmonid bearing system in the Sammamish River geographic area. The Bear Creek drainage basin covers approximately 32,100 acres (50 square miles). Throughout the basin are more than 100 miles of streams, nine (9) lakes, and over 2000 acres of identified wetlands.

The basin landscape and hydrologic network of streams have changed markedly in the past 150 years from primarily forest to a mix of forest, grass, and impervious surfaces. The landscape of the Bear Creek basin in 1985 was a mix of forest (71 percent), grass (17 percent), wetland (9 percent), and effective impervious surfaces (3 percent) (King County, 1989). The Bear Creek Basin Plan completed in 1990 identified large portions of lower Bear, Evans, and Cottage Lake Creeks needing habitat restoration.

One of the unique resource areas in this subbasin is Cold Creek. This cold-water spring is 5 to 7° C colder than the remainder of Bear Creek stream water temperatures. Bear Creek acts to cool the summer and early fall water temperatures in the Sammamish River downstream of the confluence.

Limiting Habitat Factors and Impacts on Lake Washington tributaries

In the Sammamish River and its tributaries land use practices have resulted in:

- Numerous known and unknown blockages;

- Bank hardening features (e.g.: levees) that have caused scouring, reduced side channel and off-channel habitats;
- Pool habitat is limited with very few deep pools, instream complexity, and refugia habitat is lacking and little LWD is available;
- The hydrologic connectivity to the floodplain has been degraded due to streambank hardening;
- A reduction in forest cover and increasing impervious surfaces leading to hydrologic disruption to natural stream flows, increased sedimentation and decreased water quality;
- Rechanneling of specific stream reaches that limits lateral stream migration to facilitate roads and protect property;
- The riparian buffers often are inadequate and fragmented; and
- Some stream basins have high levels of impervious surfaces.

i. Lake Sammamish

Primary designated land uses: Residential, open space and recreational areas, urban commercial, residential and agriculture.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout.

Lake Sammamish is located approximately 16 kilometers east of Seattle and is situated within the northern end of the 223 km^2 Sammamish Watershed. The lake provides a wide range of recreational and natural resource opportunities. The majority of the shoreline is privately owned; with only a few public parks that are located on the lakeshore. Water quality plays a key role in the lake's ecological health.

Lake Sammamish is approximately 13 kilometers long and 2 kilometers wide with a surface area of 19.8 km^2, a maximum depth of 32 meters and a mean depth of 17.7 meters. The major tributary to the lake is Issaquah Creek, which enters at the south end and contributes approximately 70 percent of the surface flow (and phosphorus load). Tibbetts Creek to the south, and Pine Lake Creek to the east, contribute about 6 percent and 3 percent of the flow, respectively. Surface water discharge from Lake Sammamish is through the Sammamish River at the north end of the lake, where a flow control weir at Marymoor Park controls the discharge.

Limiting Habitat Factors and Impacts on Lake Sammamish

In Lake Sammamish anthropogenic factors that effect the natural production of salmonids include:

- Alteration of the type and abundance of salmonid predators in Lake Sammamish have been identified as a probable factor of decline;
- Select areas of the Lake Sammamish contain elevated concentrations of sediment-associated contaminants;

- Eurasian water milfoil locally degrades water quality by reducing dissolved oxygen levels below minimum requirements for salmonids. The invasive nature of Eurasian water milfoil has likely decreased the overall diversity of macrophytes throughout Lake Sammamish; and
- The riparian buffers often are inadequate and fragmented.

j. Lake Sammamish Tributaries

Primary designated land uses: Residential, open space and recreational areas, urban commercial, forestry, and agriculture.

Recently documented salmonid species present: chinook, coho, sockeye, kokanee, steelhead, rainbow and coastal cutthroat trout. A single observation of two bulltrout has also been reported.

The East Lake Sammamish Tributaries encompass approximately 16 square miles and contains six main streams and 40 inventoried wetlands. There is a total of 27 miles of streams, of which only 4 miles are accessible to anadromous fish. These streams are currently inaccessible to salmonids due to erosion, dredging and culvert blockages, as well as natural stream channel gradient. Historically, there were 8 to 10 more miles accessible to anadromous fish. Most streams are short and steep, running through incised ravines. The urbanization of the basin has resulted in a variety of hydrologic and physical changes within the stream channels. Increases in peak flows and duration of high flows has resulted in expanding channel size, increased bank erosion, and increases in sediment deposition disrupting the aquatic habitat.

The Issaquah Creek Basin encompasses approximately 61 square. The basin's headwaters flow from the steep slopes of Cougar, Squak, Tiger and Taylor Mountains. Elevations range from more than 3,000 feet at the peak of Tiger Mountain to near sea level at the mouth of Issaquah Creek. The basin includes Issaquah Creek and its tributaries Holder, Carey, Fifteenmile and McDonald Creeks and the North and East Forks of Issaquah Creek as well as Tibbetts Creek.

Data from 1995 indicates that more than 75 percent of the basin was forested, with the remainder in wetlands, pastures, urban (less than 10 percent), and cleared areas. Currently, 30 percent of the basin is zoned commercial forest production, 12 percent is within the urban growth boundary, and the remaining in rural zoning (58 percent). Over 40 percent of the lands are in public ownership. Population increases in the basin and resultant pressure to develop rural lands are expected to continue. The population of the Issaquah Creek Basin is projected to increase by 18 percent between the year 2000 and 2020.

The Lewis Creek Basin drains a 1,209-acre area originating from the north slopes of Cougar Mountain. Lewis Creek flows northeasterly approximately 1.5 miles before it empties into the southern end of Lake Sammamish. Lewis Creek has numerous branched tributaries, forming a highly dendritic hydrologic pattern. Lewis Creek and its main tributaries are high gradient and

active streams with high sediment transport capacities. A multispectral analysis conducted in 2000 shows the basin has approximately 28 percent impervious surfaces

Limiting Habitat Factors and Impacts on Lake Sammamish

In Lake Sammamish tributaries the anthropogenic factors that effect the natural production of salmonids include:

- Known and unknown blockages;
- In some basins high levels of impervious surfaces have resulted in changes to hydrology;
- LWD is generally lacking;
- The loss of channel complexity as expressed through off-channel rearing refugia is believed to limit natural production of some salmonid species; and
- The riparian buffers often are inadequate and fragmented.

iv. CONCLUSIONS

There are solutions to all of the problems outlined in this report. Levees can be set back and off-channel habitats recreated. Riparian buffers can be reestablished that meet the needs of salmonids and then the vegetation allowed to mature. As an interim measure LWD can strategically be added to create niche habitats required by adult and juvenile fish.

The most basic need, shared by all life stages of all salmonid species is **water**. Water is absolutely essential to the needs of salmonids in both quality, quantity, and timing. As these urbanized basins continue to experience development and additional water is demanded by human residents there will continue to evolve a classic conflict between the needs of the fish and those of the humans. Adequate base flows in the streams, rivers and lakes will need to be set aside to meet the needs of fish. In urbanized basins protection from extreme high flows may be as important to base flows. It is not so much that humans have concentrated themselves in these basins, but what we do to the land and the method by which water is released into the streams and rivers. Finally, good water quality must be maintained.

The Limiting Factors Report is a coordinated step toward salmonid recovery in WRIA 8. It provides much of the necessary groundwork for a comprehensive recovery and conservation planning effort. The information presented in this report is a start. As new information is brought forward or is developed any conservation and recovery effort should be modified as necessary.

What This Report is Not

This report should be considered a work-in-progress. It does not examine the roles of hatcheries or harvest management. These other two “H’s” are inextricably linked, especially in basins like the Lake Washington Basin that are among the most heavily altered systems in Pacific Northwest.

PURPOSE OF REPORT

The successful recovery of naturally spawning salmon populations depends upon directing actions simultaneously at harvest, hatcheries, habitat and hydro, the 4H's.

The 1998 and 1999 state legislative sessions produced a number of bills aimed at salmon recovery. Engrossed Substitute House Bill (ESHB) 2496 is a key piece of the 1998 Legislature's salmon recovery effort. While both habitat protection and restoration need to be a part of the state's overall salmon recovery strategy, the focus of ESHB 2496 is primarily directed at salmon habitat restoration.

ESHB 2496 in part:

- directed the Conservation Commission in consultation with local government and the tribes to invite private, federal, state, tribal and local government personnel with appropriate expertise to act as a technical advisory group (TAG);

- directed the TAG to identify limiting factors for salmonids to respond to the limiting factors relating to habitat pursuant to section 8 sub 2 of this act;

- defines limiting factors as "…conditions that limit the ability of habitat to fully sustain populations of salmon."

- defines salmon as all members of the family salmonidae, which are capable of self-sustaining, natural production.

The overall goal of the Conservation Commission's limiting factors project is to identify habitat factors limiting production of salmon in the state. In waters shared by salmon, steelhead and bull trout we will include all three. Later, the Conservation Commission will add bull trout only waters.

It is important to note that the responsibilities given to the Conservation Commission in ESHB 2496 do not constitute a full limiting factors analysis. The hatchery, hydro and harvest segments of identifying limiting factors are being dealt with in other forums.

SSSB 5595 is a key piece of the salmon recovery effort from the 1999 Legislature's 1st Special Session. This legislation reaffirmed the needs to complete a limiting factors report (as found in 2496) and among other items modified the definition of limiting factors to mean "… conditions that limit the ability of habitat to fully sustain populations of salmon ..." While striking out that portion of the definition found in ESHB 2496 dealing with barriers, degraded estuarine areas, riparian corridors, stream channels and wetlands. Removing those terms does not eliminate them from inclusion in the limiting factors report, rather it expands the scope of the report to include those elements for inclusion along with other pertinent elements specific to the WRIA in this report.

The report is intended to provide the additional scientific foundation for the development of a "Near-Term Salmonid Action Agenda" to be developed by the WRIA 8 Technical and Staff Committees in. The Near-Term Action Agenda will recommend early and interim action projects, policies and programs to conserve and protect salmonids in the Cedar - Sammamish Watershed. It will primarily focus on actions the Steering Committee and its subcommittees are confident will remain high priorities as the final Conservation Plan is developed. The Near-Term Action Agenda will guide decision-making by local governments and other implementers in WRIA 8 as the final Watershed Conservation Plan is being completed.

INTRODUCTION

This report was developed by the Greater Lake Washington Watershed (WRIA 8) Technical Committee to fulfill the requirements of ESHB 2496 and for the Greater Lake Washington Watershed (WRIA 8) Steering Committee. The WRIA 8 Technical Committee has served in a dual capacity. The Technical Committee is charged with providing technical support to the WRIA 8 Steering Committee's efforts and as the Technical Advisory Group (TAG) that developed the Cedar Sammamish Basin (WRIA 8) Habitat Limiting Factors report called for in legislation passed by the Washington State Legislature Salmonid Recovery Bills (ESHB 2496 and SSSB 5595).

This report, "Salmon and Steelhead Habitat Limiting Factors Report for the CEDAR – SAMMAMISH BASIN (Water Resource Inventory Area 8)" represents the initial watershed habitat assessment for WRIA 8. The purpose of the report is to summarize existing information on salmonid populations and distribution in addition to the conditions of salmonid habitat in the watershed. The Report identifies habitat factors of decline effecting anadromous and resident salmonids in the WRIA 8 watershed and is based on available data. Salmonid habitat condition criteria obtained from peer reviewed literature articles were then applied to the known habitat conditions and ranked as *Good*, *Fair*, or *Poor*. For areas where data was incomplete or lacking a rating of *Need Additional Data* (NAD) or *No Data* (ND) was used. The report also identifies gaps in the available data and technical understanding and recommends general strategies for addressing the habitat factors of decline.

Watershed Description

Out of the 692 square miles in WRIA 8, 607 are in the Cedar - Sammamish watershed, which contains two major river systems, the Cedar and the Sammamish, and three large lakes, Union, Washington and Sammamish. The remainder of the WRIA consists of numerous small watersheds that drain directly to Puget Sound between Elliott Bay and Mukilteo. Lake Washington is the second largest natural lake in the state, with about 80 miles of shoreline (including about 30 miles along the shore of Mercer Island) and a surface area of about 35.6 square miles. Arguably, Lake Washington has the most heavily altered watershed on the West Coast, given the historic changes discussed below. Despite such heavy alteration, it supports numerous salmon runs, including the largest run of sockeye salmon outside of Alaska in the United States. Scientists from the Washington Department of Fish and Wildlife say that WRIA 8, as heavily altered and urbanized as it is, can still produce more salmon per square mile than any other WRIA in the state, largely because sockeye are a mass spawning fish and need a lake for rearing (Fresh, 1996).

WRIA 8 is located predominantly within the borders of King County, but 15 percent of it extends northward into Snohomish County. To the west it is bounded by Puget Sound, while to the east the headwaters of the Cedar River reach the crest of the Cascade Range near Stampede Pass. The northern and southern boundaries follow hilltops, ridges and plateaus that define the drainage divides between the Snohomish/Snoqualmie (WRIA 7) and Green/Duwamish (WRIA 9) watersheds, respectively. The lakes and two main rivers of WRIA 8 are fed by numerous tributaries that drain a network of streams, ponds, wetlands and

aquifers. From a geologic perspective, these hydrologic features are immature because they are located in the complex topography that is still dominated by the effects of glaciation just 14,000 years ago.

The Lake Washington watershed has been dramatically altered in the 150 years since the first Euro-American settlers arrived in the Seattle area. This started with heavy logging of old growth forest in the 19th Century. It expanded at the turn of the 20th Century, when Seattle tapped the Cedar River as its main source of water supply. A major alteration of the watershed occurred in the decade of 1910-20, when the Lake Washington Ship Canal and Hiram M. Chittenden Locks were completed. The ecological consequences of this last alteration were profound: the outlet of Lake Washington was redirected from its south end, at the Black River; the new outlet at the Locks provided an abrupt transition from freshwater to saltwater and had almost no features of a natural estuary; and the level of Lake Washington was dropped about nine feet, which drained wetlands along much of its shoreline and dramatically changed its confluences with tributaries. In a separate but related action in the same decade, the Cedar River was redirected from its normal connection with the Black River, which fed the Duwamish, and was channelized to flow into Lake Washington, with the initial hope of creating a major freshwater industrial port at Renton. Lowering Lake Washington also lowered Lake Sammamish and drained the vast wetland complex that had made up the Sammamish River Corridor between the lakes. This provided the basis for a major expansion of farming in the corridor, which led to channelization of the Sammamish River to nearly its present course in the early 1920s. Thus, by the 1920s the general hydrogeography of today's watershed was established.

In the ensuing years, the most important cause of physical change to the watershed has been the expansion of urban and suburban development. In particular, this has altered the hydrology of the watershed; both through changes in land cover and through increased water withdrawals. Changes in land cover due to urbanization have been extensively shown to relate to degradations in salmon habitat, mostly due to changes in flows but also because of degraded riparian areas. The removal of forest cover for urban and suburban development dramatically increases the size and frequency of high flows from stormwater in lowland creeks. It also reduces low flows in the summer and early fall, because cleared land and impervious surfaces dramatically reduces groundwater recharge. As to increased water withdrawals, through the 1950s these were primarily from Seattle's Cedar River Watershed, but total withdrawals from the watershed have been relatively stable since then, as Seattle and the region have developed other supplies. Major withdrawals in the watershed since then have been from groundwater below the lower Cedar River, lower Issaquah Creek, lower Bear Creek and Rock Creek (a tributary to the Cedar River). Following significant floods in the 1950s, countywide flood control efforts in the 1960s led to a dramatic expansion of levees on the Cedar River and local sponsorship of major dredging and levee construction on the Sammamish River by the Corps of Engineers. This in turn supported the greater development of the floodplains of both rivers. Meanwhile, expanding urbanization led to heavy residential development of the shorelines of Lake Washington and Lake Sammamish. Residential development has also expanded along the bluffs above Puget Sound and along parts of its shoreline. The nearshore of WRIA 8 was even more dramatically affected by the construction of a railroad line along most of its length early in the century. Bulkheads and other

protections for the railroad line and developments have significantly curtailed natural, beach-forming ecological processes along the Puget Sound nearshore.

Beside these changes in physical habitat, the introduction of non-native fauna and flora have significantly changed the biology of the Lake Washington ecosystem. There are 24 known non-native fish species in the watershed, including notably smallmouth and largemouth bass, which can be significant predators of juvenile salmonids. Sockeye salmon in the lake system are believed to be primarily the descendants of fry transplanted from Baker Lake in the 1930s. Since juvenile sockeye require a lake for a year or more of rearing, the Cedar River supported few if any sockeye prior to its connection with Lake Washington (in years of heavy floods, the historic Cedar River flowed into Lake Washington for short periods of time, but the connection was not lasting or regular). However, the Cedar did support runs of pink and chum salmon prior to being redirected into Lake Washington; these are now extirpated. As to non-native flora, Eurasian watermilfoil now dominates much of the shorelines of Lakes Washington and Sammamish. Himalayan blackberry is common in riparian areas throughout the watershed, and Japanese knotweed and reed canary grass are spreading.

The Cedar-Sammamish Watershed is comprised of two major physiographic areas. The eastern portion of the watershed (about 14 percent of its total area) lies in the Cascade Range while the western portion (the remaining 86 percent) occupies the Puget Sound Lowland. Largely because of its elevation, the eastern portion (the upper Cedar River and parts of upper Issaquah Creek) receives much more precipitation than the western portion, up to 102 inches annually compared to an average of 38 inches, respectively. The three basins in the watershed with the largest salmonid populations--the Cedar River, Bear Creek and Issaquah Creek--are distinctly different based on geology, hydrology and topography. Only the Cedar River, which originates in relatively high mountain country in the Cascade Range, develops a large annual snowpack. Issaquah Creek originates at the foot of the Cascades, in bedrock hills that are too low to hold snow for sustained spring or summer runoff. Bear Creek is entirely a lowland stream system, originating in a large are of forests and wetlands in south Snohomish and north King counties. Beside the Cedar River, all of the watershed must rely primarily on groundwater to sustain baseflows in the summer and early fall.

The division of the watershed by its topography and its two major lakes gives it ecological complexities not found in watersheds based on major river systems. Habitat issues for salmon in the Cedar River, Issaquah Creek and Bear Creek are largely unique to each system; actions to address them can be largely independent of one another. The geographic distribution of these systems, and the physical differences between them, have helped create genetic differences among their salmon populations. All of these differences contribute to the likelihood that recovery goals for salmon in the watershed will be based not just on production, but also on distribution and genetic diversity within the watershed. The lakes have their own complex ecologies, which are not especially well understood but which make salmonids from the Lake Washington watershed unusual within Puget Sound. Native salmon from Bear Creek and other streams of the original Lake Washington basin would have co-evolved with lake habitats. However, the native salmon of the Cedar River would have evolved primarily in stream conditions. The effect of native salmon from the Cedar River

migrating and rearing in Lake Washington rather than in the Cedar, Black and Green/Duwamish rivers is not known.

WRIA 8 is the most heavily populated WRIA in the state, with approximately 1.4 million people, more than twice as many as any other WRIA despite its being geographically smaller than most. Based on projections by the Puget Sound Regional Council, this population is expected to increase more than 10 percent in each of the next two decades, bringing it to more than 1.7 million in 2020. Most of WRIA 8 lies within the Urban Growth Area boundaries. However, nearly all of its most productive salmon spawning habitats are not within that area. Beside the lower Cedar River and Bear and Issaquah creeks, only Little Bear and May creeks have upper basins that are largely outside of the urban area. The official life of the current boundary of the Urban Growth Area in King County is through 2014. A long-term challenge for salmon recovery throughout Puget Sound is to preserve and enhance habitat in the face of effects of increasing human population pressures.

HISTORIC AND CURRENT SALMONID POPULATION CONDITIONS IN THE LAKE WASHINGTON BASIN

Introduction

The 1992 Washington State Salmon and Steelhead Inventory (SASSI) (WDFW and WWTIT, 1994) described three summer/fall chinook (*Oncorhynchus tshawytscha*), two coho (*O. kisutch*), three sockeye (*O. nerka*) salmon stocks, and one winter steelhead (*O. mykiss*) stock in WRIA 8. The 1998 Salmonid Stock Inventory (WDFW 1998) (WDFW 1998) provided some brief information about bull trout stocks in the Lake Washington Basin. One stock of bull trout (*Salvalinus confluentus*) has been confirmed in the upper Cedar River subbasin, in Chester Morse Lake, however others have not been confirmed elsewhere in the Lake Washington Basin. While coastal cutthroat (*O. clarki clarki*) are known to occur in the Lake Washington Basin, they were not listed in the 2000 Salmonid Stock Inventory (WDFW 2000) (WDFW 2000). Two native stocks and a naturally producing *O. nerka* stock that has been genetically characterized as a "residualized stock of sockeye" of kokanee (*O. nerka*), a landlocked sockeye salmon, are believed to occur in some of the tributaries to the Sammamish River and Lake Sammamish subbasin respectively. Downen (pers comm 2001) hypothesizes that there may be three adfluvial populations of kokanee and three anadromous *O. nerka* (sockeye) populations east of the Sammamish River based on timing and spatial segregation. He separates these into: (1) a summer run Issaquah Creek stock that spawn only in Issaquah Creek with peak spawning in August; (2) North Lake Sammamish tributary kokanee that have peak spawning activity in October; and (3) East Fork Issaquah Creek and south Lake Sammamish tributary streams whose peak spawning is in November. Recent analysis of microsatellite DNA results for Lake Washington and Sammamish *O. nerka* indicates that there are two distinct populations of kokanee and a residualized sockeye stock (WDFW 2001).

This chapter will provide current information regarding the origin and current stock status of each of the salmonid stocks in Lake Washington (WRIA 8). Table 1 provides a detailed overview of stock status, origin, production type and Endangered Species Act (ESA) status.

SASSI (1994) divided the Lake Washington Basin summer/fall chinook into Issaquah Creek, North Lake Washington tributaries and Cedar River (and associated tributaries) stocks. Issaquah Creek chinook, a non-native hatchery origin stock, were classified as "Healthy" while the native naturally produced North Lake Washington tributary and Cedar River stocks had "Unknown" stock status. The National Marine Fisheries Service (NMFS) identifies the naturally produced fall chinook stock population in the Puget Sound chinook Evolutionary Significant Unit (ESU) and in 1999 listed that ESU as Threatened under the Endangered Species Act.

The Lake Washington coho were separated into two stocks by SASSI (1994): (1) the North Lake Washington and Sammamish tributaries, and (2) the Cedar River stocks. Both stocks are of a mixed hatchery and natural origin, while the Lake

Washington/Sammamish tributaries stock status is described as "Depressed" and the Cedar River coho stock as "Healthy".

Lake Washington sockeye stocks are distinguished from other Puget Sound origin sockeye stocks by geographic and reproductive separation. In WRIA 8, SASSI (1994) lists the three distinct sockeye stocks as: (1) Cedar River; (2) Lake Washington/Lake Sammamish tributary streams; and (3) Lake Washington beach spawning. SASSI (1994) indicates the stock status of all three as "depressed". The origin of the Cedar River stock is a non-native stock first introduced in 1935 (brood year 1934) from the former U.S. Bureau of Fisheries (a precursor agency to the current U.S. Fish and Wildlife Service) Birdsview Hatchery on Grandy Creek (a tributary of the Skagit River). These fish were originally from the Baker River sockeye stock. The origin of the Lake Washington tributary and Lake Washington beach spawning stocks is unknown.

Table 1. Salmon Species and stocks found in the Lake Washington Basin (WDFW and WWTIT 1994, WDFW 1998, WDFW 2000, King County 2000). The NMFS and USFWS listed or proposed Endangered Species ACt (ESA) listing status as of June 2000 are also shown.

STOCK [1]	STOCK ORIGIN [2]	PRODUCTION TYPE [3]	STOCK STATUS (SASSI/SaSI)	ESA STATUS (NMFS/USFWS)
Issaquah Creek Summer/Fall Chinook[13]	Non-Native[5]	Composite[7]	Healthy	Listed as Threatened[17]
North Lake Washington tributary Summer/Fall Chinook[13]	Native[6]	Wild[8]	Unknown	Listed as Threatened
Cedar River Summer/Fall Chinook[13]	Native	Wild	Depressed	Listed as Threatened
Cedar River Coho[13]	Mixed[4]	Wild	Depressed	Not Currently Listed
Lake Washington and Lake Sammamish Tributary Coho[13]	Mixed	Composite	Depressed	Not Currently Listed
Winter Steelhead[13]	Native	Wild	Depressed	Not Currently Listed
Lakes Washington and Sammamish Tributary Sockeye[13]	Unknown	Wild	Depressed	Not Currently Listed
Lake Washington Beach Spawning Sockeye[13]	Unknown	Wild	Depressed	Not Currently Listed
Lake Washington – Cedar River Sockeye[13]	Non-Native	Composite	Depressed	Not Currently Listed

Table 1. continued

STOCK [1]	STOCK ORIGIN [2]	PRODUCTION TYPE [3]	STOCK STATUS (SASSI/SaSI)	ESA STATUS (NMFS/USFWS)
Issaquah Creek Summer Run Kokanee[14]	Native	Wild	Critical	Petitioned as Endangered
Big Bear, Little Bear and North Creeks Residualized Sockeye[16]	Naturally Reproducing	Wild	Unknown	NA
Late Run Lake Sammamish Kokanee	Native	Wild	Unknown	Petitioned as Endangered
Lake Washington Rainbow Trout[15]	Non-Native	Composite	Unknown	Not Currently Listed
Chester Morse Bull Trout[11]	Native	Wild	Unknown But stable	Listed as Threatened
Coastal Cutthroat Trout[12]	Native	Wild	Unknown	Not Currently Listed

Table 1 Notes:

1. As defined in WDFW and WWTT (1994), the fish spawning in a particular lake or stream(s) at a particular season, which fish to a substantial degree do not interbreed with any group spawning in a different place, or in the same place at a different season.
2. The genetic history of the stock
3. The method of spawning and rearing that produced the fish, which constitutes the stock.
4. A stock whose individuals originated from commingled native and non-native parents, and/or by mating between native and non-native fish (hybridization) or a previously native stock that has undergone substantial genetic alteration.
5. A stock that has become established outside of its original range
6. An indigenous stock of fish that have not been substantially impacted by genetic interactions with non-native stocks, or by other factors, and is still present in all or part of its original range.
7. A stock sustained by both wild and artificial production.
8. A stock that is sustained by natural spawning and rearing in the natural habitat, regardless of parentage (includes native)
9. A stock that depends on spawning, incubation, hatching, or rearing in a hatchery or other artificial production facility.
10. Not listed in WDFW and WWTT (1994)
11. Listed in WDFW SaSI (1998)
12. Not listed in WDFW (2000)
13. Listed in WDFW and WWTIT (1994)
14. Listed in King County (2000)
15. This category includes only the hatchery stocks released into WRIA 8.
16. Source: WDFW 2001 Internal Memorandum dated April 26, 2001, Young et al 2001.
17. Naturally produced chinook only. Does not include hatchery produced chinook.

The Lake Washington system supports one native winter steelhead stock but not a summer steelhead stock (SASSI 1994). The winter steelhead stock was listed in SASSI as "Depressed" but has recently shown some evidence of rebounding. A limited hatchery program utilizing the native winter steelhead stock was initiated in 1997 as a supplementation type program to assist in recovery of winter steelhead populations in the north Lake Washington tributaries. The sharp decline in Lake Washington winter steelhead was noted as a reason for concern by NMFS in their stock status review (Busby 1996).

A naturally producing population of bull trout is known to occur in the upper Cedar River subbasin in Chester Morse Lake (WDFW 1998). The presence and/or absence of a reproducing native char (i.e.: bull trout/Dolly Varden) population elsewhere in the Lake Washington Basin has not been confirmed, though individuals have been found in several

places in the WRIA (e.g.: Carey Creek, the lower Cedar River, Chittenden Locks). The stock status of the Chester Morse Lake bull trout population was listed as "Unknown" by SaSI. Bull trout were listed under the Endangered Species Act as Threatened by the U.S. Fish and Wildlife Service in 1999.

Coastal cutthroat trout, a subspecies of cutthroat trout (*O. clarki*) are known to occur throughout the Lake Washington Basin. This stock was not listed as a distinct stock by WDFW (WDFW 2000) but was mentioned as present by Williams (1975). Foley (2000) is of the opinion that the stock is largely adfluvial with fish up to 24 inches common in Lakes Sammamish and Washington and that the population is healthy. However, because of the lack of quantifiable data the stock status of coastal cutthroat is classified "Unknown" in this report.

Kokanee salmon is the freshwater resident form of anadromous *O. nerka* (sockeye salmon). The Lake Washington Basin is thought to support two distinct kokanee populations and a population of residualized sockeye that are managed as kokanee. A summer (early) and presumed native run that returns in August primarily to Issaquah Creek, and a native stock returning to East Lake Sammamish Tributaries in November through January. A third stock, that was recently determined to be more closely linked genetically to sockeye, is found in North, Little Bear and Big Bear creeks. In March 2000, the summer run kokanee stock that returns to Issaquah Creek was petitioned for listing as Endangered under the Endangered Species Act.

Before being rerouted in 1916, the Cedar River drained into the Duwamish River via the Black River and it is thought that Pink and chum salmon utilized the Cedar River at that time. Outside of the Cedar River, spring chinook, pink and chum salmon are not believed to historically have had naturally sustaining populations in WRIA 8.

LAKE WASHINGTON BASIN SUMMER/FALL CHINOOK SALMON POPULATION TRENDS

Chinook salmon returning to the Lake Washington Basin (WRIA 8) are distinguished from other Puget Sound chinook stocks by geographic separation, but exhibit many similar life history characteristics. Return timing, spawn timing, and juvenile emigration from their natal rivers are similar to other Puget Sound stocks. With the exception of direct independent drainages to Puget Sound and the University of Washington hatchery stocks, a unique attribute in of WRIA 8 chinook stocks is that they must migrate through Lake Washington and for Issaquah Creek stocks they must also pass through Lake Sammamish. No other chinook stocks in Puget Sound, and only a few in Washington, utilize a large lake for adult migration and juvenile rearing. The utilization of Lake Washington by adult and juvenile fish is not fully understood.

Confounding our understanding of chinook is the presence of the hatchery stock from Issaquah Creek and the wild stocks in the Cedar River and North Lake Washington tributary streams. The Issaquah State Fish Hatchery (SFH) and University of Washington hatchery release a locally acclimated chinook stock of Green River origin. Production goals are 2.0 million for the Issaquah SFH and 180,000 for the University of Washington hatchery sub-

yearling chinook fingerlings. While the vast majority of adult chinook that are released from the Issaquah SFH and the University of Washington will return to their natal creek, some straying into other streams is probable.

Chinook salmon returning to the Cedar - Sammamish Basin have been a mixture of natural spawning and hatchery chinook salmon since approximately the late 1930s when the first hatchery fish returned to the Issaquah Creek State Fish Hatchery located at approximately RM 3.0 on Issaquah Creek. Harvest and spawning escapement data for WRIA 8 (and other Puget Sound drainages) are unavailable prior to the mid-1960s. The only index of chinook salmon returns to Puget Sound during the early 1900s is commercial and sport harvests in the Strait of Juan de Fuca and Puget Sound. However, these data are confounded by the presence of chinook salmon destined for British Columbia and the interception of Puget Sound-bound chinook in Washington coastal troll and other interception fisheries.

Commercial harvests of chinook salmon in Puget Sound were high during 1913-1933 (200,000 to 450,000 per year), then declined sharply in 1934 due to prohibition of set gillnets and traps (Figure 2). Commercial harvests remained low during 1934-1960 (average 60,000 per year), then gradually increased to peak levels in 1975-1990 (average 235,000 per year). This period of increasing harvests corresponded to increasing releases of hatchery salmon. Commercial harvests declined sharply during 1991-1998 (average 88,000 per year). The harvest in 1998 was the lowest since 1962. Sport harvests are available since 1946. Total harvests in Puget Sound (commercial and sport) peaked in 1975 (587,000 chinook), then declined steadily to 138,000 chinook in 1997 (sport data not available for 1998).

As a result of recent efforts by the WDFW and the Western Washington Treaty Tribes, more accurate records of chinook spawning escapement and stock-specific harvests are available since 1968. Enhanced accounting of chinook escapements and runs in Puget Sound drainages arose, in a large part, as a response to the 1974 Supreme Court U.S. v WA. (Boldt) decision which influenced natural resource and harvest managers to switch from harvest rate based management to spawning escapement based management. However, the harvest component in the stock-specific WDFW run reconstruction database is limited to commercial harvests (mainly net harvests) in Puget Sound (treaty and non-treaty Indian). Many chinook salmon whose origins are from Puget Sound rivers and streams are harvested by sport and commercial fishermen in British Columbia. Figure 3 shows reconstructed run sizes as they enter Puget Sound but does not include harvests from prior interception fisheries.

Readers should be aware that the reconstructed run estimates for Cedar - Sammamish Basin chinook salmon are subject to a variety of measurement errors, which are typical of fishery estimates such as these. For example, the spawning escapement in the Cedar River is estimated by live chinook salmon in a portion of the basin, and then extrapolated using a methodology described elsewhere in this chapter called the “Area Under the Curve”. This methodology is currently under review as there are a number of inherent assumptions associated with the protocols and any reanalysis may lead to changes in escapement numbers.

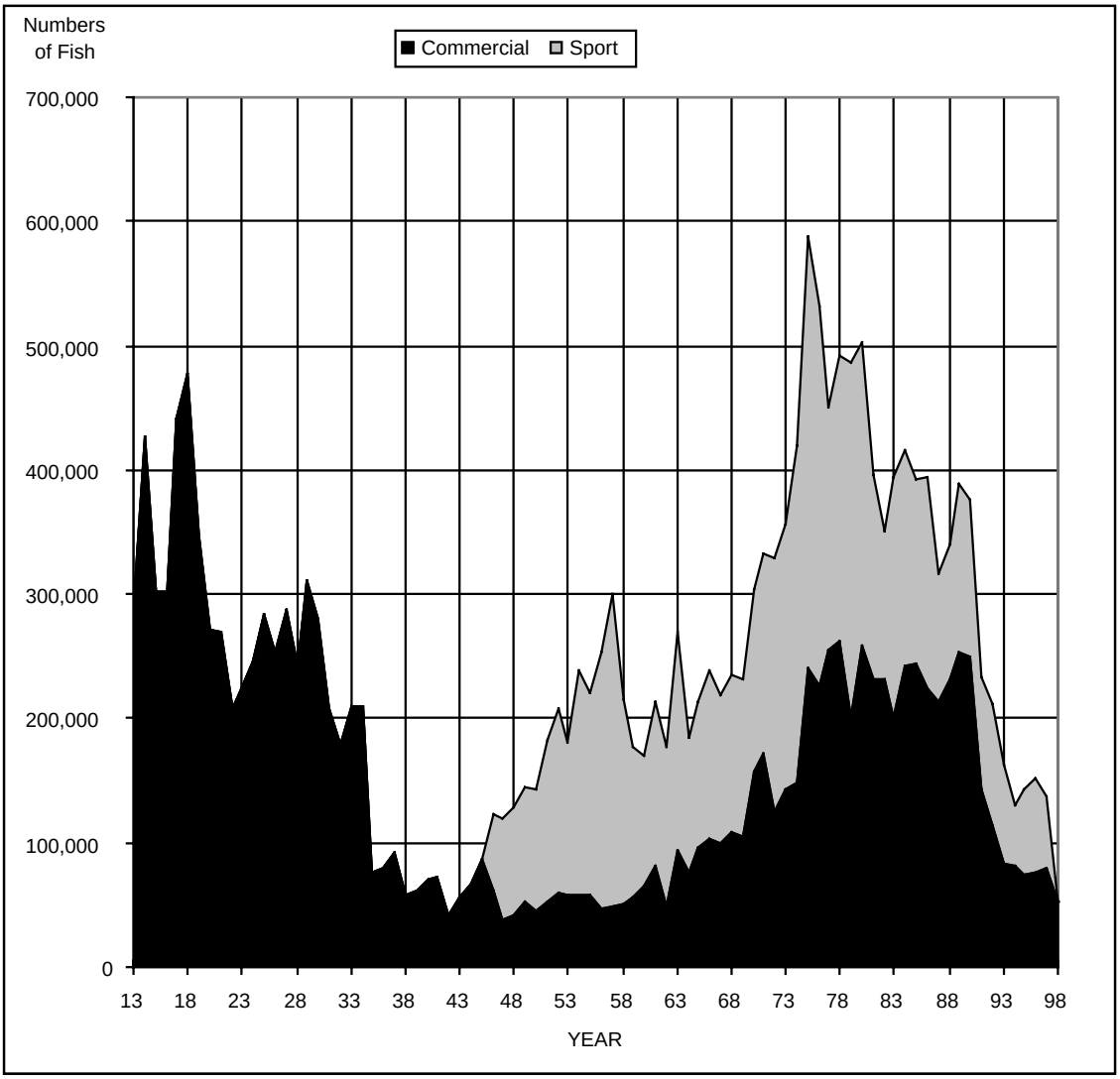


Figure 2. Commercial (tribal and non-tribal) and sport harvests of chinook salmon in Puget Sound, 1913-1998. Sport harvest not available prior to 1946 and in 1998. Harvests include chinook salmon destined for some Canadian streams. Hatchery and wild stocks are included (Data source: WDFW annual reports).

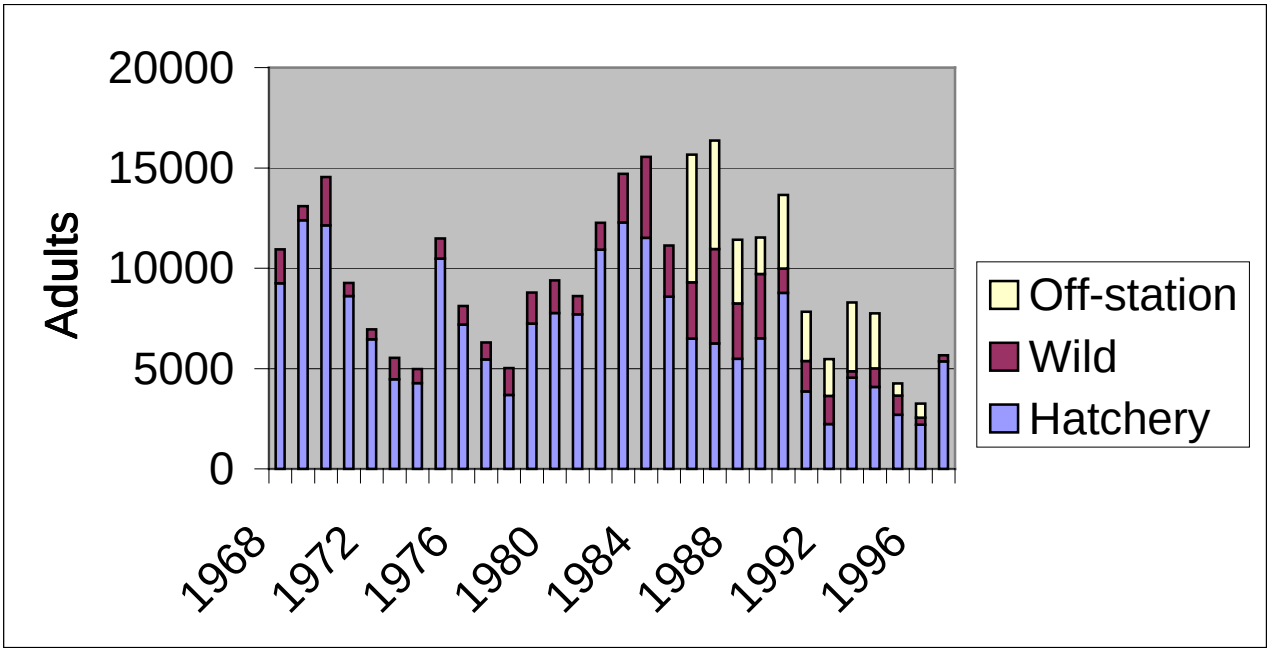


Figure 3. Total Puget Sound chinook run-size for WRIA 8 1968-1997. (Data source: WDFW Puget Sound Chinook Salmon Stock Strength Calculation Summary Database).

In this chapter, we describe WRIA 8 chinook runs returning to the hatcheries and to the spawning grounds. The natural spawning population includes hatchery salmon that stray to the spawning grounds. Thus, "wild" or natural chinook, which are produced by naturally spawning parents (wild and hatchery origin), are overestimated to the extent that hatchery chinook stray to the spawning grounds. Because the WDFW run reconstruction approach utilizes the ratio of chinook returning to the hatchery compared to the spawning grounds to estimate hatchery versus "wild" chinook salmon in harvests, the true wild run is overestimated and the hatchery run is underestimated. The confounding effect of hatchery strays on wild chinook production estimates in systems such as the Cedar - Sammamish Basin was identified in the NMFS status review as a key concern leading to the listing of Puget Sound chinook salmon (Myers et al. 1998).

For this report, we use the term "wild" chinook salmon to mean fish produced by natural spawning parents that return to the spawning grounds plus hatchery fish that stray to the spawning grounds. This terminology is used because existing WDFW escapement data do not distinguish between true wild fish and hatchery strays. Ongoing efforts are being made to use coded-wire-tag recoveries in the hatcheries and spawning grounds to estimate stray rates.

Harvest and spawning escapement data for Lake Washington stocks (and other Puget Sound drainages) are unavailable prior to the mid-1960s. The only index of chinook salmon returns to Puget Sound during the early 1900s is commercial and sport harvests in the Strait of Juan

de Fuca and Puget Sound. . As a result of recent efforts by the WDFW and tribes, more accurate records of chinook spawning escapement and stock-specific harvests are available for the Cedar River beginning in 1964. Consistent and complete surveys were initiated in 1973, and escapement estimates have ranged from 156 (1993) to 1,540 (1987). Limited spawner survey information is available prior to 1973. Enhanced accounting of chinook escapements and runs in Puget Sound drainages arose, in part, as a response to the 1976 Boldt (U.S. vs. WA.) decision which influenced managers to switch from harvest rate based management to spawning escapement based management. However, the harvest component in the stock-specific WDFW run reconstruction database is limited to commercial harvests (mainly net harvests) in Puget Sound (treaty and non-treaty). Sport and commercial fishermen in British Columbia harvest many chinook salmon that originated from Puget Sound rivers and streams.

Spawning escapement estimates currently include hatchery strays, a fact that leads to overestimation of the "natural" chinook run produced by naturally spawning parents. Ongoing efforts to remove this bias are discussed below. The most accurate component of fishery statistics is commercial harvest, but significant error may occur when allocating the harvest to the various basins in Puget Sound and British Columbia using the Fishery Regulatory Assessment Modeling (FRAM) and Pacific Salmon Commission models.

For this report, Lake Washington Basin chinook runs returning to the hatcheries and to the spawning grounds. The natural spawning population includes hatchery salmon that stray to the spawning grounds. Thus, "natural" chinook, which are produced by naturally spawning parents (wild and hatchery origin), are overestimated to the extent that hatchery chinook stray to the spawning grounds. Because the WDFW run reconstruction approach utilizes the ratio of chinook returning to the hatchery compared to the spawning grounds to estimate hatchery versus "natural" chinook salmon in harvests, the true natural run is overestimated while the hatchery run is underestimated. The confounding effect of hatchery strays on natural chinook production estimates in systems such as the Green River was identified in the NMFS status review as a key concern leading to the listing of Puget Sound chinook salmon (Myers et al. 1998).

One method of distinguishing hatchery origin chinook from naturally produced chinook on the spawning grounds and at hatchery traps is to have a distinguishing mark on hatchery origin chinook. This involves the removal of a fin from all of the hatchery fish prior to their release. The "mass marking" of hatchery origin chinook began in the Lake Washington basin in 2000. This program will allow for differentiation of hatchery from naturally produced chinook on the spawning grounds in significant numbers beginning with the returns in 2003. Conclusive results will probably not be available until 2004 or 2005 when all age classes from the first "mass marked" fish will have returned. The mass marking program does not apply to the various educational egg box and salmon in the class projects, which are not being clipped before, release.

For this report, the term "natural" chinook salmon refers to fish produced by natural spawning parents that return to the spawning grounds, plus hatchery fish that stray into the spawning grounds. This terminology is used because existing WDFW escapement data can not

distinguish between true natural fish and hatchery strays. Ongoing efforts are being made to use coded-wire-tag recoveries in the hatcheries and spawning grounds to estimate stray rates.

NATURALLY PRODUCED LAKE WASHINGTON BASIN SUMMER/FALL CHINOOK SALMON

Lake Washington Basin adult chinook first arrive at the Ballard Locks in mid-June. The peak time of entry through the Locks and into the Lake Washington Basin occurs in mid to late August and is generally complete by early November. Lake Washington Basin summer/fall chinook stocks range in spawn timing from mid September through November.

Juvenile chinook are believed to incubate in the gravel until late January or early February through early March, and outmigration to Lake Washington and the estuaries occurs over a broad time period. Typical juvenile summer/fall chinook outmigrate from January through August but the complete migratory time period for juvenile Lake Washington summer/fall chinook is not currently known. It is probable that juvenile chinook migrate in low numbers through Lakes Washington and Union after August. However, tagging results from 1999 indicate that the bulk of the juvenile chinook arrived at the Ballard Locks the last week of June (Goetz 2000). In the Lake Washington Basin, juvenile summer/fall chinook are found entering the lake from their natal streams on the first day a juvenile sockeye trap is operated near the mouth of the Cedar River in mid-January and are still found outmigrating when that trap is removed in late August. The timing of juvenile chinook outmigration from the Cedar River and Bear Creek is better understood than is the distribution, abundance, growth, diet, and survival of juvenile summer/fall chinook in Lake Washington. Typically, the Lake Washington Basin summer/fall chinook migrate within their first year of life. A few juveniles remain in the lake for an additional year. There are no data to indicate that there is a large component of Lake Washington Basin stock summer/fall chinook juveniles that remain in freshwater for that additional year after emerging from the redds. However, other Puget Sound chinook stocks (e.g.: Snohomish summer chinook and Snohomish fall chinook) produces a significant number of juveniles that remain in the freshwater environment for an additional year.

For most chinook stocks, the estuary is an especially important transition zone as they migrate from fresh to salt water. The estuary provides essential resources such as food and salinity gradients that aid in the transition from fresh to saltwater habitats. In the Lake Washington Basin, the estuary is extremely limited in Salmon Bay. Historically, Cedar River summer/fall chinook smolts would have migrated out through the Duwamish estuary. With the rerouting of the Cedar River into the Lake Washington in 1916, these smolts must migrate through Salmon Bay, an area where a much more rapid transition to saltwater occurs than that which these fish ancestors evolved under. Certainly there are chinook stocks that have evolved in basins with only limited estuaries. In Washington State the Lake Quinault chinook stock is one example and there are numerous riverine chinook stocks in Alaska where there are only limited estuaries. The Cedar River stock evolved with an estuary prior to being rerouted into Lake Washington in 1916.

Lake Washington chinook use the Cedar River, Issaquah Creek, the Bear/Cottage Lake system (Williams et al. 1975), with smaller numbers using streams such as Kelsey, Little Bear, North Swamp, May, Lewis, McAleer, and Thornton creeks. The extent to which adult chinook utilize other creeks is not completely known in all instances. Additionally, the extent of any natural juvenile chinook rearing in non-natal tributary, streams is unknown. Summer/fall chinook adults have been observed spawning in the mainstem Cedar River as far upstream as the pipeline crossing at RM 21.3 (WDFW Spawning Ground Survey Database). Because of the difficulty in differentiating between a single chinook redd and multiple sockeye redds it is not possible to distinguish all of the chinook spawning locations in the Cedar River. The downstream extent of adult Chinook spawning appears to vary from year to year. It is unclear what determines the downstream extent but it is likely influenced by environmental factors such as water flow and temperature. In 1999, significant numbers of live adult chinook and redds were located in Kelsey Creek and the Cottage/Bear Creek system. The Cottage/Bear Creek system has seen increases in escapement for the previous three years (1998-2000). Lake Washington Basin summer/fall chinook spawn from mid September into late November.

Historically, naturally produced adult chinook were present in the mainstream Cedar River and some streams upstream of the City of Seattle's water diversion dam and pipeline located at RM21.3. Landsburg Dam is a complete barrier to anadromous fish migration and upstream there is 12.5 miles of high quality mainstem Cedar River habitat and approximately up to 9.7 miles of potential habitat in smaller streams.

Chinook spawning begins in the tributary streams in mid-September peaks around October 6-10 and continues through mid-November. Emergence from spawning nests is dependent on water temperatures but begins in January of the year following egg deposition and is typically completed by March. The summer/fall chinook in WRIA 8 are typically an "ocean" type. "Ocean" type chinook are characterized by a rearing trajectory in that they rear in their natal freshwater environment for one to four months prior to their seaward migration. A major difference in the Lake Washington Basin chinook from other Puget Sound stocks of chinook is that all the chinook juveniles must enter, rear for some period of time, and migrate through a large lake system.

The distribution, population, diet, growth rates and survival of juvenile chinook that enter Lake Washington is not fully understood. Many of the studies of juvenile salmonids in Lake Washington have focused on sockeye salmon but some information about chinook has also been collected as a part of these studies. Collectively known as The Lake Washington Ecological Studies, data collected during these studies suggests that juvenile chinook utilize the littoral zone of Lake Washington for rearing. During sampling in 1994, 1995, 1997 and 1998 small numbers of juvenile chinook were consistently caught, in the littoral zone, with catches increasing through late May.

Cedar River Stock Summer/Fall Chinook Salmon

During 1964-1999, the estimated naturally produced run of summer/fall Cedar River chinook salmon ranged from 156 in 1993 to 1,745 in 1970 and averaged 727 fish. Run size tended to be lower during recent years (1988-1999) compared to earlier years (1968-1987), indicating the downward trend common to other Puget Sound stocks is evident among ”natural” Cedar River chinook salmon.

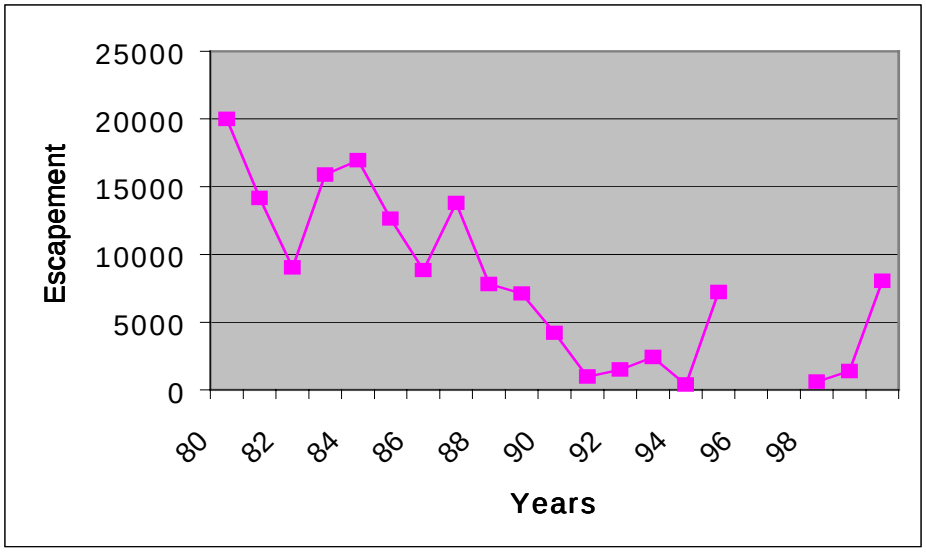
The Cedar River chinook spawning escapement goal of 1,250 natural spawners was established in the mid-1970s using average escapement of adult chinook wild and hatchery strays during 1965-1976 (Ames and Phinney 1977). Spawning escapement estimates are derived from live fish counts that are then expanded using the methodology described by Cousens et al (1981). The estimated spawning escapement during 1964-1999, including unknown hatchery strays, averaged 727 fish and it exceeded the goal during 5 (13.9percent) of 36 years. During the past 12 years (1988-99), spawning escapements have been relatively small (average 426 fish) and escapements have never exceeded the goal.

The analysis of spawning escapements of “natural” chinook salmon includes stray hatchery chinook salmon that spawned in the Cedar River. Hatchery chinook salmon observed on the spawning grounds may have originated from fish released from the Issaquah SFH, other hatcheries or from off-station releases or some combination of all three. The implication is that the natural run, harvest, and escapement of Cedar River chinook salmon is overestimated to the extent that hatchery fish contribute to natural spawners on the Cedar River. Hatchery strays affect harvest estimates of natural chinook because the spawning escapement approach used by WDFW and the MIT is dependent on the estimated escapement to the spawning grounds. For example, if 30 percent of the chinook escaping to the river return to the spawning grounds and 70 percent return to hatcheries, then WDFW and MIT assumes 30 percent of the harvest of Lake Washington origin chinook (hatchery and wild) is allocated to the “natural” run and 70 percent to the hatchery run.

A modeling exercise to reconstruct wild chinook runs and escapements based on a range of stray rates for cultured chinook salmon in the Lake Washington Basin would be useful to more closely identify hatchery and harvest influences on natural chinook populations. The mass marking of chinook salmon released from the Issaquah SFH programs in 2000 will be extremely valuable in making this analysis. The analysis will remove stray hatchery fish from escapement and harvest estimates during the year of return.

The chinook spawning escapement estimates in Figure 4 includes hatchery strays, a fact that leads to overestimation of the “wild” chinook run produced by naturally spawning parents. If large numbers of hatchery strays are included in SASSI escapement estimates, the SASSI status designation for this population could be changed to reflect that contribution. Additionally, escapement estimates are not always indicative overall habitat productivity because they do not necessarily reflect the harvest of Lake Washington basin origin subadult and adult chinook.

Figure 4. Cedar River stock summer/fall chinook escapement 1964-1999.

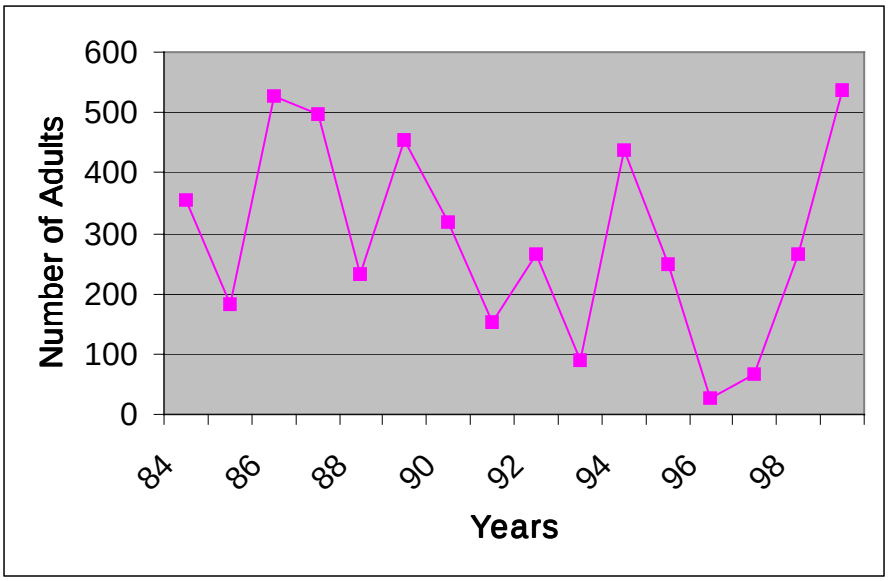


North Lake Washington Tributaries Summer/Fall Chinook Salmon Stock

Based on their geographic isolation, North Lake Washington tributaries are thought to contain one distinct stock. The distribution of this stock includes Bear, Cottage Lake, Little Bear, McAleer, North and Swamp Creeks and the Sammamish River. Marshall (2000) more closely examined the summer/fall chinook runs in Issaquah, Cottage Lake and Bear Creeks for genetic differences however significant genetic differences were not identified among the adults sampled.

As with the Cedar River, the degree of influence of hatchery strays on this stock is unknown. The escapement goal for Bear and Cottage Lake Creeks is set at 350 adults. Warner and Fresh (1999 Draft) indicated actual escapements into the Bear/Cottage Lake Creek subbasin averaged approximately 300 adults for the years 1983-87 and less than 100 from 1992-97. Escapement estimates in 1998 indicated an increase to approximately 260 adults. SASSI estimates for the North Lake Washington tributaries from 1984 to 1999 indicate a downward trend through the early 1990's that shifts upward in 1998 (Figure 5).

Figure 5. North Lake Washington stock tributaries chinook escapements 1984-1999.



Issaquah Creek Stock Summer/Fall Chinook Salmon

SASSI (WDFW and WWTIT 1994) identified chinook in both Issaquah Creek and the East Fork Issaquah Creek as a distinct stock based on geographic separation. As previously mentioned, an analysis of genetic sampling studies conducted in 1998 and 1999 (Marshall 2000) did not find any significant genetic differences between Issaquah Creek and North Lake Washington tributary stocks. However, when samples were treated separately there are differences. Chinook escapement into Issaquah Creek is strongly influenced by management practices of the Issaquah SFH and water flows. The natural spawning population has historically been confined to reaches downstream of the impassable barrier at the hatchery. During years when escapement goals were met at the hatchery, surplus fish were passed upstream.

The Issaquah Creek summer/fall chinook salmon stock was the only chinook stock with a status listed as "Healthy" in SASSI (WDWF and WWTIT 1994). Stream flows and water temperatures present during the period when adult chinook return to the hatchery influence the ability of these large fish to successfully migrate upstream into the hatchery trap. Thus, when flows are low, escapement counts in Issaquah Creek, downstream of the hatchery, tend to be higher as fish cannot successfully make their return to the hatchery trap. Smaller numbers of chinook have been observed in other streams draining directly into Lake Washington. These would include streams such as Little Bear, North, Swamp, May, Kelsey, Lewis and Bear Creeks.

LAKE WASHINGTON COHO SALMON

Two stocks of coho salmon enter the Lake Washington River Basin (WRIA 8) (WDFW and WWTIT, 1994): (1) Lakes Washington and Sammamish tributaries, and (2) Cedar River stocks. The total escapement goal for Lake Washington tributaries is 15,000. Escapement and run size (run size reconstruction) from 1965 to 1999 shows that the number of coho fluctuates over a very broad range. The escapement goal has not been met since 1978. While the Cedar River coho stock has unique spawn timing, neither stock displays any other documented unique biological characteristics.

As with other Puget Sound coho stocks, these two stocks return in the fall of the year primarily as either 2 (jacks) or 3-year old adult fish. Their progeny exit the spawning redds the ensuing year and then rear for 12-14 months prior to exiting the Lake Washington Basin into saltwater. However, the extent of their utilization of Lake Washington is not fully understood.

The naturally spawning coho population in the Lake Washington Basin is comprised of an unknown mixture of natural and hatchery origin fish. The magnitude of adult hatchery fish that contribute to the natural spawning population has not been determined. The spawning escapement estimates in Figures 4 and 5 include hatchery strays, a fact that leads to overestimation of the "wild" coho run produced by naturally spawning parents. If large numbers of hatchery strays were included in SASSI escapement estimates, the SASSI status designation for these populations could be changed to "Critical" to reflect that contribution. The "mass marking" of hatchery produced coho was started in 1997. Excluding coho fry produced as a part of educational programs which are not marked, hatchery produced coho adults returning to non-natal streams beginning in 1999 are distinguishable from wild produced fish.

The onset of coho salmon spawning is tied to the first significant fall freshet. Lake Washington Basin coho stocks typically enter fresh water from August to early December. They often mill near the river and creek mouths or in lower river pools until the fall freshets occur. Spawning usually occurs between November and early December, but is sometimes as early as mid-October and typically occurs in tributary stream. High stormwater flows and sedimentation in the tributaries can suffocate eggs. As chinook salmon fry exit the shallow low-velocity rearing areas, coho fry, which emerge from the gravel later than chinook, utilizes those same areas for the same purpose. As they grow, juvenile coho move into faster water and disperse into tributaries and areas which adults cannot access (Neave 1949). Pool habitat is important not only for returning adults, but also for all stages of juvenile development. Preferred pool habitat includes deep pools with riparian cover and woody debris in the form of individual pieces to debris jams.

The Lake Washington Basin coho juveniles remain in freshwater for a full year after leaving the gravel nests, but during the summer after early rearing, low flows can lead to problems such as a physical reduction in available habitat, increased stranding, decreased dissolved oxygen, increased temperature, and increased predation. Juvenile coho are highly territorial and can occupy the same area for long periods of time (Hoar, 1958). Investigators have found

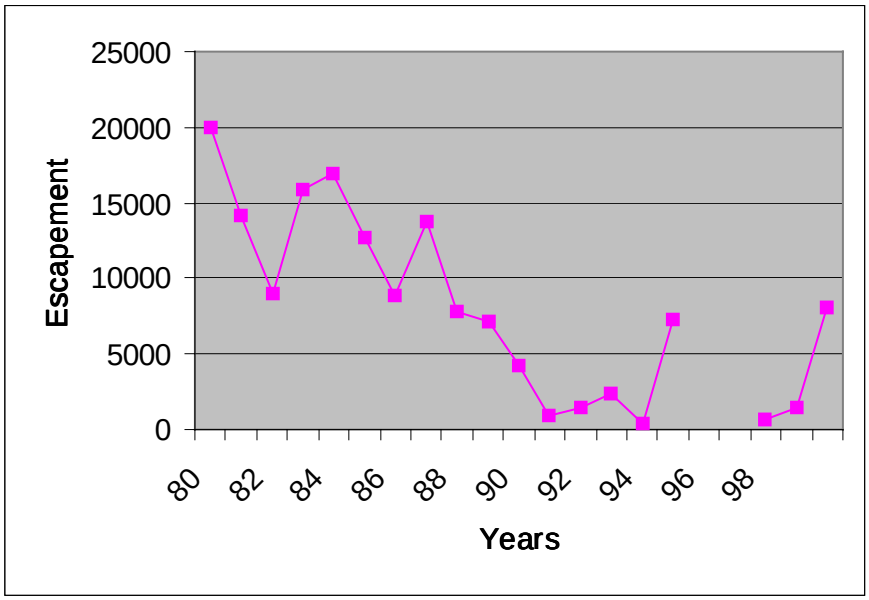
that the abundance of coho can be limited by the number of suitable territories available (Larking, 1977). Streams with more structure (Logs, undercut banks, etc.) support more coho (Scrivener and Andersen, 1982), not only because they provide more territories (useable habitat), but they also provide more food and cover. Large wood also assists in the retention of salmon carcasses by adding habitat complexity in the form of pools where these carcasses may settle out and add nutrients for stream productivity. There is a positive correlation between juvenile coho's primary diet of insect material in stomachs and the extent the stream was overgrown with vegetation (Chapman, 1965). In addition, the leaf litter in the fall contributes to macroinvertebrate and aquatic insect production (Meehan et al., 1977).

In the autumn as the water temperatures decrease, the juvenile coho move into deeper pools, hide under submerged logs, overhanging and submerged tree roots, and undercut banks (Hartman, 1965).The fall freshets redistribute them (Scarlett and Cederholm, 1984), and the preferred habitats for over-wintering juvenile coho generally occurs in available side channels, spring-fed ponds, and other off-channel sites to avoid high stream velocities associated with winter floods (Peterson, 1980). Cederholm and Scarlett (1981) found that a lack of side channels and small streams may limit coho survival. As coho juveniles grow into yearlings, they tend to become more predatory on other salmonids. Lake Washington Basin origin coho begin to leave the basin over a year after emerging form their gravel nests with the peak outmigration occurring in early May. Outmigrating coho use the Salmon Bay estuary primarily for interim feeding while they adjust physiologically to saltwater.

Lakes Washington and Sammamish Tributaries Coho Salmon Stock Population Trends

Escapement estimates for the Lakes Washington and Sammamish tributaries coho stock from 1980 to 1999 are shown in Figure 5, averaged 8,058 and ranged from 399 to 20,002. During some spawning seasons (1996 and 1997), escapement estimates were not calculated due to insufficient surveys or poor viewing conditions. Additionally, escapement estimates are not always indicative overall habitat productivity because they do not necessarily reflect the harvest of Lake Washington basin origin subadult and adult coho.

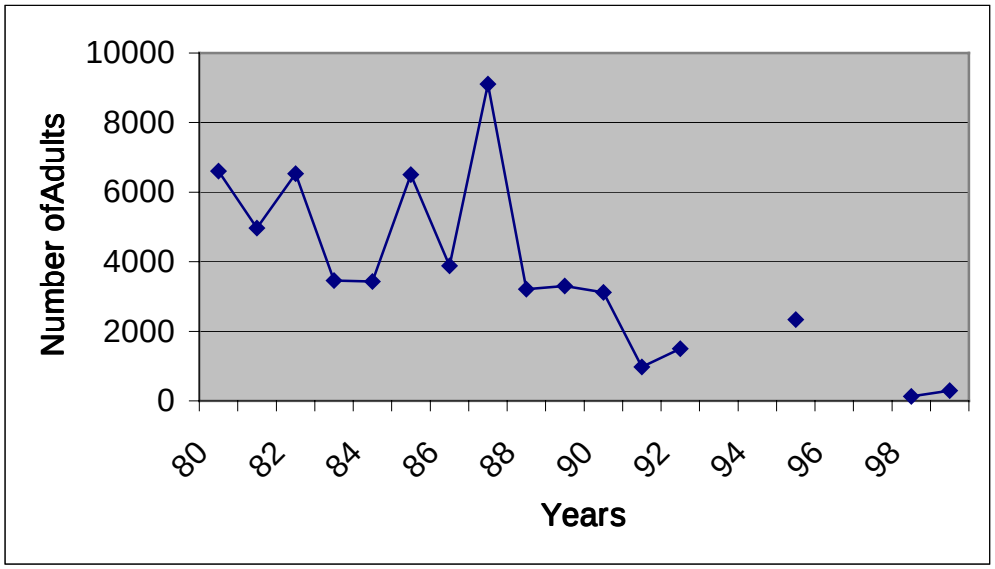
Figure 6. Lakes Washington and Sammamish tributaries coho salmon escapement 1980-1999.



Cedar River Coho Stock Population Trends

The Cedar River coho stock was identified as unique based on its spawn timing (late October thru early March) and its geographic isolation. SASSI (WDFW and WWTIT 1994) indicated a stock status of "Healthy" but cautioned that there appeared to be a downward trend in escapement of this stock and that the status may change. Between 1980 and 1999 the average escapement was 3,710. While there has been insufficient or no escapement data collected in four of the ensuing 10 years, the most recent two years indicate extremely poor returns. Since 1991, where data is available, the average coho escapement has been 697 fish. Any discussion of the status of this stock should now center around whether it should be classified as "Depressed" or "Critical". In this report the stock was classified as "Depressed". Figure 7 shows Cedar River coho escapement for 1980 through 1999 inclusive.

Figure 7. Cedar River coho salmon escapement 1980-1999.



LAKE WASHINGTON BASIN WINTER STEELHEAD

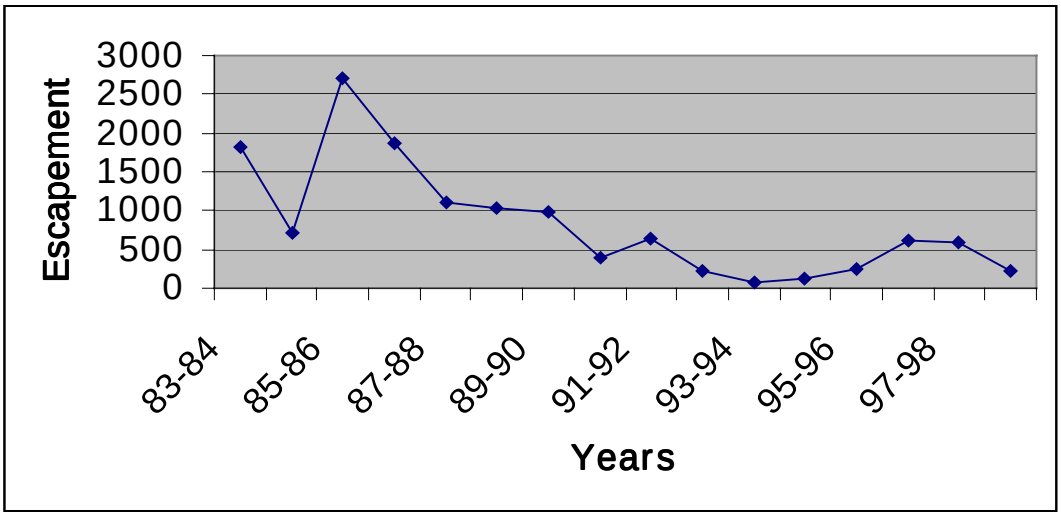
There is one native Lake Washington Basin winter steelhead stock as characterized in SASSI (WDFW and WWTIT 1994) and by NMFS (Busby 1996). The status of the winter steelhead stock was characterized as "Depressed" in SASSI (WDFW and WWTIT 1994). From a genetic perspective, Phelps et al. (1994) determined there was limited hatchery introgression into Cedar River wild winter steelhead. They utilized this stock as a statistical surrogate for a "pure" Puget Sound wild winter steelhead stock in other aspects of that study. Nehlsen et al. (1991) identified Lake Washington winter steelhead at a moderate risk of extinction. The Lake Washington native winter steelhead population began a steady decrease in the mid-1980's, similar to those of many other regional stream systems. Recently, escapement estimates of this stock has shown a slight upward trend although currently not enough information is available for a definitive conclusion. Population trends for Lake Washington winter steelhead are shown in Figure 8 below.

Steelhead have one of the most complex life history patterns of any anadromous Pacific salmonid species (Shapovalov and Taft, 1954) In Washington, there are two major run types, winter and summer steelhead. The Lake Washington Basin does not have a summer steelhead stock and winter steelhead adults begin river entry in a mature reproductive state in December and generally spawn from February through May.

Naturally produced juvenile winter steelhead can either migrate to sea (anadromy) or remain in freshwater as a resident rainbow trout. The vast majority of juvenile steelhead in the Lake Washington Basin smolt and migrate to saltwater. Lake Washington Basin origin steelhead usually spend 1 to 3 years in freshwater, with the greatest proportion spending two

years(Busby et al, 1996). Because of this, juvenile steelhead rely heavily on the freshwater habitat are present in streams all year long. No escapement data for Lake Washington basin origin winter steelhead stocks is available prior to 1984.

Figure 8. Lake Washington basin winter steelhead escapement estimates for run years 1983/84 - 1998/99



LAKE WASHINGTON BASIN BULL TROUT

The stock status for bull trout in the basin is unknown (WDFW 1998). Information on the presence, abundance, distribution, utilization and life history of bull trout in the Lake Washington Basin is either unavailable or extremely limited. There are reproducing populations of native char in the upper Cedar River subbasin, principally associated with Chester Morse Lake. These populations are located upstream of Cedar Falls, a complete natural barrier to anadromous fish. Reproducing populations of char in the lower Cedar River, Lake Washington or Lake Sammamish or their tributaries have not been confirmed. However, one char was identified from Lake Washington during a creel survey (Pfeifer and Bradbury 1992). This fish was a 370-mm specimen caught by a recreational angler near Kirkland in 1981. Two char were reported downstream of a culvert in the headwaters of Issaquah Creek during the fall of 1993 (B. Fuerstenberg pers comm contained in SaSI (1998)) and observations of individuals have been made in the lower Cedar River and at the Chittenden Locks.

Native char were first observed in the Pacific Northwest by Suckley in the Nisqually and Duwamish Rivers, to the south of the Lake Washington Basin, during an expedition in June 1856. At this time, the Cedar River flowed into the Duwamish/Green River Basin (WRIA 9) prior to its diversion to the Lake Washington Basin in 1916. Suckey observed specimens as large as two feet in length in the Duwamish and another individual fish was captured

approximately 35 miles upstream in June 1856 (Suckey and Cooper 1860). These fish were described as "red-spotted salmon trout" with the scientific name of *Salmo spectablis*.

Presently, only one life history form, adfluvial, of bull trout is known to be present in Chester Morse Reservoir. Resident forms may be present in the upper headwaters of the Cedar or Rex Rivers or within some of their tributaries. Quantitative information concerning life history and abundance of these fish in WRIA 8 is sparse. Redd counts conducted during the early 1990's range from 26 to 109 (SaSI 1994).

SOCKEYE SALMON

In order to more fully understand the current conditions of sockeye populations in the Lake Washington Basin it is important to have a historical perspective of the activities that have led us to current sockeye populations. The following section provides an overview of the historic events that have impacted the sockeye population in WRIA 8.

The completion of the Lake Washington Ship Canal in 1916 profoundly altered the drainage pattern of Lake Washington. The Cedar River was permanently diverted into Lake Washington in 1912. Historically, the Cedar River drained into the Black River (a tributary to the Duwamish/Green River (WRIA 8)) and Lake Washington drained south to the Black River and then into the Duwamish/Green prior to emptying into Puget Sound. With the lowering of Lake Washington by the Ship Canal and the diversion of the Cedar River into Lake Washington, the Cedar River became the primary source of water for Lake Washington.

Prior to the Ship Canal project and its associated impacts, it is not clear in the literature as to the status of salmon, and in this case sockeye salmon runs. What is clear is that kokanee were present in the Lake Washington/Lake Sammamish Basin. There are reports that prior to the construction of the Ship Canal Project fishing for "silvers" and trout was best in the vicinity of the Black River where it entered Lake Washington. Currently, the term "silver" is most often used to refer to coho salmon. However, historically and to some extent currently, the term "silver" refers to kokanee salmon. The term "silver trout" is thought to have its origins from somewhere around the turn of the 19th Century and still refers to kokanee.

Fish collected in Lake Washington early in the 19th Century (1895) were initially identified as sockeye but later examination indicates that because of their relatively small size they were most likely kokanee. Observations by a Professor O.B. Johnson (as reported in Jordan and Evermann (1896)) report "large redfish" and "small redfish" at Lake Washington. Numerous other authors have indicated that a small sockeye salmon population existed in Lake Washington (Rathbun 1900, Evermann ad Goldsborough 1907, Cobb 1911, 1914, 1930). Somewhat in conflict with these reports are other reports that the Baker River contained the only sockeye population in Puget Sound (Cobb 1927, Rounsefell and Kelez 1938, Royal and Seymour 1940, Kemmerich 1945). In his review of the history of sockeye in the Lake Washington Basin, Hendry (1995) concluded, "limited runs of sockeye salmon…were probably present at the turn of the century (19th).

The vertebral remains of sockeye salmon have been found and positively identified in prehistoric fish remains recovered from archeological sites on the Duwamish River. These sites were used by aboriginal humans between AD 15 and AD 1654 (Butler 1987).

Based on the discussion above, there appears to be indisputable evidence that kokanee were present in Lake Washington and that evidence also indicates sockeye salmon existed, at least during prehistoric times. However, several factors may have favored the evolution of the resident form of *O. nerka* (kokanee) over that of the anadromous form (sockeye). Most notably, changes in water quantity and quality due to the diversion of the Cedar River into Lake Washington and the lowering of Lake Washington (thus increasing its flushing rate) may favor anadromy.

The U. S. Bureau of Fisheries introduced sockeye salmon fry and fingerlings into the Lake Washington basin from their Birdsview Hatchery on Grandy Creek (a tributary of the Skagit River) beginning in 1935. The Birdsview Hatchery stock takes its origins beginning in 1908 from Fraser River sockeye salmon captured at Point Roberts. Egg takes from 1912 and 1916 indicate substantial numbers of fish returned to the Birdsview Hatchery from these initial on-station releases at Grandy Creek and Grandy Lake (located upstream of the Birdsview Hatchery) (Kemmerich 1945). Sockeye salmon eggs taken in 1915 from Quinault Lake were used to supplement the Birdsview Hatchery stock in 1916. However between 1914 and 1945 inclusive, the broodstock utilized at the Birdsview Hatchery was predominantly Baker Lake sockeye (Kemmerich 1945).

Sockeye salmon releases in to Lake Washington whose origins were from outside the Lake Washington Basin totaled in excess of 3.4 million fry between 1917 and 1954. The origin of these fish is from: (1) an unknown stock in 1917; (2) the Birdsview Hatchery sockeye stock between 1935 and 1945; and (3) Cultus Lake (British Columbia, Canada) sockeye salmon released in 1944, 1950 and 1954.

Sockeye salmon stocks have been recognized as three distinct stocks according to SASSI (WDFW and WWTIT 1994): (1) Cedar River; (2) tributary streams Lakes Washington and Sammamish; and (3) Lake Washington beach spawners. These stocks are distinguished from other Puget Sound sockeye stocks by geographic and reproductive separation. Genetic studies suggest the current stocks in the Cedar River and Issaquah Creek are similar to the Baker River stock transferred from the Birdsview Hatchery and first released in 1935 into Lake Washington. Electrophoretic genetic analysis of fish taken from North Lake Washington tributaries are different from the introduced stocks. As such, these fish may be of native origin.

Lake Washington sockeye are found entering the Chittenden Locks as early as mid-May and continues through early November in some years (Goetz 2000). Sockeye spawning in the Lake Washington Basin occurs in the Cedar River, tributaries to Lakes Washington and Sammamish and along specific beaches in Lake Washington. In the Cedar River, sockeye spawn in the mainstem river channel, in side channels and spring-fed ponds. The spawning beaches along Lake Washington provide a unique habitat that is often altered by human

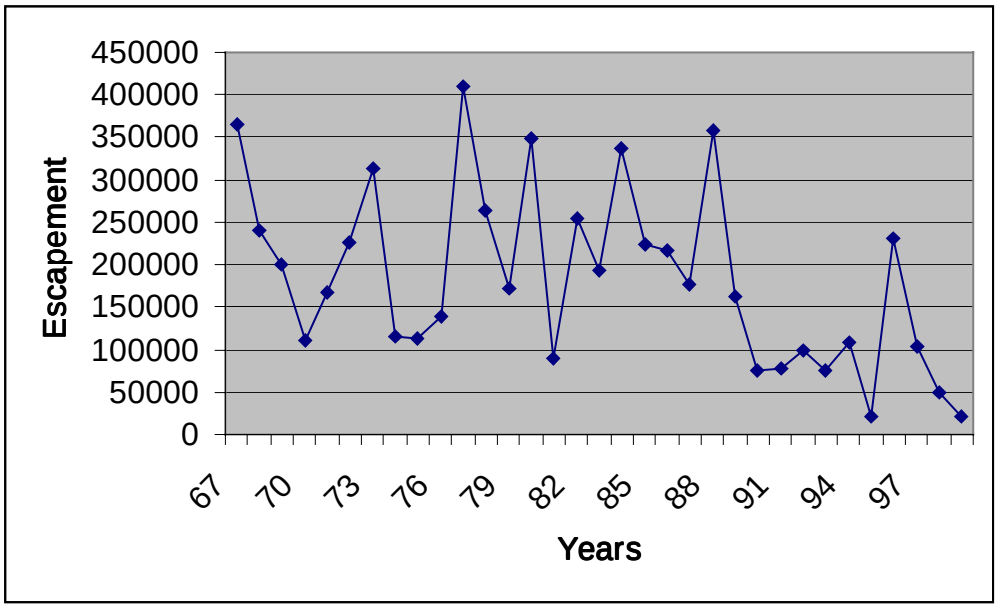
activities, such as pier and dock construction, dredging, sedimentation, and weed control. Timing of sockeye spawning ranges from September through January.

After fry emerge from the gravel, Lake Washington sockeye migrate to a lake for rearing. Lake rearing of juvenile sockeye ranges form one to three years with most juveniles rearing two years. In the spring after lake rearing is completed, juveniles enter the Puget Sound and then the ocean where more growth occurs prior to adult return for spawning.

Lake Washington Cedar River Stock Sockeye Salmon

The Cedar River sockeye salmon stock makes up the largest production unit of the aggregate Lake Washington sockeye salmon run. These fish are genetically indistinguishable from the Baker River sockeye and are considered descendants of the initial introductions of those fish. Sockeye salmon fingerlings were transferred from the Birdsview Hatchery initially during the spring of 1935 when approximately 96,000 fingerlings were released into the Cedar River and 76,000 into Issaquah Creek. Releases were repeated in 1937, and from 1942 through 1945. Over this time period a total of 3,111,805 fry and fingerlings were released into Issaquah Creek and the Cedar River. A total of 83,268 sockeye salmon fingerlings from Cultus Lake (a tributary of the Fraser River, British Columbia, Canada) were released in 1944, 1950 and 1954.

Figure 9. Cedar River sockeye salmon escapement estimates 1967 – 1999.

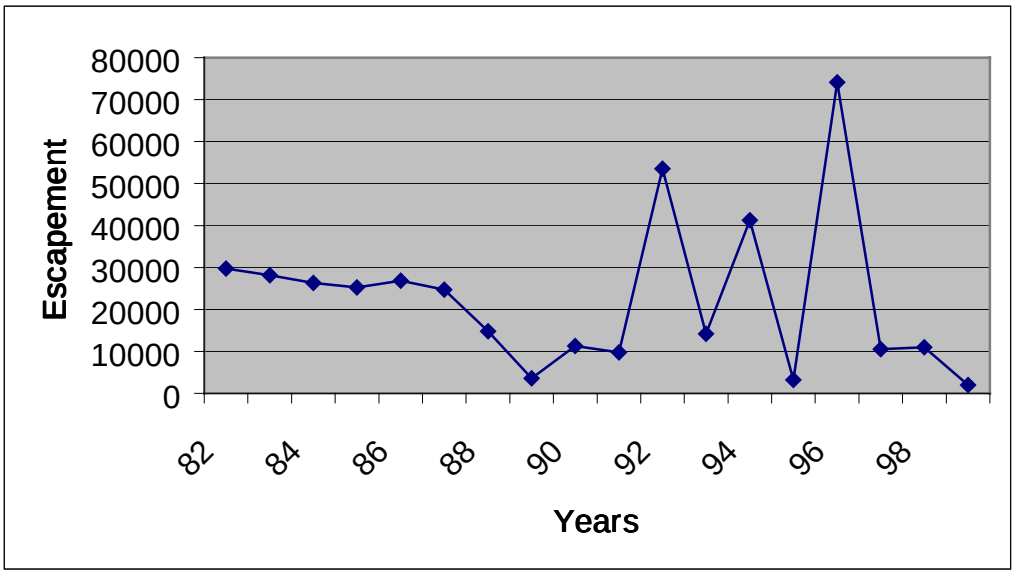


We do not fully understand the challenges these fish face for survival but there does appear to be a direct and adverse relationship between Cedar River flood flows and juvenile sockeye survival in the redds. The long-term trend for this stock is negative and the stock status is "Depressed". Escapement trends are shown in Figure 9.

Lakes Washington/Sammamish Tributaries Sockeye Salmon Stock

This stock is separated due to geographic isolation from other stocks present in the Lake Washington Basin. While sockeye spawn in a number of Lakes Washington and Sammamish tributaries, sockeye adults primarily spawn in Big Bear, Cottage Lake and the East Fork Issaquah Creeks. Smaller numbers of adults are observed spawning in several creeks including Laughing Jacobs and Lewis Creeks (Ostergaard 1994) along with Kelsey Creek (Paulsen 2000). The stock origin of these fish is unknown. Electrophoretic genetic analysis of tissue samples from fish taken from North Lake Washington tributaries indicates they are different from the introduced stocks. SASSI (WDFW and WWTIT 1994) classified this stock as "Depressed" and the long-term trend is negative. Escapement trends are shown in Figure 10. NMFS (Gustafson 1997) concluded that the Big Bear Creek was an Evolutionary Significant Unit (ESU) that warranted close monitoring but was not in immediate danger of extinction, nor was it likely to become endangered in the foreseeable future. Nehlson et al (1991) did not identify the Big Bear Creek sockeye as a stock at risk.

Figure 10. Lakes Washington and Sammamish tributaries sockeye salmon escapement estimates 1982 - 1999.



There is speculation that sockeye salmon adults have been observed intermingling with early run timing kokanee adults in Big Bear Creek, the Cedar River, Issaquah Creek (Pfeifer 1992). Similar observations were made by Ostergaard et al. (1995) in Laughing Jacobs and Lewis Creeks. Spawning sockeye salmon commingle with spawning late timing kokanee at numerous locations throughout WRIA 8 (Pfeifer 1992; Ostergaard 1995). Others feel that these fish were not sockeye adults but rather large adult kokanee (Higgins pers comm).

Big Bear, Little Bear and North Creeks Residualized Sockeye

Recently, the analysis of microsatellite DNA results from samples obtained from fish described as *O. nerka* in Big Bear, Little Bear and North creeks indicates that these fish are more closely genetically related to sockeye from Big Bear, North, and Issaquah creeks than kokanee stocks found elsewhere in the Lake Washington Basin (Young 2001). Additional analysis of otoliths confirmed that these fish were residualized sockeye (Young 2001). However, they are still managed by WDFW as a kokanee stock.

Lakes Washington Beach Spawning Sockeye Salmon Stock

Beach spawning sockeye are separated into a distinct stock by SASSI (WDFW and WWTIT 1994) because of the specific habitat niche they utilize. Specifically, these adult sockeye key in on specific graveled beaches with upwelling sources of water around the perimeter of Lake Washington and Mercer Island. While sockeye spawning occurs in many areas, concentrations of fish have been observed at the Pleasure Point Beach along the southeast shoreline, along the shoreline near Juanita Point in the vicinity of the City of Bellevue, along Enatai Beach (Buckley 1965). Observations made in 1997 and 1998 by volunteers of beach spawning sockeye have also been made on the eastern side of Mercer Island south of Meydenbauer Bay (Paulsen 2000).

SASSI (WDFW and WWTIT 1994) classified the stock status as “Depressed” and the long-term escapement trend as negative. However, the amount of knowledge of these fish is very limited. Unknown behavioral patterns, spawning locations, depth and redd life all need additional investigations to provide more confidence to escapement numbers. Escapement trends are shown in Figure 11.

While beach spawning sockeye are also observed in Lake Sammamish, it is not clear if they represent a distinct stock. Berrgren (1974) reported observations of beach spawning sockeye in Lake Sammamish between 1969 and 1972 ranged from 125-200 in 1969 to 1,400 – 1,900 in 1971.

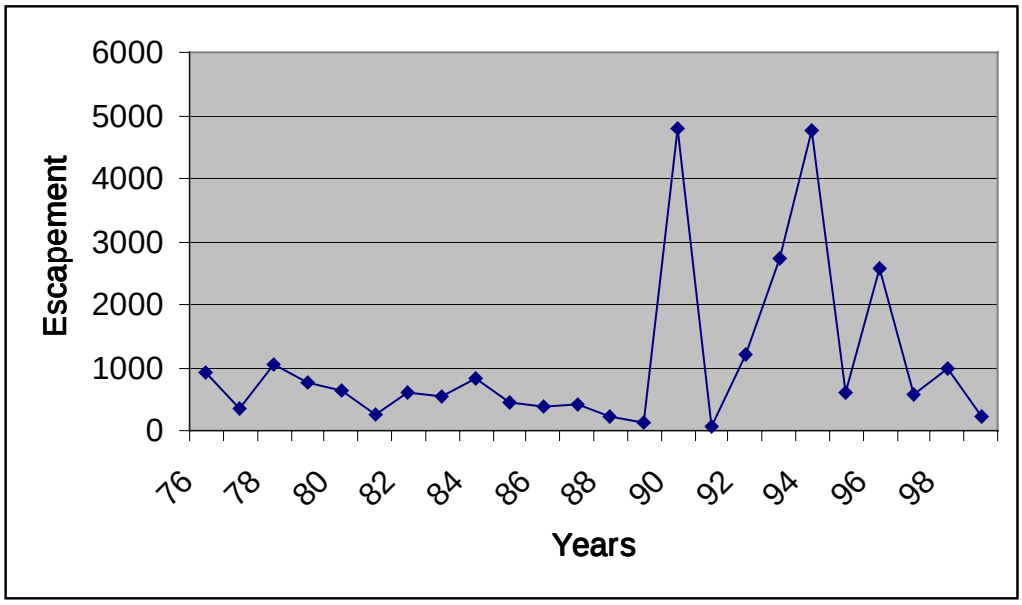


Figure 11. Lakes Washington beach spawning sockeye escapement estimates 1976 - 1999.

KOKANEE SALMON

Lake Washington kokanee (*O. nerka*), the resident form of sockeye salmon, have been separated into three distinct stocks based on a number of key characteristics, the most important being run timing and unique genetic traits. The early run stock of kokanee that return to Issaquah Creek are considered native to the Lake Sammamish drainage (Ostergaard et al 1995). These fish return to spawn beginning in late July and conclude in early September.

A second group of kokanee are present in the Lake Washington basin with a much later run timing. This later returning fish spawns in early September thru October in Big Bear, North, Little Bear, and Swamp Creeks, October and November in Webster Creek (a tributary to Walsh Lake in the Cedar). The origin of these fish is unknown but is believed to be non-native. Recently, the analysis of microsatellite DNA results from samples obtained from fish described as *O. nerka* in Big Bear, Little Bear and North creeks indicates that these fish are more closely genetically related to sockeye from Big Bear, North, and Issaquah creeks than kokanee stocks found elsewhere in the Lake Washington Basin (Young 2001).

As discussed above, what had been thought to be a separate kokanee stock present in Bear Creek (sometimes referred to as Big Bear Creek) and North Creek is now believed to be genetically more closely related to sockeye and has been characterized as a residualized sockeye stock (Young et al 2001). The analysis of microsatellite DNA results from samples obtained from fish described as *O. nerka* in Bear, Little Bear and North creeks indicates that these fish are more closely genetically related to sockeye from Bear, North, and Issaquah

creeks than kokanee stocks sampled elsewhere in the Lake Washington Basin (Young et al 2001). It has been hypothesized that these fish are residualized sockeye (Young et al 2001). However, they are still managed by WDFW as a kokanee stock. Fletcher (1973a) concluded that this kokanee stock was extinct, primarily due to introductions of non-native hatchery origin kokanee. However, there are still small numbers of kokanee adults observed annually in these creeks.

There is evidence of an early Washington Department of Game Hatchery program centered on egg takes of Bear Creek kokanee (WDG unpublished). Early WDG hatchery production records indicate that the following numbers of eggs were taken from Bear Creek kokanee and reared at the Tokul Creek SFH. A summary of that production is shown in Table 2. The disposition of the fish from this program is not known and requires additional investigation beyond the scope of this investigation.

Table 2. Bear Creek stock kokanee egg takes (Source: WDG unpublished).

Year	Number of Eggs Taken	Started
1933-34	6950,500	9/30/33
1934-35	371,300	10/13/34
1935-36	7,460,000	11/16/35
1936-37	10,535,000	10/3/36
1937-38	511,000	10/30/37
1938-39	6,104,200	10/1/38
1939-40	1,698,900	8/19/39
1940-41	1,199,300	8/31/40
1941-42	1,599,740	9/1/41
1942-43	0	Na
1943-44	0	Na
1944-45	0	Na
1945-46	5,550,100	9/30/45

Note: Bear Creek is also referred to as Big Bear Creek in some records.

A third, historic stock of kokanee salmon enters east and south Lake Sammamish tributaries from October through early January. The adult kokanee are morphologically distinct from the kokanee mentioned above with a heavy spotting pattern along their entire dorsal surface and both caudal lobes along with varying degrees of red coloration laterally.

Lake Washington Early Run Timing Kokanee Stock

Native kokanee were historically widespread throughout Lake Washington and its tributaries (Bean 1891). Currently, the native early run timing kokanee stock is found largely in Issaquah Creek and is believed to be one of only two remaining native stocks of kokanee present in the Lake Washington Basin (Pfeifer 1995, Young et al 2001). There is some evidence to suggest that historically, kokanee stocks were also present in at least North and Bear Creeks (see previous discussion on residualized sockeye). During the 1930's and 1940's, WDG took up to 10 million eggs annually from kokanee that were trapped in Bear Creek (Table 2). If it is assumed that the run was comprised of 50 percent males and 50 percent females, the females had a fecundity of 1,000 eggs each, then egg takes of this size would have required the trapping of in excess of 10,000 adults and as high as 25,000 in some years.

The run timing of the Bear Creek fish is somewhat confounding. One scenario is that the "Started" date, shown in Table 2 and taken directly from handwritten hatchery production records of that time, could be presumed to represent the date these fish were started on feed. Kokanee eggs require approximately 1400 daily temperature units (Sisson 2000) for egg development until emergence. The hatchery water supply at Tokul Creek SFH is still a spring water source and has not changed. By calculating the amount of daily temperature units needed for embryonic development with current and historic incubation water temperatures (48° F) at the Tokul Creek SFH where the eggs were taken, the adult kokanee that were trapped in Bear Creek may have been spawned in early July. It is possible that the eggs went to another hatchery prior to their shipment to Tokul Creek SFH during which embryonic development might have been increased. However, sockeye eggs begin to experience increased mortality between 55° F to 57° F and/or embryonic deformities (Piper 1982) so it is assumed that any increases in kokanee embryonic development would not have resulted in large increases in initiation of feeding. However, this would lead us to believe that fish returned over a period of 3 months, which would be unusual unless there were early and late timing stocks returning to the creeks.

An additional concern is that a very early spawning kokanee population would have placed itself on a less than advantageous life history trajectory. These kokanee that spawned as early as the first part of July would have their eggs/alevins still in the redds that would then go through a low flow period in August and September and be subjected to desiccation. The surviving juveniles would presumably emerge in the late fall and early winter when food resources would at best be declining or more likely scarce.

Another and more likely scenario is that the "Started" date indicated in the hatchery records represents the date when the eggs were taken. Historic unpublished data from WDG files indicates that a fish trap for capturing kokanee was put into Bear Creek on September 18, 1941 and September 10, 1945. This would be representative of an early fall run timing.

Scattergood (1949), as reported in Pfeifer (1995), indicated ranges and means for kokanee standard lengths obtained from fish collected on October 2, 1938. He, unfortunately, reported

that the fish were obtained from "North Bear Creek" so it is unclear if the sampled fish came from Bear Creek or North Creek. Regardless of the collection location, the date of collection is indicative of a fall kokanee run timing.

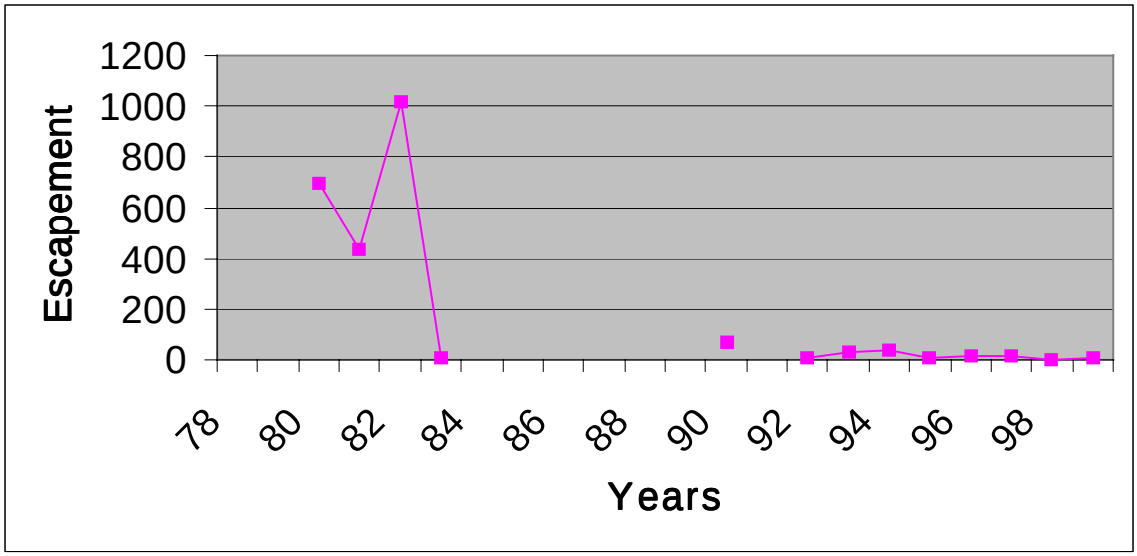
Another possibility is that there were two temporally separate runs into Bear Creek. Anecdotal information by long term residents suggests this possibility. If there were indeed two runs then it would help explain the relatively large time over which these fish returned (Heller 2000).

Declining catch rates by recreational anglers in the mid-1970's caused concern within the Washington Department of Game (WDG) biological staff. This concern persisted through the 1980's when a comprehensive creel survey was conducted by the WDG and later the Washington Department of Wildlife (WDW) (WDG was renamed WDW by the 1986 Legislature). The results of this survey indicated that the historic kokanee fishery was largely absent.

Annual escapement estimates into Issaquah Creek were reported to vary between one and three thousand individual spawners during the early 1970's (Berggren 1974). From 1980 through 1982, estimated kokanee escapement into Issaquah Creek ranged between approximately 400 and 1,000 individuals (Pfeifer 1992). In 1983, only ten (10) early run timing adult kokanee were observed in Issaquah Creek. Kokanee escapement counts conducted from 1992 through 1998 showed a continual low escapement. Figure 12 shows the estimated escapement trend of early run timing kokanee into Issaquah Creek.

In response to the declining escapement of early run timing kokanee into Issaquah Creek through the last 30 years and the current extremely low levels of adults observed, this stock was petitioned in 1999 for listing as "Endangered" under the Endangered Species Act.

Figure 12. Estimated escapement of Issaquah Creek early run timing kokanee 1978 - 1998. (Source: Pfeifer 1992; Ostergaard 1998b).



Lake Washington Late Run Timing Kokanee Stock

The late run timing kokanee present in the Lake Washington Basin have historically spawned in several Sammamish River and Lake Sammamish tributary streams including: Big Bear, Issaquah, Cottage lake, East For Issaquah, Lewis, Laughing Jacobs, Ebright, Pine Lake, Swamp and Little Bear Creeks (Ostergaard 1996, 1998a, 1998b). There is also a population of kokanee in Webster Creek that appear to use Walsh Lake for rearing. Walsh Lake is connected to the Cedar River. (Seattle 1999).

It is unclear when hatchery plants of kokanee were first made into the Lake Washington system but records exist which indicate large numbers of kokanee were released into Lakes Washington and Sammamish and their tributaries beginning in the 1930's. From April 1, 1935 to March 31, 1936, the following numbers of kokanee were released by WDG into the Lake Washington Basin: 300,000 one inch kokanee into Bear Creek; 200,000 one inch kokanee into Bush Creek ; 600,000 one inch kokanee into Evans Creek; 100,000 one inch kokanee into Cottage Creek; 100,000 one inch kokanee into Issaquah Creek; and 500,000 one inch kokanee into E.F. Issaquah Creek (WDG unpublished release data). While numbers of early fish releases and their size at release are available, the origin of these fish often is not.

Most of these fish were believed to have originated from the Lake Whatcom SFH. The Lake Whatcom SFH was historically the egg taking facility responsible for the collection of kokanee eggs used throughout Washington State. The spawning period of the Lake Whatcom kokanee was historically from late October through late December. Currently these kokanee spawn from late October through early December. The Lake Whatcom spawn timing is similar to the presumed spawning period of the native late run timing kokanee in the Lake Sammamish/Sammamish River subbasin. The genetic status of the late run timing kokanee present in the Lake Washington Basin is currently unknown. It has been incorrectly assumed that because of large numbers of introduced hatchery origin fish this population is comprised mainly of Lake Whatcom origin kokanee (Fletcher 1973b; Pfeifer 1995; Ostergaard et al 1995). The recent analysis of microsatellite DNA results from samples obtained from fish described as *O. nerka* in Bear, Little Bear and North creeks indicates that these fish are more closely genetically related to sockeye from Big Bear, North, and Issaquah creeks than kokanee stocks found elsewhere in the Lake Washington Basin (Young 2001).

Escapement estimates into Lakes Washington and Sammamish have not been generated for this stock due to a lack of historic data. However, since 1992 data has been collected that indicates late run timing kokanee escapement was somewhat constant in the early years (1992 through 1996) but decreased in 1997. Because of this downward trend and the lack of quantitative data we have chosen to classify the stock status of this stock as "Unknown".

LAKE WASHINGTON RAINBOW TROUT

Native rainbow trout (*O. mykiss*) were initially distributed in coastal streams in the north from the Kuskokwim River, Alaska as far south as the Santa Domingo River, Baja California, Mexico (Needham and Gard 1959). Throughout most of its range, these fish are anadromous

wherever the opportunity for migration to the Pacific Ocean is possible. The resident form of the native coastal rainbow trout (*O. mykiss irideus*) (Behnke 1992) are thought to be non-anadromous steelhead (*O. mykiss*). While anadromous and non-anadromous forms have long been classified within the same species, the exact relationship between the two is poorly understood. In most coastal populations, it is unusual for the two forms (anadromous and non-anadromous) to coexist. However, there is ample evidence that "residualism" occurs as Shapovalov and Taft (1954) reported evidence of steelhead trout that matured in freshwater and spawned prior to any ocean migration.

The rainbow trout found in Lake Washington are believed to be from one of two origins. They are growing juvenile steelhead trout that will ultimately smolt and migrate to Puget Sound and beyond or the from non-native stocks of hatchery reared fish released into WRIA 8 and intended for a put-grow and take or put and take recreational fisheries. The later group is not believed to be a self-sustaining population as there is no evidence of natural reproduction and the recreational harvest is quite high.

LAKE WASHINGTON COASTAL CUTTHROAT TROUT STOCK COMPLEX

Coastal cutthroat trout (*O. clarki clarki*) are a subspecies of cutthroat trout *(O. clarki*) that are believed to have diverged into separate lines about 1 million years ago (Behnke 1997). Currently, WDFW uses the concept of a "Stock Complex" to identify coastal cutthroat stocks. The definition of a Stock Complex is: A group of stocks typically located within a single basin or other relatively limited geographic area believed to be closely related to one another. This concept was developed in response to genetic analyses conducted by a number of investigators that showed there is a high degree of genetic diversity among coastal cutthroat trout populations even within small stream systems.

Pfeifer (contained in DeShazo 1980) reported on the presence of what was then termed sea-run cutthroat trout in streams of Lakes Washington and Sammamish. He indicated the abundance of sea-run cutthroat trout was decreasing in Bear Creek and that the Cedar River had a "significant population". In Issaquah Creek, Portage Bay/Lake Union, Rock Creek, Lake Sammamish, the Sammamish River, and Swamp Creek he was unable to obtain any significant quantifiable data. However he did mention that cutthroat trout were reported in all the bodies of water evaluated, with the exception of Issaquah Creek. No attempts to determine abundance were made due to lack of data at the time.

Muto and Shefler (1983) reported on the presence of game fish in selected Lake Washington Basin streams. They attempted to determine the upstream distribution of gamefish for selected streams but did not report on population estimates.

SaSI (2000) did not identify a distinct stock of coastal cutthroat trout in the Lake Washington Basin. The NMFS coastal cutthroat status review (Johnson et al 1999) indicated that between 1932 and 1946 a coastal cutthroat stock used in hatchery programs to stock western Washington waters was obtained from Lake Washington. During the 1930's and 1940's,

several hundred thousand coastal cutthroat eggs were obtained from fish in Lake Washington and its' tributaries and released back into "local waters" (Lynch 1941, Donaldson 1947).

The NMFS ESU (Appendix E) for coastal cutthroat trout includes Lake Washington (Johnson et al 1999) but does not provide any specific insight into abundance of Lake Washington stocks.

Assessing populations of coastal cutthroat trout in the Lake Washington Basin is particularly difficult. Ludwa et al. (1997) estimated the abundance of coastal cutthroat trout in McAleer Creek at 8 fish per 50 meters of stream. In that same study, the number of coastal cutthroat trout in Lyons Creek was estimated at 30 fish per 50 meters of stream. Scott et al. (1986) examined Kelsey Creek in 1979 and found 4 to 5 fish per 50 meters but that was increased to 23 fish per 50 meters in 1996 (Ludwa et al 1997).

A reduction in habitat capacity for coastal cutthroat within the Puget Sound ecoregion has been widespread as streams were extensively modified beginning in the late 1800's and continuing through today. Data for trends in coastal cutthroat trout abundance in Lake Washington Basin streams is not available at the time of this report. Data from other Puget Sound river systems is mixed and often times coastal cutthroat trout are caught incidentally to a targeted species such as coho. With a paucity of specific coastal cutthroat data it is not within the scope of this report to determine population abundance for these fish.

NMFS found the scarcity of available information made a risk assessment extremely difficult for coastal cutthroat trout. In their final conclusion they determined there were two alternative conclusions: "(1) there is not enough evidence to demonstrate that coastal cutthroat trout are not at a significant risk of extinction, and (2) there is not enough evidence to demonstrate that coastal cutthroat trout are not at risk." (Johnson 1999).

Foley (pers. comm.) states that while there may be a few fish that are anadromous, the population is primarily adfluvial with fish up to 24 inches in length common. He feels that the populations that utilize Lakes Washington and Sammamish rebounded significantly after the closure of the tributary streams to recreational fishing in the mid 1980's. Fresh (2000) is of the opinion that cutthroat trout populations in the Lake Washington and Lake Washington Basin tributaries have increased significantly throughout the basin during the last 30 years.

KNOWN FRESHWATER DISTRIBUTION OF SALMONIDS IN THE CEDAR - SAMMAMISH BASIN (WRIA 8)

The WRIA 8 Technical Advisory Committee developed salmonid distribution maps for the WRIA 8 watershed. The process, organized by King County Department of Natural Resources, was initiated in 1999. Maps for chinook, coho, sockeye, kokanee and winter steelhead for WRIA 8 have been completed, and are included as Appendix A. Self-sustaining populations of chum and pink salmon are not found in WRIA 8 and the occasional adult fish observed is thought to be a stray from other basins. The supporting data for the maps are also contained in Appendix A. The WRIA 8 Technical Advisory Committee used data from 1970 to the present in developing this map. That time frame was chosen because of a large effort undertaken by the Washington Department of Fisheries (a precursor state agency to the Washington Department of Fish and Wildlife) during the fall of 1974/75 to locate spawning salmonids. The purposes of this salmonid distribution mapping exercise are to:

1. Create a consistent, shared understanding of what is known and not known about the current distribution of salmonids in WRIA 8 and to develop GIS layers depicting that understanding. These maps will be used as a building block for improved knowledge of fish distribution and for more complex species and habitat analysis;

2. Drive identification of areas where improvements to hydrogeomorphic information (e.g., GIS depiction of channel location and configuration) are and are not needed; and

3. Initiate a longer-term WRIA-based process that produces regular updates to GIS layers depicting salmonid distribution and hydrography and makes them available to a broad audience.

Process: This will be an iterative, multi-year exercise: the process of gathering this information, identifying data gaps, filling data gaps, and presenting products will involve the production of multiple, more comprehensive versions of these maps over time. The initial construction of this mapping exercise relied primarily upon: 1) the direct knowledge of technical staff regarding distribution of salmonids, 2) the documentation of salmonid distribution in databases, reports and studies, and 3) existing depictions (i.e., GIS layers) of river and stream channel location and configuration.

To elicit this information, technical staff from jurisdictions, agencies, tribes and stakeholder groups were asked to participate in an information-sharing workshop, and to review draft maps for verification of workshop findings. A final review of the revised maps was conducted by the workshop participants and the WRIA 8 Technical Advisory Committee before the first edition of the salmonid distribution maps was completed.

Given that salmonid distribution and channel location and configuration are dynamic and change with time, the process of compiling and depicting that information (e.g., GIS layers, maps, etc.) will also be an ongoing task. The WRIA 8 technical staff will undertake this task.

Products: The products of this exercise are GIS layers depicting the current knowledge of both salmonid distribution, river channel location and configuration. At this time it is anticipated that a new version of these GIS layers would be created on an annual basis. The frequency of revision will be dependent upon variables such as the comprehensiveness and accuracy of existing information sources, the rapidity of the generation of new information, the capacity of information-sharing systems to incorporate new information, the level of technology available to interested parties in the WRIA, the availability of funding, and other variables.

Anadromous Zone: In addition to the known distribution, an additional feature depicting an "anadromous fish zone" is depicted on these maps. This anadromous fish zone represents a geographic range anadromous fish species might be expected to be found in downstream of 12 percent slope natural stream gradient break points. Because of the difficulty of defining which streams might be utilized by specific anadromous fish species, this zone is not species specific. Rather, it is intended to be an aid in assisting natural and land use managers in locations where they might expect to expand the known range through additional fish surveys.

THE RELATIVE ROLE OF HABITAT IN HEALTHY POPULATIONS OF NATURAL SPAWNING SALMONIDS IN THE LAKE WASHINGTON BASIN (WRIA 8)

Since the recession of the last ice age 10,000 years ago, Washington State anadromous salmonid populations have evolved in their specific habitats (Miller, 1965). Water chemistry, flow, and the physical and biological processes unique to their natal streams, estuaries and ocean environment have helped shape the genotypic and phenotypic characteristics of each salmonid population. These unique attributes have resulted in a wide variety of distinct salmon stocks for each salmon species throughout the State. Within a given species, stocks are relatively distinct population units that do not extensively interbreed with each other. Stocks do not extensively interbreed with each other because returning adults rely on a stream's unique chemical and physical characteristics to guide them to their natal spawning grounds. This maintains the separation of stocks during reproduction, thus preserving the distinctiveness of each stock.

Throughout the salmon's life cycle, the dependence between the environment and a stock continues. For example, adults spawn in areas near their origin because reproductive survival favors natural selection for those that exhibit this behavior. The timing of juvenile salmon leaving the river and entering the estuary is tied to high natural river flows and springtime abundance of preferred prey. It has also been theorized that rapid out-migration reduces predation on the young salmon and perhaps coincides with favorable feeding conditions in the estuary (Wetherall, 1971). These are but a few examples that illustrate how a salmon stock and its environment are intertwined throughout the entire life cycle.

Salmon habitat includes the physical, chemical and biological components of the environment that support salmon. Within the freshwater and estuarine environments, these components include water quality; water quantity or flows; stream and river physical features such as sediment, substrate and woody debris; riparian zones; upland terrestrial conditions; and ecosystem interactions as they pertain to habitat. All of these components are closely intertwined. For instance, low stream flows can alter water quality by increasing water temperatures and decreasing the amount of available dissolved oxygen, while concentrating toxic materials. Heavy sediment loads can also impact water quality by increasing the instability of the channel and decreasing spawning and incubation success. The riparian zone interacts with the stream environment, providing nutrients and a food web base, woody debris for habitat and flow control (stream channel complexity), filtering runoff prior to surface water entry (water quality), and providing shade to aid in water temperature control. In the estuarine and nearshore, riparian zones serve similar functions.

Optimal freshwater habitat for salmonids includes clean, cool, well-oxygenated water flowing at a normal (natural) rate for each stage of freshwater life. Salmonid survival depends upon specific habitat requirements for egg incubation, juvenile rearing, migration of juveniles to

saltwater, estuary rearing, ocean rearing, adult migration to spawning areas, and spawning. These requirements can vary by species and even by individual stock.

When adult salmon return to spawn, they not only need adequate flows and water quality, but also unimpeded passage to their spawning grounds. They need deep pools for resting in conjunction with vegetative cover and instream structures such as root wads for shelter from predators. Successful spawning depends on sufficient gravel of the right size for that particular population, in addition to the constant need of adequate flows and water quality, all in unison at the necessary location. Delaying the upstream migration of adult salmonids can be critical. After entering freshwater, adult salmon have a limited time to migrate upstream and spawn, in some cases, as little as two to three weeks. Delays can result in pre-spawning mortality, incomplete spawning, or spawning in a sub-optimal location.

After spawning, the eggs need stable gravel that is not choked with fine-grained sediment. River channel stability is vital at this life history stage. Floods have their greatest immediate impact to salmon populations during incubation where they can scour redds. Flood impacts may be exacerbated by human activities that lead to increased sediment loads, point and non-point source pollutants, and the removal of instream LWD. Floods can also be beneficial as they also produce and maintain habitats where they provide the necessary energy to scour deep pools, connect off channel habitats, and create side channels.

In a natural river system, the upland areas are heavily forested with mature stands of mixed native species of trees. These trees and their roots store precipitation, which slows the rate of storm water into the stream. A natural, healthy river is sinuous and contains large pieces of downed wood contributed by an intact, mature riparian zone. Both slow the speed of water downstream. Natural river systems have floodplains that are connected directly to the river at many points, allowing the floodplains to store flood water and later discharge this storage back to the river during lower flows. In a healthy river, erosion or sediment input is great enough to provide new sediments (i.e.: gravel) for spawning and incubation, but does not overwhelm the system, raising the riverbed and increasing channel instability. A stable incubation environment is essential for salmon, requiring a complex interaction of nearly all the habitat components contained within a natural river ecosystem.

After the young salmonid fry emerge from the gravel nests (redds), certain species such as chum, pink, and some chinook salmon quickly migrate downstream to the estuary. Other species, such as coho, steelhead, bull trout, cutthroat, sockeye and chinook, will search for suitable rearing habitat within the side sloughs and channels, tributaries, and spring-fed "seep" areas, as well as the outer edges of the stream and in some instances lakes (sockeye). These quiet-water side margins and off channel slough areas are vital for early juvenile rearing habitats. The presence of woody debris and overhead cover aid in food and nutrient inputs, provide localized areas of reduced water velocities for energy conservation as well as provide protection from predators. For most of these species, juveniles use this type of habitat in the spring. Most sockeye populations migrate from their gravel nests quickly to larger lake environments where they have unique habitat requirements.

As growth continues, the juvenile salmon (parr) move away from the quiet shallow areas to deeper, faster areas of the stream. The species that exhibit this behavior include coho, steelhead, bulltrout, and certain chinook. For some of these species, this movement is coincident with the summer low flows. Low flows typically limit salmon production for stocks that rear during summer within the stream. In non-glacial streams, precipitation, melting snow packs, connectivity to wetland discharges, and groundwater maintain summer flows inputs. Reductions in these inputs will reduce that amount of habitat; hence the number of salmon which are dependent on adequate summer flows are reduced.

In the fall, juvenile salmon that remain in freshwater begin to move out of the mainstems, and again, off-channel habitat becomes important. During the winter, coho, steelhead, bull trout, cutthroat and any remaining chinook parr require off-channel habitats to sustain their growth and protect them from predators and high winter flows. Wetlands, off-channel/side channel stream habitat protected from the effects of high flows, and pools with overhead cover are important habitat components during this time.

Except for resident bull trout, cutthroat and steelhead (rainbow), juvenile parrs convert to smolts as they migrate downstream towards the estuary. Again, flows are critical, and food and shelter are necessary. The natural flow regime in each river is unique, and has shaped the stock's characteristics through adaptation over the last 10,000 years. Because of the close inter-relationship between a salmon stock and its stream, survival of the stock depends heavily on natural flow patterns.

Estuaries and nearshore areas support a critical life stage that can be a determinant to successful juvenile survival and the subsequent adult returns. The estuary provides essential habitat for physiological transition, refuge, foraging and rapid growth. Some salmon species are more heavily dependent on estuaries, particularly chinook, chum, and to a lesser extent pink salmon. Estuaries contain new food sources to support the rapid growth of salmonid smolts and an area in which to undergo physiological adaptation from freshwater to saltwater. The complexity of the healthy nearshore environment provides juvenile salmonids with necessary prey items, including insects falling from marine riparian vegetation, bottom-dwelling crustaceans, and crustaceans that live on marine plants such as eelgrass and kelp. Smolts prefer the shallow-water habitats. In particular, habitats that support the detritus-based food web, such as tidal marshes and channels, eelgrass beds, and sand and mud flats, provide a complex system of protection from and opportunities for predators and while allowing juvenile salmonids opportunities for places to rest and forage. As smolts grow larger and begin to move into deeper waters, they rely more heavily on planktonic prey, but some, especially chinook, continue to eat insects that drift out from shore. Returning adult salmonids use the nearshore as staging areas and safe places to make the physiological transition from saltwater to freshwater.

The physical, chemical, and biological processes that create nearshore and estuarine habitats must be maintained for salmonids. For example, sediment transport provides appropriate substrates for eelgrass and other organisms that contribute essential nutrients to the nearshore environment. Marine riparian vegetation must be sufficient to provide woody debris, nutrients, and insects to these environments. Common disruptions to these habitats include

dikes, shoreline armoring, dredging and filling activities, pollution, and shoreline development. Some of the most pressing problems along urban shorelines are interrupted sediment transport processes, filling of intertidal habitat to support development, removal of LWD, and the loss of marine riparian vegetation.

All salmonid species need adequate flow and water quality, spawning riffles and pools, a functional riparian zone, and upland conditions that favor stability. However, some of these specific needs vary by species, such as preferred spawning areas and gravel. Although some overlap occurs, different salmon species and/or stocks of the same species within a river are often staggered in their use of a particular type of habitat. Some are staggered in time, and others are separated by distance. During these times, low flows and associated high temperatures and low dissolved oxygen can be problems. Other disrupted habitat components such as less frequent and shallower pools caused by sediment inputs as well as a lack of canopy from an altered riparian zone or widened river channel can worsen these flows and water quality

While chum and pink salmon use freshwater streams the least amount of time there are no known stocks of these salmon species in the Lake Washington Basin. An occasional chum salmon adult is observed in tributary streams of Lake Washington and adults are observed in several of the direct drainages to Puget Sound but they do not constitute a stock.

Chinook salmon have three major run types in Washington State. Only the summer/fall chinook run type is present in WRIA 8. Lake Washington Basin adult chinook first arrive at the Ballard Locks in mid-June. The peak time of entry through the Locks and into the Lake Washington Basin occurs in mid to late August and is generally complete by early October. Lake Washington Basin summer/fall chinook stocks range in spawn timing from mid September through November.

Juvenile chinook are believed to incubate in the gravel until late January or early February through early March, and outmigration to Lake Washington and the estuaries occurs over a broad time period. Typical juvenile summer/fall chinook outmigrate from January through August but the complete migratory time period for juvenile Lake Washington summer/fall chinook is not currently known. However, tagging results from 1999 indicate that the bulk of the juvenile chinook arrived at the Ballard Locks the last week of June (Goetz 2000). In the Lake Washington Basin, juvenile summer/fall chinook are found entering the lake from their natal streams on the first day a juvenile sockeye trap is operated near the mouth Cedar River in mid-January and are still found outmigrating when that trap is removed in late August. The timing of juvenile chinook outmigration from the Cedar River and Bear Creek is better understood than is the distribution, abundance, growth, diet, and survival of juvenile summer/fall chinook in Lake Washington. Typically, the Lake Washington Basin summer/fall chinook migrate within their first year of life, but a few juveniles remain in the lake for an additional year. There are no data to indicate that there is a large component of Lake Washington Basin stock summer/fall chinook juveniles that remain in freshwater for that additional year after emerging from the redds. However, other Puget Sound chinook stocks (e.g.: Snohomish summer chinook, Snohomish fall chinook, upper Columbia summer chinook) have juveniles that remain in the freshwater environment for an additional year.

For most chinook stocks, the estuary is an especially important transition zone as they migrate from fresh to salt water. The estuary provides essential resources such as food and salinity gradients that aid in the transition from fresh to saltwater habitats. In the Lake Washington Basin, the estuary is extremely limited in Salmon Bay. Historically, Cedar River summer/fall chinook smolts would have migrated out through the Duwamish estuary. With the rerouting of the Cedar River into the Lake Washington Basin in 1916, these smolts are forced to migrate through Salmon Bay, an area where a much more rapid transition occurs than that which these fish's ancestors evolved under. Certainly there are chinook stocks that have evolved in basins without estuaries. In Washington State the Lake Quinault chinook stock is one example and there are numerous riverine chinook stocks in Alaska where there are only limited estuaries. However the Cedar River stock evolved with an estuary prior to being rerouted into Lake Washington in 1916.

Lake Washington chinook use the Cedar River, Issaquah Creek, the Bear/Cottage Lake system (Williams et al. 1975), with smaller numbers using streams such as Kelsey, Little Bear, North, Swamp, May, Lewis, McAleer, and Thornton creeks. The extent to which adult chinook utilize other creeks is not completely known in all instances. Additionally, the extent of any natural juvenile chinook rearing in non-natal tributary streams is unknown. Summer/fall chinook adults have been observed spawning in the mainstem Cedar River as far upstream as the pipeline crossing at RM 21.3 (WDFW Spawning Ground Survey Database). Because of the difficulty in differentiating between a single chinook redd and multiple sockeye redds it is not possible to distinguish all of the chinook spawning locations in the Cedar River. The downstream extent of adult chinook spawning appears to vary from year to year. It is unclear what determines the downstream extent but it is likely influenced by environmental factors such as water flow and temperature. In 1999, significant numbers of live adult chinook and redds were located in Kelsey Creek and the Cottage/Bear Creek system. Lake Washington Basin summer/fall chinook spawn from mid September into late November.

Historically, naturally produced adult chinook were present in the mainstem Cedar River and some streams upstream of the City of Seattle's water diversion dam and pipeline located at RM 21.3. Landsburg Dam is a complete barrier to anadromous fish migration and upstream there is 12.5 miles of high quality mainstem Cedar River habitat and approximately up to 9.7 miles of potential habitat in smaller streams.

The onset of coho salmon spawning is tied to the first significant fall freshet. Lake Washington Basin coho stocks typically enter freshwater from August to early December. They often mill near the river and creek mouths or in lower river pools until the fall freshets occur. Spawning usually occurs between November and early December, but is sometimes as early as mid-October and typically occurs in tributary streams. High stormwater flows and sedimentation in these streams can suffocate eggs. As chinook salmon fry exit the shallow low-velocity rearing areas, coho fry, which emerge from the gravel later than chinook, utilizes those same areas for the same purpose. As they grow, juvenile coho move into faster water and disperse into tributaries and areas which adults cannot access (Neave 1949). Pool habitat is important not only for returning adults, but for all stages of juvenile development.

Preferred pool habitat includes deep pools with riparian cover and woody debris in the form of individual pieces to debris jams.

The Lake Washington Basin coho juveniles remain in freshwater for a full year after leaving the gravel nests, but during the summer after early rearing, low flows can lead to problems such as a physical reduction of available habitat, increased stranding, decreased dissolved oxygen, increased temperature, and increased predation. Juvenile coho are highly territorial and can occupy the same area for long periods of time (Hoar, 1958). Investigators have found that the abundance of coho can be limited by the number of suitable territories available (Larkin, 1977). Streams with more structure (logs, undercut banks, etc.) support more coho (Scrivener and Andersen, 1982), not only because they provide more territories (useable habitat), but they also provide more food and cover. Large wood also assists in the retention of salmon carcasses by adding habitat complexity in the form of pools where these carcasses may settle out and add nutrients for stream productivity. There is a positive correlation between juvenile coho's primary diet of insect material in stomachs and the extent the stream was overgrown with vegetation (Chapman, 1965). In addition, the leaf litter in the fall contributes to macroinvertebrate and aquatic insect production (Meehan et al, 1977).

In the autumn as the water temperatures decrease, the juvenile coho move into deeper pools, hide under submerged logs, overhanging and submerged tree roots, and undercut banks (Hartman, 1965). The fall freshets redistribute them (Scarlett and Cederholm, 1984), and the preferred habitats for over-wintering juvenile coho generally occurs in available side channels, spring-fed ponds, and other off-channel sites to avoid high stream velocities associated with winter floods (Peterson, 1980). Cederholm and Scarlett, (1981) found that a lack of side channels and small streams may limit coho survival. As coho juveniles grow into yearlings, they tend to become more predatory on other salmonids. Lake Washington Basin origin coho begin to leave the basin over a year after emerging from their gravel nests with the peak outmigration occurring in early May. Outmigrating coho use the Salmon Bay estuary primarily for interim feeding while they adjust physiologically to saltwater.

Sockeye salmon have a wide variety of life history patterns, including landlocked populations of kokanee, which never enter saltwater. Of the populations that migrate to sea, adult freshwater entry varies from spring for the Quinault stock and summer for Ozette and Columbia River stocks. Lake Washington sockeye are found entering the Ballard Locks as early as mid-May and continues through early November in some years (Goetz 2000). Sockeye spawning in the Lake Washington Basin occurs in the Cedar River, tributaries to Lakes Washington and Sammamish and along specific beaches in Lake Washington. In the Cedar River, sockeye spawn in the mainstem river channel, in side channels and spring-fed ponds. The spawning beaches along Lake Washington provide a unique habitat that is often altered by human activities, such as pier and dock construction, dredging, sedimentation, and weed control. Timing of sockeye spawning ranges from September through January.

After fry emerge from the gravel, Lake Washington sockeye migrate to a lake for rearing. Lake rearing of juvenile sockeye ranges from one to three years with most juveniles rearing two years. In the spring after lake rearing is completed, juveniles enter the Puget Sound and then the ocean where more growth occurs prior to adult return for spawning.

Steelhead have one of the most complex life history patterns of any anadromous Pacific salmonid species (Shapovalov and Taft, 1954). In Washington, there are two major run types, winter and summer steelhead. The Lake Washington Basin does not have a summer steelhead stock and winter steelhead adults begin river entry in a mature reproductive state in December and generally spawn from February through May.

Naturally produced juvenile winter steelhead can either migrate to sea (anadromy) or remain in freshwater as a resident rainbow trout. The vast majority of juvenile steelhead in the Lake Washington Basin smolt and migrate to saltwater. Lake Washington Basin origin steelhead usually spend 1 to 3 years in freshwater, with the greatest proportion spending two years (Busby et al, 1996). Because of this, juvenile steelhead rely heavily on the freshwater habitat and are present in streams all year long.

Washington's native char, bulltrout/Dolly Varden stocks are also very dependent on the freshwater environment, where they reproduce only in clean, cold, relatively pristine streams. Temperatures in excess of approximately 15° C. are thought to limit bull trout distribution (Allan 1980; Brown 1992; Ratliff 1992 and others). Goetz (1989) believed that optimum water temperatures for rearing were about 7 to 8° C.. However, other investigators (McPhail and Murray 1979, Pratt 1984) have suggested that bull trout grow more quickly in cold waters than warm waters. Spawning areas for bull trout are most often found in the coldest streams in a basin and optimal temperatures for egg incubation are 2 to 4° C.(McPhail and Murray 1979). Rieman and McIntyre (1993) concluded that water temperature represented a critical habitat characteristic for bull trout.

Within a given stock, some adult bull trout/Dolly Varden remain in freshwater their entire lives, while others migrate to the estuary where they rear during the spring and summer. They then return upstream to spawn in late summer. Those that remain in freshwater either stay near their spawning areas as residents, or migrate upstream throughout the winter, spring, and early summer, residing and rearing in pools. Bull trout return to spawning areas in late summer with spawning occurring from August through November (McPhail and Murray 1979, Brown 1992) and this activity is associated with decreasing water temperatures between 5 and 9° C.. Bull trout eggs, and subsequent alevins, incubate over the winter with hatching occurring in late winter and early spring (Weaver and White 1985). In some stocks juveniles migrate downstream in spring, overwinter in the lower river, then enter the estuary and Puget Sound the following late winter to early spring (WDFW, 1998). Because these different life history types have different habitat characteristics and requirements, bulltrout/Dolly Varden are generally recognized as a sensitive species by natural resource agencies. Reductions in their abundance or distribution are inferred to represent strong evidence of habitat degradation.

In the Lake Washington Basin, a stock of bull trout/Dolly Varden, occurs in the upper Cedar River basin in Chester Morse Lake (WDFW 1998). Populations of native char have not been confirmed in the lower Cedar River, Lake Washington or other tributary streams in the Lake Washington Basin. No native char were observed in a one-year survey on Lake Sammamish (Bradbury and Pfeifer 1992) although one fish was identified during a two-year creel survey

on Lake Washington (Pfeifer and Bradbury 1992). Two native char were reported in the plunge pool of a culvert in the headwaters of Issaquah Creek in the fall of 1993 (Fuerstenburg personal communication as reported in SaSI 1998). It is probable that these three fish were strays into the basin and not a part of a local population since water temperatures in Issaquah Creek and other tributary streams outside of the headwaters of the Cedar River are believed to be to high to support spawning adults of bull trout/Dolly Varden.

In conclusion, all of the salmonid species have similar general habitat needs such as unimpeded access to spawning habitat, a stable incubation environment, favorable downstream migration conditions (adequate flows in the spring), and a healthy estuarine environment. Some species, such as chinook, rely more heavily on the estuary for foraging, growth, and physiological transition that requires good estuary habitats.

In addition to the above-described relationships between various salmonid species and their habitats, there are also interactions between the species that have evolved over the last 10,000 years such that the survival of one species might be enhanced or impacted by the presence of another. Pink and chum salmon fry are frequently food items of coho smolts, cutthroat, bull trout, and steelhead (Hunter, 1959). Chum fry have decreased feeding and growth rates when pink salmon juveniles are abundant (Ivankov and Andreyev, 1971), probably the result of occupying the same habitat at the same time (competition). Salmon carcasses can provide a direct and indirect food resource for the same or other salmonid species. These are just a few examples.

The Lake Washington Basin is home to several salmonid species, which together, rely upon freshwater and estuary habitat the entire calendar year. As this habitat and salmonid review indicated, there are complex interactions between different habitat components, between salmonids and their habitats, and between different species of salmonids. For just as habitat dictates salmonid types and production, salmonids contribute to habitat and to other species. Specific information about individual runs and stocks is contained the chapter titled “Current Salmonid Population Conditions in the Lake Washington Basin” elsewhere in this report.

Most streams in Washington are home to several salmonid species, which together, rely upon freshwater and estuary habitat the entire calendar year. As this habitat and salmonid review indicated, there are complex interactions between different habitat components, between salmonids and their habitat, and between different species of salmonids. For just as habitat dictates salmonid types and production, salmonid production contributes to habitat and to other species.

WATERSHED CONDITION

General Overview

The Lake Washington Basin includes in excess of 470 identified streams with approximately 700 miles of habitat historically accessible to anadromous salmonids. These rivers and streams are among some of the most altered hydrological streams in the Puget Sound Region. Most exist in heavily urbanized settings and are subjected to the adverse habitat impacts that accompany this setting. These streams generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems. As one moves upstream, habitat conditions show some improvement but with a few exceptions do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival. While the habitat around these streams is generally better than that found in rivers ands streams located closer to the urban cores, it has problems typically associated with commercial forestry and damage to habitat forming processes are less permanent.

In this chapter, the lakes and streams of the Lake Washington Basin (WRIA 8) are subdivided into important lakes and streams as follows:

- Streams Draining Directly to Puget Sound
  - Snohomish County Nearshore Tributaries
  - Pipers Creek
  - Boeing Creek
- Nearshore/Estuary Habitats
- Hiram Chittenden Locks
- Lake Union / Lake Washington Ship Canal
- Lake Washington
- Lake Washington Tributaries
  - Thornton Creek
  - McAleer Creek
  - Lyon Creek
  - Juanita Creek
  - Kelsey Creek
  - May Creek
  - Coal Creek
  - East lake Washington Small Tributaries
  - Lower Cedar River and Cedar River Tributaries
  - Upper Cedar River and Cedar River Tributaries
- Sammamish River and Sidewall Tributaries
- Northern Tributaries
  - Bear Creek Subbasin
  - Swamp Little Bear Creek Subbasin
  - North Creek Subbasin
  - Creek Subbasin

- Lake Sammamish
- Lake Sammamish Tributaries
  - East Lake Sammamish Tributaries
  - West Lake Sammamish Tributaries
  - Lewis Creek
  - Issaquah Creek Subbasin

There are numerous additional tributary streams not covered in this assessment. Generally these streams do not have anadromous fish access or have very limited amounts of access. However, the absence of these creeks in this report should not be interpreted as diminishing their importance, rather the lack of information that was located during the course of this investigation.

HABITAT LIMITING FACTORS IDENTIFICATION

The information contained in this report was developed by synthesizing existing habitat descriptions, data derived from field assessments of salmonid habitats, and personal communications from natural resource professionals with first hand experience of the Cedar - Sammamish Watershed (WRIA 8). These individuals served in various capacities on the WRIA 8 Technical Committee, which both contributed information and provided technical review of this project. This report is intended for use as a tool to guide and prioritize salmonid habitat restoration projects within the Cedar - Sammamish Watershed. The descriptions of salmonid habitats, assessments, and Technical Committee knowledge were used to describe the current habitat conditions in the lakes, river, streams and marine nearshore throughout the watershed. These descriptions were compared to a set of salmonid habitat rating criteria (Table 45) resulting in a good, fair, or poor rating for habitat quality averaged throughout the length of the body of water. In many instances this exercise also identified DATA GAPS and those too were identified.

HABITAT LIMITING FACTORS ASSESSED

FISH ACCESS AND PASSAGE BARRIERS

Anthropogenic obstructions include dams, culverts, dike and levees that limit and/or block salmonid migration up and down streams and into and out of lakes. Depending on the longevity of the barrier, the negative impacts may be limited to a portion of only one fish generation up to and including the extirpation of an entire population or stock of salmonids. The types of passage barriers typically encountered by salmonids in WRIA 8 include improperly placed culverts and dams.

Increased Sedimentation and Altered Sediment Transport Processes

Sediment and its transport from source to the downstream reaches of the river is an important process that produces and maintains salmonid habitat. In a properly functioning system, sediment provides a quality substrate for salmon egg incubation, food source production and cover from predators. When the process is disrupted, as with excessive erosion, landslides or dam construction, fish habitat degradation results.
Substrate embeddedness is the product of fine sediment washed into streams and rivers. Soils eroded from changes in land uses such as the conversion of historic forests to urban environments are the main source of fine sediment inputs in WRIA 8. Naturally unstable stream banks are also responsible for significant contributions but historically they are also a source of gravel recruitment necessary for good quality in-stream habitats.

Loss of Channel Complexity / Connectivity

Natural floodplains provide an area for dissipation of energy during flood events. A floodplain has a larger surface area, and generally a flatter slope than that of a stream channel. Once flood water spills onto a floodplain, it spreads out and loses energy. The interface between water and riparian vegetation further reduces stream energy. In the floodplain, water

slows down and sediments settle out which in turn gradually build up the surface height of the floodplain. Water also seeps into the groundwater table, recharging wetlands, off-channel areas and shallow aquifers.

Off-channel areas provide juvenile salmonids refugia from flood flows and for some species an ideal rearing environment. Typically, fewer predators are present in these areas than in the main river channel and juvenile salmonids expend less energy in the slower waters than they would in the faster mainstem. These energy savings, along with an abundant food supply enables juvenile salmonids to grow rapidly. Wetlands and aquifers in turn meter water to the streams during summer months through a process called hydraulic continuity. Fully functional floodplains meter instream peak and low flows through the process of water storage and release. This type of flow maintenance ensures adequate instream flows (water) for salmonids during summer months and reduces the possibility of high-energy flood events that limit spawning success.

Degradation of Riparian Conditions

Riparian zones are the interface between the aquatic habitats and upland areas. Typically, they are an area on or by land bordering a stream, lake, tidewater, or other body of water. Along rivers and streams, this zone is normally covered with vegetation that include large coniferous and deciduous trees and to a lesser extent forbs and shrubs. Along lakes, this zone would have also included grasses that grew in the areas where the shoreline receded during seasonal fluctuations.

Riparian zones have several important functions in maintaining riverine processes. Complex tree and shrub root matrices hold streambanks together. This matrix stabilizes channels, enabling the creation of undercut banks and reduces erosion. Overhanging tree canopies shade the water, maintaining cooler stream water temperatures. Leaf liter falling into the stream is an important component of primary production within the aquatic community. Insects on overhanging trees and shrubs also are an important food source for rearing juvenile salmonids. Mature trees in the riparian zone are also recruited into the rivers and streams when knocked over by erosion (landslides) or windthrow. These large trees act to stabilize stream beds and banks, capture and sort gravels, encourage pool formation, provide refugia for juvenile and adult salmonids, capture salmon carcasses for stream nutrient input, and creates habitats for insects and other forage important to salmonids. Additionally, vegetation in the riparian zone can filter pollutants from stormwater runoff and reduces flood damage by dissipating stream energy by slowing down floodwater velocities.

Altered Hydrology / Flow

In most cases, alterations to hydrology/flow in WRIA 8 is directly linked to changes in land cover, including the clearing of forests and the creation of impervious surfaces, which combine to increase storm flows and reduce base flows. In many cases, stream hydrology or flows have also been altered by water and wastewater management practices.

Water Quality

Salmonids require a supply of cold and clean water for optimal survival success. While water temperature requirements vary depending on salmonid species and life stage, generally salmonids require stream temperatures less than 17.8° C for successful migration and rearing and less than 15.6° C for spawning. Optimal stream water temperatures would be between 10 - 14° C. Stream water temperatures above 17.8° C cause additional stress and reduce survival while long term exposure to water temperatures greater than 24° C are fatal to salmonids. Bull trout require colder water.

Salmonids require a minimum dissolved oxygen concentration of 5 mg/L (also read as parts per million (ppm)) for survival. Washington State water quality standards require a value of 8 mg/L of dissolved oxygen for the protection of fish resource in Class A or better waters. Total suspended solids (TSS) refers to the weight of particles, including soils, and algae suspended in a given volume of the water column. The US Fish and Wildlife Service recommend a maximum TSS level of 80 mg/L to protect salmonids. Other water quality parameters including pH (the concentration of hydrogen ions in water) and chemical pollution can be responsible for degrading habitat quality.

Biological Processes

Biological Processes include the number of salmonid stocks meeting escapement goals. There is a considerable amount of scientific evidence that supports the hypothesis that anadromous salmonids act as “keystone species” by providing marine derived nutrients to oligotrophic inland ecosystems. Nutrients from decomposing salmonid carcasses are a critical component of the aquatic food chain. With only a few exceptions in some years, anadromous salmonid populations throughout the Cedar - Sammamish Basin are returning well below historic levels.

DIRECT DRAINING STREAMS TO PUGET SOUND

BOEING CREEK

A. PHYSICAL DESCRIPTION

The headwaters of Boeing Creek (08.0017) are in the Aurora Square commercial development, and the mainstem is tightlined through the developed area to the stormwater facility at Shoreline Community College. At this point Boeing Creek flows through a ravine that includes a fairly wide riparian forest, much of it mid to late seral stage. The majority of Boeing Creek is contained within this forested ravine that empties directly into Puget Sound. The mainstem Boeing Creek is identified as stream 08.0017, and the north fork is recorded as 08.0019 (Williams 1975). Boeing Creek has sometimes been referred to as Hidden Lake Creek. Hidden Lake was a constructed lake that has filled in with sediments and been restored.

Though Boeing Creek has experienced little recent development, past urban development on the surrounding plateau within the basin has removed forested uplands and most wetlands. Urbanization within the Boeing Creek basin has resulted in the substantial increase of impervious surfaces (approximately 40 percent of the entire basin) and a corresponding increase in peak stormwater discharges (Boehm 1994). Most of the Boeing Creek stream system between the saltwater outlet and the mainstem stormwater retention/detention facility is characterized by a continuous green belt of mid to late seral stage forest. This mid to late seral stage forest component has contributed a substantial amount of large woody debris (LWD) recruited onto the valley floor and into the stream. The LWD component in the stream has helped retain some pool complexes and fish habitat amidst slope failures, colluvial sediment loading into the stream, and high sediment loads transported throughout the streambed. Several landslides were observed in the lower stream reaches. The topography of the mainstem stream system of Boeing Creek can be generalized as a V-shaped ravine increasing in depth from the head of the watershed at the eastern edge of the plateau towards saltwater. There are areas throughout the ravine with steep, unstable slopes.

B. SALMONID UTILIZATION

The known freshwater distribution of anadromous and resident salmonids is depicted Appendix A. A 1993 stream survey found cutthroat trout (*Oncorhynchus clarki clarki*) and coho salmon (*O. kisutch*) below the Seattle Golf Course dam. Cutthroat trout have been observed in the upper reaches, but adult salmon are not able to migrate past a series of barriers beginning with the dam.

C. HABITAT FACTORS OF DECLINE

GENERAL

Boeing Creek is representative of many of the problems typically associated with urbanized stream systems: "flashy" storm flows, downcutting and erosion, sedimentation, embeddedness, loss of large woody debris, and decrease in size and number of large pools.

Sedimentation is exacerbated due to the natural features of the subarea such as steep, unstable slopes and soils, and source bed deposits of sediments.

FISH ACCESS AND PASSAGE BARRIERS

The stream reach between the Seattle Golf Club dam and Northwest Innis Arden Way has several series of large cascades and slope failures that are major blockages to fish passage. These slope failures are likely the direct result of changes to the hydrologic regime caused by urbanization. A series of notch cut logs and what are believed to be historic water diversion dams just upstream of Innis Arden Way may delay or prevent passage under some flow conditions.

Several programs have introduced salmon above the dam with eyed coho salmon eggs in gravel-filled tubes planted in stream sections, and school participation in planting coho salmon juveniles. Juveniles are able to migrate downstream to Puget Sound.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Channel downcutting and fluvial sediment deposition varies within each stream reach and stream gradient. Downcutting within the lower section of the lower reach has not been as severe as upstream. The low gradient (2-7 percent) has encouraged a dropping out of sediment recruited from upstream bank erosion areas, and extensive channel bed sediment accumulation. Within the mid-section of the lower reach there is an extensive area of colluvial deposition and slope failure (left bank) that contributes a significant amount of fine sediments recruited into the stream channel. Several local slides comprised mainly of fine sands were observed in this reach (Kerwin, pers. obs.). Maximum downcutting in the upper end of the lower reach is 0.5 meters (Boehm 1994). The lower end of the upper reach, which includes the restored Hidden Lake, varies in gradient from 1-3 percent, and has experienced excessive stream channel bed infilling with sediment (Boehm 1994). The upstream section of the upper reach, a steep ravine that terminates at a surface water management dam, varies in gradient from 4-12 percent (Boehm 1994). There are more cascades, scour sections, and LWD in this part of the reach, which has collectively helped control some of the channel infilling.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

The headwaters of Boeing Creek are in the Aurora Square commercial development, and the mainstem is tightlined through the developed area to the stormwater facility at Shoreline Community College. At this point Boeing Creek flows through a ravine that includes a fairly wide riparian forest, much of it late seral stage. In addition, much relict woody debris from this forest is in the channel area, maintaining some fish habitat and a number of natural springs are still functioning. These springs emerge from the ravine banks throughout the length of the creek, providing infusions of year-round cold water. An abundance and variety of LWD and debris jams exists in areas of the upper and lower reaches, especially in those areas where the riparian corridor consists of mid and late stage trees. Within the mid-section

of the lower reach there is an extensive area of colluvial deposition and slope failure. This section also has sufficient LWD in the form of debris jams. The upper section varies from 3-12 percent in gradient, with sufficient LWD to break up the extensive length of riffle habitat and create roughness in the stream channel.

DEGRADATION OF RIPARIAN CONDITIONS

The riparian vegetation of the lower reach of the stream is composed of mixed forest of deciduous and coniferous trees. A significant number of these trees appear to be mid and late seral stage conifers, with composite areas of open space for shrubs and young trees to regenerate. The riparian vegetation of the upper reach is also a mixed-species, mid to late seral stage forest, but with larger sections of mid growth forest established along Hidden Lake and the upper area of Shoreview Park. Boehm (1994) indicates that these forests are "old growth" but the presence of numerous stumps with springboard notches in them would seem to indicate that this area was logged. Examining the size and density of the trees present indicates the logging probably occurred in the very early part of the 20th Century. The mixed forest vegetation throughout the upper and middle reaches of the area is dense and provides an almost intact canopy over the stream. However, several sections of the riparian community are, for the most part, not mature coniferous forests but immature, mixed forests, especially true of the alder saplings in the Hidden Lake area. Riparian vegetation is sufficiently dense and intact to provide good buffer functions for the stream, but the potential for recruitment of LWD is somewhat limited.

In the lower and mid stream reaches the riparian zone does have some single family residences that are close to the creek. In the vicinity of these houses, large boulders have been placed against the toe of the hill in an effort to limit erosion and stabilize the hill. The effects of these houses and riprap are minimal and the lower reaches of Boeing Creek have some of the best riparian zone of any direct drainage into Puget Sound in WRIA 8.

ALTERED HYDROLOGY / FLOW

Boeing Creek has had a history of increased erosion and flood damage over the last 50 years (Boehm 1994). Uncontrolled runoff damaged residential properties, flooded homes in the upper watershed, and produced flooding along the North and mainstem tributaries, and caused siltation of Hidden Lake. There is evidence of landslides and mass wasting along much of the slope length adjacent to Boeing Creek and its tributaries. The greater part of the watershed basin area is now urbanized and serviced by a well-developed stormwater drainage system with regional ponds. Both newly constructed and retrofitted R/D ponds constrain much of the storm flows which have in the past contributed to large erosive flows and excessive stream bed sedimentation with the Boeing Creek mainstem. Typically, storm flow contribution to base flows to Boeing Creek disappears by late spring and does not normally reoccur until storm weather systems return in the fall. Throughout the entire summer, however, seepage areas in the upper and lower ravine provide base level flows to the mainstem, which gain in volume downslope. North tributary flow rates for late summer (1993) were estimated to be 1.2 cfs, and during storm events can be as high as 30 cfs (Boehm 1994).

Urban development on the surrounding plateau of the Boeing Creek basin has removed the historic forest and most of the wetlands. These habitats historically stored water and released it over a longer period of time. Under historic forested land cover conditions there was almost no run-off produced except during very large storm events or rain-on-snow events (Booth 1991). The urbanization of Boeing Creek has resulted in impervious surfaces covering approximately 40 percent of the total land area (Boehm 1994).

WATER QUALITY

The greater part of the watershed basin area is now urbanized. Water quality data for the creek was unavailable for this report.

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek nor is any reach of the creek an index area. Counts of adult salmonids, primarily coho, have been sporadic.

NON-NATIVE SPECIES

ANIMALS

No information was obtained to indicate the presence of non-native aquatic animal species.

PLANTS

Non-native plant species found in the subbasin include numerous ornamental species associated with plantings by private and public landowners. Exotic species of plants more closely associated with riparian and aquatic environments include: scotch broom (*Cytisus scoparius*) and reed canarygrass (*Phalaris arundinacea*) which is abundant throughout this subbasin and Himalayan blackberry.

Non-native animal and/or plant species do not appear to currently be a limiting factor to natural salmonid production.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- There are several known barriers to adult salmonid fish passage in Boeing Creek (see Appendix D);
- The riparian zone in the lower stream reaches is some of the best riparian habitat of any direct drainage into Puget Sound in WRIA 8;
- The amount of total impervious surfaces in the Boeing Creek basin was 40 percent in 1994; and
- A dam on the Seattle Golf Course blocks anadromous salmonid migrations.

E. DATA GAPS

- No information was available during the course of this report to assess either the historic or existing extent or condition of off-channel habitat in the Boeing Creek subbasin;
- The extent to which plant and animal non-native species are impacting salmonid survival is not fully understood. A comprehensive assessment of non-native species needs to be initiated, completed and action plan developed;
- A baseline habitat inventory is lacking in this subbasin and would provide the necessary information from which to gauge changes in the future; and
- The extent of actual usage by anadromous and resident salmonids is not known.

PIPERS CREEK

A. PHYSICAL DESCRIPTION

Pipers Creek (08.0020) is a heavily urbanized watershed with a total drainage basin of approximately 1835 acres (2.9 mi^2). The creek flows in a northeasterly direction and enters the Puget Sound estuary at the Carkeek Park Beach. There is little to no estuarine habitat off the mouth of the creek, although divers documented the presence of eelgrass beds offshore in 2000 (N. Malmgren, personal communication 2001). Lower Pipers Creek mainstem has a constructed wetland, which is bordered on its downstream side by the railroad right-of-way at the mouth of the creek (1998 SPU CIP project). Sub basins of Pipers Creek include the mainstem, Upper Pipers, and Venema/Mohlendorph.

The upper section of Pipers Creek Watershed, covering about 80 percent of the drainage basin, is an urbanized upper plateau. Single family residences occupy most of the area, with small businesses and multifamily housing along the arterial streets (SPU Pipers Creek Watershed Action Plan 2000). The human population in this basin is about 17,000 (Malmgren, 1996).

A portion of the creek and its tributaries lie within the boundary of City of Seattle's Carkeek Park (223 acres) in the lower 20 percent of the watershed. The riparian habitat within the park is characterized by steep-sided ravines, covered with second growth forest composed of mature alders and big leaf maples, interspersed with occasional cedars, hemlocks, and firs streets (SPU Pipers Creek Watershed Action Plan 2000). The mainstem of Pipers Creek is relatively straight and appears to have been relocated to its current channel site along the south side of the floodplain (GAIA Northwest, 1997). A small, but disconnected floodplain separated from the creek by a reinforced right-bank along the north side (right-bank) is located in the lower mainstem Pipers Creek.

Pipers Creek and its tributaries total approximately 5.0 miles in length (Washington Trout/SPU watershed study in progress). Elevation ranges from 0' to 486' (SPU GIS). Soil types in the Pipers Creek valley floor and lower ravine slopes are clay and Esperance Sand, and the Venema/Mohlendorph sub basin is mostly Vashon Till (GAIA Northwest, 1997). A constructed surface water drainage system conveys surface water from most of south section of upper plateau to Pipers Creek. The northern section storm water is conveyed through open ditches to Venema/ Mohlendorph sub basin.

B. SALMONID UTILIZATION

A few fish surveys have been conducted in Pipers Creek (Pfeifer 1984, Thomas 1992, Washington Trout/SPU In Progress). Salmonid species currently found in Pipers Creek include chum salmon (adult), coho salmon (adult and juveniles), resident *O. mykiss* (juveniles), and coastal cutthroat trout (Washington Trout/SPU In Progress). Historically, Pipers Creek and its tributaries had runs of winter steelhead, coastal cutthroat, coho, and chum

(Malmgren, 1996). A few young of the year chinook juveniles were sighted in the mainstem in June 1999, but these may have been released by schools participating in the Salmon in the Classroom Program (B. Miller personal communication 2001). Carkeek Park Salmon Stewards reported seeing a chinook adult in the mainstem in 1998 (B. Gay, personal communication 2001).

Anadromous fish spawning occurs in the lower mainstem Pipers Creek and lower Venema sub basins (Washington Trout/SPU In Progress). The Carkeek Watershed Community Action Project (CWCAP) has been releasing coho (1980-83) and chum (1984-present) each spring (Malmgren, 1996). Salmon are primarily a chum stock obtained from the Minter Creek State Fish Hatchery near Gig Harbor. The chum are introduced as fingerlings into an imprinting pond in Mohlendorph Creek, where they are held for 3-4 days before being released (Malmgren, 1996). Observed adult chum returns have been in the hundreds for the period 1993-1996 while coho were 12 in 1999 and about 30 in 2000.

C. HABITAT FACTORS OF DECLINE

GENERAL

Fish passage barriers are known to limit the natural production of salmonids in Pipers Creek. The loss of channel complexity and flood plain connectivity, degradation of riparian conditions, and increases in sedimentation and altered sediment transport processes (GAIA Northwest, 1997) are also believed to limit the natural production of salmonids. Poor water quality resulting from, altered hydrology and altered flow regimes have been identified as possible factors of decline. High stream water temperatures have not been found to be a problem, and temperatures typically run between 13 and 14º C (Minton, 2000).

FISH ACCESS AND PASSAGE BARRIERS

Culverts at RM 0.4, adjacent to the Metro King County Treatment Plant are a partial barrier to the upstream migration of salmon into Upper Pipers Creek (Washington Trout/SPU In Progress). Volunteers have reported sighting adult chum salmon upstream of these culverts (N. Malmgren, personal communication 2001). An estimated total of ~0.65 river miles is accessible to anadromous salmonids, and approximately 1.75 river miles is accessible to coastal cutthroat trout. Stream-typing indicates that there is potentially up to approximately 2.5 river miles of WDNR Type 2 and 3 fish-bearing stream in the Pipers Creek drainage basin (Washington Trout/SPU In Progress). A culvert at 100th Place and 7th Ave NW is a complete barrier to salmonids and represents the upper extent of resident trout habitat in upper Pipers Creek. The inaccessible salmonid habitat is located in the developed residential areas of the upper plateau.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Portions of Pipers Creek are located in a ravine with steep (50 percent) slopes, which are susceptible to erosion and failure. A high percentage of fines have been found in the streambed (GAIA Northwest, 1997).

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

Pool habitat is limited and is mostly associated with artificial structures (weirs). Little LWD is available in Pipers Creek for channel complexity and pool formation, although LWD and logjams are found in the Venema-Mohlendorph sub basin (Washington Trout/SPU In Progress). Refugia habitat is lacking due in part to both the steep nature of the topography and a reduction in floodplain connectivity (GAIA Northwest, 1997).

The loss of channel complexity and floodplain habitat due to channel incision, roads, and bank hardening structures limits natural production of salmonids.

DEGRADATION OF RIPARIAN CONDITIONS

Forested riparian buffers are absent in the headwaters of upper Pipers Creek. A forested buffer is found along most of the creek's left bank, but is lacking from most of the right bank of the lower Pipers Creek mainstem. Although the forested left bank is not considered a fully functional buffer, the canopy dominated by mature alder/big leaf maple does provide shade for the creek as it travels through Carkeek Park (SPU 1995-96 Stream survey, unpublished data, UW Center for Urban Resources Management Annual Stream Temperature Survey 1998-2000 unpublished data).

Land use activities in this creek will generally preclude riparian conditions from achieving adequate function. In particular, the residential development in areas adjacent to the channel upstream of Carkeek Park will continue to prohibit development of mature riparian vegetation capable of providing shade. The condition of the riparian zone limits the natural production of resident and anadromous salmonids.

ALTERED HYDROLOGY / FLOW

Alterations to the hydrologic regime are likely with impervious surface and an extensive stormwater drainage system. Limited flow data are available. Measured flows have ranged from 3.0 - 9.0 cubic feet per second (cfs) in mainstem Pipers Creek, 0.3 - 1.3 cfs in Mohlendorph, and 0.5 - 3 cfs in Venema, during January to March 1999 (Grady, 2001). Estimated storm flows for the mouth of Pipers Creek range from 336 cfs for the 1-year storm to 850 cfs for the 100-year storm (SPU Drainage staff, reported in GAIA Northwest, 1997). SPU plans to install flow gauges by 2001. Groundwater seepage from the areas around the steep slopes contributes to stream base flows (GAIA Northwest, 1997).

With the lack of mid and/or late seral stage forest stands (aged 25 years or greater) in the watershed, the alteration to the stream hydrology limits natural production of salmonids.

WATER QUALITY

Low B-IBI scores indicate degradation of aquatic macroinvertebrate diversity (SPU 1994, 1996, 1998). Copper, iron, manganese, aluminum and zinc were detected in water samples collected during five storm events in 1988 and 1995, but usually below set standards (Minton, 2000). Lead and zinc appear to be higher in upper Pipers Creek, and chromium, copper, and nickel seem to be higher in Venema Creek (Minton, 2000). Additional sampling is needed. A limited program for testing for the presence of organics and pesticides in sediments (4 samples, one each in 1987, 1988, 1994, and 1995) found that all parameters were below detection levels, except for benzoic acid and phenol in one sample (Minton, 2000). More sampling should be conducted to be conclusive (Minton, 2000). Phosphorus levels approached Ecology's accepted guidelines of 0.100 mg/L during the summer in upper Pipers Creek, (Minton, 2000). Fecal coliform levels are high and have been traced mostly to animal (cats, dogs, ducks, wildlife) waste (Herrera *et al.*, 1993).

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek nor is any reach of the creek an index area. Counts of adult salmonids, primarily chum and coho, are sporadic.

NON-NATIVE SPECIES

ANIMALS

No information was obtained to indicate the presence of non-native aquatic animal species.

PLANTS

Non-native plant species found in the subbasin include numerous ornamental species associated with plantings by private and public landowners. Examples include mountain ash (*Sorbus spp.*), blue beech (*Carpinus spp.*), butterfly bush (*Buddleia spp.*), cherry laurel *Laurocreasus officenalis*), dogwoods (*Cornus spp.*), and non-native rhododendrons (*Rhododendron spp.*). Exotic species of plants more closely associated with riparian and aquatic environments include: scotch broom (*Cytisus scoparius*) and reed canarygrass (*Phalaris arundinacea*) which is abundant throughout this subbasin and Himalayan blackberry.

Non-native animal and/or plant species do not appear to currently be a limiting factor to natural salmonid production.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- There are several known anthropogenic barriers that limit anadromous salmonid access;
- The basin suffers from effects of extensive urbanization;
- The condition of the riparian zone limits the natural production of resident and anadromous salmonids;
- Increased sedimentation and altered sediment transport processes;
- With the lack of mid and/or late seral stage forest stands (aged 25 years or greater) in the watershed, the alteration to the stream hydrology limits natural production of salmonids;
- Land use activities in this creek will generally preclude riparian conditions from achieving adequate function;
- Hydrologic regime has been severely altered along with system's ability to support salmonids;
- Although only limited quantifiable storm-flow information was available, it was the professional judgement of the TAG that flood flows due to increased impervious surfaces would serve to adversely limit any successful egg incubation; and
- There are only limited amounts of off-channel habitat suitable for juvenile salmonid rearing and holding.

E. DATA GAPS

- Water quality and possible sediment contamination require additional studies;
- A basin wide habitat inventory program needs to be completed; and
- There is no LWD inventory for the subbasin.

SNOHOMISH COUNTY STREAMS DRAINING DIRECTLY TO PUGET SOUND

A. PHYSICAL DESCRIPTION

The nearshore streams of WRIA 8 within Snohomish County includes at least twelve independent streams that directly enter Puget Sound. These streams include (from North to South); Big Gulch Creek (08.0001), Upper Chenault Creek (08.0002), Lower Chenault Creek (08.0003), Hulk Creek (unnumbered), Picnic Point Creek (08.0004), Norma Creek (08.0005), Lund's Gulch Creek (08.0006), Perrinville Creek (08.0007), unnamed tributary (08.0008), Shell Creek (08.0009), Willow/Shelleberger Creek (08.0010), Deer Creek (08.0012) and two unnamed tributaries (08.0013 and 08.0014). Some of the smaller streams may have local names or not have formally recognized names. All are typical of rain-dominated Puget Sound lowland drainages that receive their flow from springs, lakes, and ground- and surface-water runoff. The largest lake, at 42.3 acres, is Lake Serene and drains into Norma Creek.

In general, these nearshore streams originate on broad plateau-like headwater areas at an elevation of between 450 to 600 feet with sandy-gravelly streambeds, then drop quickly through steep erodible ravines to Puget Sound beaches. Tracks of the Burlington Northern Sante Fe Railroad traverse the mouths of all these streams. Land uses include residential development throughout the sub-area and business/light industrial uses concentrated along State Highway 99 and in the Cities of Edmonds, Lynwood, and Mukilteo. Impervious area in these tributary sub-basins ranges up to 51 percent (Simmonds and Purser, Snohomish County Surface Water Management, unpublished data). Total forest cover is approximately 25 percent (4 percent mature forest) and forest cover within 300 feet of streams and wetlands is approximately 38 percent (8 percent mature forest, Simmonds and Purser, unpublished data).

B. SALMONID UTILIZATION

The known freshwater distribution of anadromous and resident salmonids is depicted Appendix A. These nearshore streams support small numbers of anadromous and resident salmonids (Snohomish County, Planning and Development Services, unpublished data, 1985-1987; C. Kraemer, 2001; M. Chamblin, 2001; S. Foley, 2001; J. Jacobson, 2000). The larger of the streams, such as Big Gulch Creek, Picnic Point Creek, Lund's Gulch Creek, Norma Creek, and Shell Creek, are capable of supporting naturally spawning coho salmon (*O. kisutch*) populations. Many of these streams have been routinely stocked with coho fingerlings by school and fishing groups (Kraemer, 2001).

In Lund's Gulch Creek, juvenile coho and cutthroat were sampled near 52nd Ave SW and 164th St SW on January 8, 1991 (Mike Nelson, personal communication to Tom Murdoch, January 28, 1991). Prior to that, the Washington Department of Wildlife quantitatively sampled juvenile coho and cutthroat in the lower reaches of Lund's Gulch Creek (to RM 1.2) (Pfeifer 1979). Interestingly, one adult steelhead was observed in lower Lund's Gulch creek in 1978 (Hendrick 1978).

These nearshore streams to Puget Sound also support coastal cutthroat trout (*O. clarki*) and occasionally steelhead (*O. mykiss*). Resident coastal cutthroat trout were found in all streams with adequate flow (Snohomish County, Planning and Development Services, unpublished data, 1985).

C. HABITAT FACTORS OF DECLINE

GENERAL

Habitat factors responsible for the decline of salmonids in the nearshore streams of Puget Sound of WRIA 8 in Snohomish County include loss of channel complexity, degradation of riparian conditions, and altered hydrology from loss of wetland areas and changes in land cover. Increases in sedimentation and altered sediment transport have also contributed to the decline of salmonids in these basins, as well as the reduction of instream LWD (Snohomish County Planning and Development Services, unpublished data). Some fish access and passage barriers have been identified, but an additional assessment is needed. Chemical contamination and increases in nutrient loading have been detected (Thornburgh and Williams 2000). These factors have been identified as probable factors of decline. With better documentation, these would likely be considered known factors of decline. Snohomish County Public Works (1988) has determined that salmonid populations in these streams are, "generally limited by low flow conditions in summer, lack of suitable spawning sites, high water temperatures, and high winter flows that scour channel beds and banks."

FISH PASSAGE AND PASSAGE BARRIERS

The Burlington Northern Santa Fe railroad track crosses the mouth of each of these Puget Sound streams and on low tides temporary fish passage barriers typically exist as the creek mouths travel across localized small deltas. Additionally, fish passage barriers may exist depending on stream flow conditions, sediment transport, debris accumulation, and maintenance of these culverts. It is unknown whether any of the railroad-associated culverts are complete blockages. All are at least 60 feet in length (Snohomish County, unpublished data). Farther upstream, where stream gradients increase in steep ravines, mass wasting has been observed and potentially acts to restrict upstream/downstream passage of salmonids (Jacobson, 2001).

On Picnic Point Creek, a known barrier exists at Picnic Point Road (approximately RM 0.5) (Aldrich, 2001). On Lund's Gulch Creek, a barrier exists at 52nd Avenue SW, where a stormwater detention facility is located (Aldrich, 2001). On Big Gulch Creek a barrier exists at Harbor Pointe Boulevard (Aldrich, 2001). Other seasonal barriers could include those associated with low instream flows, high water temperature and low dissolved oxygen levels. The location of fish passage barriers can be found on maps in Appendix B.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Asynchronous pulses of sediment originating from basin-wide soil disturbing activities (e.g., clearing and grading, streambank disturbance) characterize the delivery and routing of sediments in these Puget Sound nearshore streams. Sediment is also be routed to streams by way of the increased drainage network of roads, ditches, outfalls, and surface flow. Where stream discharge has increased, stream channels tend to over-widen, and mass wasting of streambanks and side slopes in the higher gradient stream gullies is common (Snohomish County, unpublished data). Total Suspended Solids (TSS) have been measured as high as 1500 mg/l in winter in Norma Creek (Thornburgh and Williams 2000). Much of the sediment contributing to high turbidity levels likely comes from eroding streambanks and mass wasting of side slopes. As gradient moderates in the lower reaches, riffles tend to dominate (>90 percent in Big Gulch, Picnic, Lund's Gulch and Norma creeks) and substrate is embedded (Snohomish County, unpublished data).

The percent of fines in spawning gravels has not been assessed.

The direct and indirect effects of the altered sedimentation regime include fine sediment intrusion into redds, pool filling, turbidity, and gill abrasion. Fine sediment intrusion into streambeds also effects the macroinvertebrate community, as observed in Norma Creek (Thornburgh and Williams 2000), and indirectly, trophic support of fish.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

In these Puget Sound nearshore streams, channel complexity and connectivity with the floodplain and adjacent stream reaches are reduced due to road crossings/culverts, streambank hydromodifications, abrupt land-use changes, wetland losses, channel incision and instability, and historical and on-going clearing and development in upland and riparian areas.

Changes in land cover and land-use practices have exacerbated stormwater flows and limited in-stream large wood recruitment. The combinations of loss of channel structure along with scouring flood flows have contributed to form channel beds that are less stable and riffle dominated, especially in lower reaches (Snohomish County, Department of Planning and Development Services, unpublished data). These factors may contribute to the lack of spawning success. Where gradient is steeper, through ravine areas, roads running parallel or utilities (sewer) often impinge the stream channels and eliminate the potential for lateral channel migration.

One example of how development can influence channel complexity is the road that parallels most of Picnic Creek, which limits the lateral migration of the stream channel. The loss of channel complexity, floodplain habitat and floodplain connectivity have all contributed to limiting the natural production of salmonids in these streams.

DEGRADATION OF RIPARIAN CONDITIONS

Development throughout these tributary sub-basins and in the riparian corridors has reduced/changed the amount and kind of land cover from predominantly coniferous and mixed forests to deciduous forest, scrub/shrub, landscaped or impervious land cover types. In headwater areas, most land cover has been converted to impervious surfaces (approximately 51 percent), and total forest cover is approximately 25 percent (Simmonds and Purser, unpublished data). Within the riparian zone of headwater areas (within 300 feet of streams and waterbodies), forest cover is approximately 38 percent. Higher forest cover in riparian areas is reflective of the fact that development within the steep gullies is limited and those riparian forested areas, in many cases, have been designated as County parks. However, functionally, the greater riparian cover may be of limited value, as mass wasting is common, and stormwater flow are tightlined directly into the creeks in numerous locations (Jacobson, 2001).

ALTERED HYDROLOGY / FLOW

There are no hydrological records for these Puget Sound nearshore streams. However, changes in land cover characteristics (e.g., roads, impervious area, forest cover, and wetland loss) are predictors that deleterious effects from hydrologic change will occur to instream habitat conditions throughout a sub area.

The observed and expected effects will be peak flows of greater magnitude and duration, lower seasonal low flows, increased flashiness, over-widening of the stream channel, bank erosion, and scour of the streambed (Snohomish County, unpublished data). Less well-understood are in the indirect effects on salmonids of documented effects of altered hydrologic regimes on aquatic macroinvertebrates.

Increases in impervious surfaces and a corresponding reduction in forest cover of any kind can alter a stream's hydrology to the point where the streams natural production of salmonids can be reduced.

WATER QUALITY

These Puget Sound streams are designated Class A waterbodies by the WDOE. Snohomish County has monitored the water temperature in Norma Creek since 1992. Water temperatures did not violated WDOE water quality standards during this period of record (Thornburgh and Williams 2000). However, higher water temperatures in these Snohomish County streams are expected to have resulted from riparian clearing, direct runoff from impervious surfaces, decreased groundwater recharge/discharge, and low flows.

In another example, staff from Snohomish County Surface Water Management sampled one site at the mouth of Lund's Gulch Creek monthly from 1990-1991 (Thornburgh and Williams 2000). Concentrations of fecal coliform bacteria, copper, mercury, lead and turbidity exceeded Class A WDOE standards.

Snohomish County Surface Water Management staff also sampled water quality at two additional sites on Norma Creek (the outlet stream to Lake Serene) monthly from 1992-1998. Sediment and metals were found to be the primary water quality problems. In winter, total suspended solids were measured as high as 1500 mg/l. Some of the highest concentrations of metals in Snohomish County were observed at the upper Norma Creek site, which receives runoff from heavily urbanized areas. A mean conductivity of 222 umhos/cm, measured from 1992-1998, is the highest in Snohomish County (Thornburgh and Williams 2000).

Biological sampling for macroinvertebrates in Norma Creek 1997 and 1999 determined few long-lived and "clinger" macroinvertebrate species persist in this drainage. The WDOE has determined Norma Creek does not meet its designated uses as a Class A waterbody. Norma Creek contains 303d listed stream segments for violations of WDOE water quality criteria that exceeded dissolved oxygen and fecal coliform limits. These degraded water quality conditions observed in Norma Creek are assumed to be representative of conditions prevailing in other Snohomish County Puget Sound nearshore streams. It is unknown at this time what direct, indirect and cumulative effects these water quality conditions have upon the survival of salmonids using these streams.

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek nor is any reach of the creek an index area. Surveys for the presence of adult salmonids, primarily chum and coho, are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- There are numerous barriers to upstream migration in all of these streams.
- Salmonid populations in these streams are, "generally limited by seasonal (summer) low flow conditions, lack of suitable spawning areas, high water temperatures, and high winter flows that scour channel beds and erode banks."
- Stream hydrology, water quality, riparian zone degradation, increases in sedimentation and the loss of floodplain connectivity and channel complexity all serve to limit the natural production of salmonids in these streams.

E. DATA GAPS

- Data on water quality, hydrology, floodplain connectivity, LWD, sediments and riparian conditions and their impacts to salmonids in these streams is scarce or lacking.
- Fish passage barriers have not been fully inventoried.
- The level and extent of chemical contamination and increases in nutrient loading have not been ascertained.

NEARSHORE MARINE HABITATS OF WRIA 8

NEARSHORE MARINE HABITATS OF WRIA 8

The majority of the information below is from the DRAFT Report *State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound including Vashon and Maury Islands (WRIAs 8, 9 and portions of 15)* (King County DRAFT 2001). This report should be available in final form in July 2001.

Regional Setting

The Greater Puget Sound is the southernmost of a series of interconnected, glacially scoured channels that include the Strait of Juan de Fuca and Strait of Georgia. The entrance to the Sound is approximately 81 miles from the Pacific Ocean. Glaciers have repeatedly occupied the Puget Lowland. At least three and possibly as many as six episodes of glaciation have rearranged the landscape and left evidence of their passage in the rocks and sedimentary record. The most recent glaciation, called the Fraser, extended as far south as Olympia, WA. At its maximum extent 14,000 to 15,000 years ago, the ice sheet is estimated to have been about 7,000 feet thick at the international border and tapered to about 4,000 feet at Port Townsend. The Puget Lobe of the most recent glacier created the north-south fabric of the topography and deposited in its wake the Vashon Till that currently blankets much of the region.

On most geographic maps, Puget Sound is defined as the total body of water south and east of a line between Partridge Point on Whidbey Island and Point Wilson at Port Townsend. This definition includes the water east of Deception Pass, which is at the north end of Whidbey Island. These waters are generally divided into four major basins: Hood Canal, South Sound, Whidbey Basin, and the Main Basin. The Main Basin has been further subdivided into two subbasins: Admiralty Inlet, which extends from the northern limit of Puget Sound to the southern tip of Whidbey Island, and the Central Basin, which extends from the southern tip of Whidbey Island to Commencement Bay. Each of the above described basins forms a depression on the sea floor in which a shallower ledge separates the relatively deep water from the adjacent basin. The shoreline lengths, volumes, and depths of the Puget Sound basins can be obtained from several sources (cf., Ebbesmeyer et al. 1984, Burns 1990, Duxbury 1987, Bostick 1955). There are slight differences among these sources, apparently because of the tidal datum of the calculation. The data of Duxbury (1987) are summarized in Table 3.

Table 3. Comparison of basin physical characteristics for Puget (Source: Duxbury 1987).

Region	Area* km^2/%	Volume* km^3/%	Shoreline* km	Mean Depth* m	Tideland km^2
Admiralty Inlet	437.1/17.0	15.2/9.4	171.3	34.7	18.2
Central Basin	747.5/29.1	74.0/45.7	535.3	98.5	48.5
Whidbey Island	378.6/14.7	24.0/14.8	471.0	63.0	130.3
Southern Basin	618.4/24.1	28.0/17.3	620.9	45.1	63.6
Hood Canal	385.6/15.0	20.9/12.9	342.6	53.8	42.4
Total	2567.2	162.1	2141.0	62.8	303.0

Note: Admiralty Inlet and the Central Basin comprise the Main Basin.
* Based on MHW datum

While WRIA 8 is entirely within the Central Basin, some comparisons between the WRIA 8 and neighboring basins are of interest. A more detailed comparison can be found in Burns (1985). The total length of shoreline of the Puget Sound is 1330 miles (2141 km) consisting of shore platform, coastal bluffs, and numerous beaches. The Main Basin (comprised of the Admiralty Inlet and Central Subbasins) is the largest, comprising about 46 percent of the surface area and more than 55 percent of the water volume. The Central Basin has the greatest average depth of nearly 100 meters. The deepest point in Puget Sound is found in the Central Basin; over 280 meters (over 920 feet) located just south of the ferry route between Kingston and Edmonds. The average depth of Admiralty Inlet is less than half of the average depth of the Central Basin. The main ledge of the Puget Sound is located at the north end of Admiralty Inlet where the water shoals to a depth of 65 meters at its shallowest point between the north Quimper Peninsula near Port Townsend, and Whidbey Island north of Admiralty Bay.

Approximately 43 percent of the Puget Sound's tideland is located in the Whidbey Island Basin. This reflects the large influence of the Skagit River, which is the largest river in the Puget Sound system and whose sediments are responsible for the extensive mudflats and tidelands of Skagit Bay.

The waters of Puget Sound function as a partially mixed, two-layer system, with relatively fresh water flowing seaward at the surface and salty oceanic water entering at depth. This layered system can often be viewed in Commencement Bay where the fresh waters of the glacial origin Puyallup (and White) Rivers enter the marine waters of Commencement Bay. During summer months, fresh water flowing out of the Puyallup River is heavily "colored" by glacial flour and large boats crossing Commencement Bay leave a wake or "trail" of clearer marine water thru the colored freshwater found on the surface.

Primary contributors to the fresh water input of Puget Sound are the Skagit and Snohomish Rivers, both of which discharge into the Whidbey Basin. These rivers, along with the smaller Stillaguamish, typically contribute approximately 60 percent of the freshwater inflow and account for about 50 percent of the drainage area of Puget Sound. About 50 percent of this freshwater is thought to enter the Main Basin of Puget Sound while the remainder is thought to work its way through Deception Pass into Rosario Strait (Barnes and Ebbesmeyer 1978). The freshwater input directly into the Main Basin, primarily from the Puyallup and the Duwamish, accounts for only 20 percent of the total drainage into the Puget Sound (Downing 1983, Burns 1985). As a result of the small fresh water inflow into the Central Basin and the great amount of tidal energy, the water is not strongly stratified most of the year. Stratification is greatest in summer due to the combined effects of river discharge and solar heating, and is least in winter due to winter cooling and the mixing effect of the increased wind.

Figure 13. WRIA 8 Marine Areas

See Appendix B for Figures

Definition of the Nearshore Zone

For the purposes of this report, the nearshore zone is defined as that area between the lower limit of the photic zone (approximately minus 30m MLLW) and the upland–aquatic interface (i.e., the riparian zone). The nearshore environment extends landward to include coastal landforms such as coastal bluffs, the backshore, sand spits and coastal wetlands, as well as marine riparian zones on or adjacent to any of these areas. In addition, the nearshore environment includes subestuaries such as the tidally influenced portions of river and stream mouths.

Geographic Scope

The marine shoreline of the Lake Washington-Cedar-Sammamish watershed (WRIA 8) extends roughly from Elliot Point in the north to Elliot Bay at the City of Seattle in the south.

The entire study area is presented in Figure 13. The area covered in this chapter has further divided the study area into 4 sub-areas (reaches) to assist in describing the location and status of particular marine resources in this report. WRIA 8 encompasses reaches 1 through 3, and portions of reach 4 are in both WRIAs 8 and 9 (reach 4 represents Elliott Bay and the Duwamish estuary).

Reach 1: Elliot Point to Edwards Point
Reach 2: Edwards Point to Meadow Point
Reach 3: Meadow Point to West Point
Reach 4: West Point (WRIA 8) to Alki Point (WRIA 9)

A. SELECTED NEARSHORE HABITAT TYPES

Numerous habitat types occur within the nearshore environment, including eelgrass meadows, kelp forests, flats, tidal marshes, subestuaries, sand spits, beaches and backshore, banks and bluffs, and marine riparian vegetation. These habitats provide a myriad of critical functions. For example, eelgrass meadows, kelp forests, flats, tidal marshes, sand spits and riparian zones provide primary production. All habitat types support invertebrates and juvenile and adult fishes (including juvenile salmonids), and provide foraging and refuge opportunities for birds and other wildlife.

Several known factors cause these habitats stress, including physical disturbances from shoreline armoring, marina construction, and bivalve harvesting; shading from overwater structures; contamination by chemicals; and competition from non-native species. Unfortunately, numerous data gaps in our understanding of these habitats exist, making it difficult to fully assess them. Information about the historical distribution/abundance of these habitats is lacking, and there are no comprehensive maps. What role these habitats play in the

food web is also not well understood, as are the effects of shoreline armoring and bivalve harvesting.

This section provides more detail about the functions of, stressors to, and data gaps about several selected nearshore environments. This section is not an encompassing discussion of all habitat types in WRIA 8, rather a discussion of those most critical to salmonids. Where known, it also discusses the current and historical distributions of these habitats in WRIA 8.

A.1. Eelgrass Meadows

Functions within Ecosystem

Eelgrass (*Zostera marina* L.) is one of about five species of seagrass that occurs in the Pacific Northwest. It forms small patches to large meadows in the low intertidal and shallow subtidal zone in Puget Sound. Phillips (1984) lists the following functions for eelgrass:

- Primary production
- Nutrient processing
- Wave and current energy buffering
- Organic matter input
- Habitat for fish and invertebrates
- Food for birds

Eelgrass, sometimes referred to as a submerged aquatic vegetation (SAV), is a rooted, flowering plant that lives in shallow coastal waters, growing in beds (often times dense) or "eelgrass meadows." Eelgrass is not a seaweed or algae; it is a true flowering plant and a monocot (a plant having a single seed leaf). This places it in a category unique among marine species. Millions of years ago, eelgrass evolved from terrestrial plants. Its land based ancestors moved toward the sea for survival, evolving into a highly specialized plant organism adapted to life in saline water. Eelgrass reproduces sexually, through seeds, and asexually, as the roots spread and sprout new shoots.

Studies reveal that eelgrass communities are valuable as sediment traps that help stabilize the coastal zone. Because their leaves are so closely packed together they may also act as dampers reducing the motion of the water. Suspended materials carried by currents move into these areas, where the waters are calmer, and there they sink to the bottom. In September, the leaves break away from the roots. Some float away, carried by currents; others fall to the bottom where at least 85 percent of them decompose. Certain microscopic organisms called *Detritivores* begin to break it down into smaller particles, and these become surrounded by bacteria and fungi. They, in turn, are consumed by filter feeders such as clams and scallops. Deposit feeders (sea urchins) and the sediment feeders (worms and snails) also consume this marine "soup." The adult and larval forms of these invertebrates become food for larger life forms such as fish. It is a continuous cycle of life and death and life again. So important is *Zostera's* role in this food cycle that estimates reveal that more than 20 species of commercially valuable fish species feed in these eelgrass meadows at some point in their lives.

The surface of the leaves form a substrate for many invertebrate species. In 1937, R.C. Stouffer subdivided the eelgrass invertebrate community into four major categories: those on the plants, among the plants, on the mud surface, and in the mud. Perhaps the invertebrates most easily seen in New England waters are two related worms that secrete about themselves a hard tube of calcium carbonate. *Spirobus borealis* and *Spirobus spirillum* look alike, but a little study reveals that *Spirobus spirillum* coils to the right and *Spirobus borealis* to the left. If placed in a marine aquarium, these worms will emerge displaying delicate plume-like appendages. Another species, the *Bryozoans*, will appear as a flat crust growing on the blades, but a magnifying glass or microscope will show the individual animal, or *Zooecia*, that makes up this colony.

A nursery, or shelter, and a food source for animals, eelgrass has also provided many benefits to humans. In some Scandinavian countries eelgrass was used as roof thatch and upholstery. Burned, it gave not only heat but also soda and salt. Early historical records indicate that in the United States eelgrass brought $20.00 to $30.00 a ton as insulation and sound-deadening material. In the 1920s and 30s, the Samuel Cabot Company (which still markets stains) sold a product called Cabot's Quilt, which consisted of two layers of building paper with a layer of eelgrass stitched between in quilt fashion for insulation. A researcher's studies indicate that a six-inch layer of eelgrass spread to a density of 1.5 pounds per square foot has the insulation efficiency of six inches of fiberglass insulation. Further studies reveal that *Zostera* will burn if subjected to a flame but will not support combustion by itself.

The vital importance of eelgrass was believed to have initially been noted by Danish biologists in 1890. This importance was revealed dramatically along the Atlantic coast of North America in 1931 when a serious fungal disease (black spot disease) and a change in ocean currents, that brought warmer waters to the extensive *Zostera* meadows teamed up to kill this species. With this catastrophic decline, which killed over 90 percent of the North Atlantic eelgrass population, many species of ducks and geese vanished. In addition, lobster, crabs, scallops, clams, and other invertebrates declined. A vital part of the food chain in coastal areas had been removed, and the decline in *Zostera* also caused significant problems with coastal erosion. It was not until 1945 that a recovery began.

In WRIA 8, eelgrass is found from about minus 1 meter to minus 7 meters relative to mean sea level (MSL) (Bulthius 1994, Thom et al 1998). This equates to about plus 1 meter to minus 5 meters relative to mean lower low water (MLLW). The primary factor controlling the distribution at the upper boundary is desiccation stress, and at the lower boundary is light penetration (Thom et al. 1998).

The current distribution and range of eelgrass in the marine waters of WRIA 8 is limited because a comprehensive range and distribution assessment survey has not been performed. The primary sources of range and distribution data are from field surveys that included observations made during low tides and covered primarily only intertidal and very shallow subtidal meadows and patches. These data sources include the Coastal Zone Atlas, which is over 20 years old, and recent estimates provided by the Washington State Department of Natural Resources (WDNR 2001). Currently, the most comprehensive maps of eelgrass range

and distribution, which include subtidal meadows, have been developed for the reach between Picnic Point and Shilshole Bay (Woodruff et al. 2000).

There is a growing understanding of the importance of eelgrass in the Puget Sound nearshore ecosystem. Studies of primary production in Puget Sound indicate that eelgrass productivity can equal or exceed the productivity rates of most other aquatic plants. Rates reported for eelgrass productivity in the Pacific Northwest range from 200-806 g C m^{-2} yr^{-1} (Thom 1984, Kentula and McIntire 1986, Thom 1990).

Processes that Maintain Eelgrass Meadows

Based on a variety of investigations over the past 10 years, we have learned a great deal about the factors that control the presence and growth of eelgrass. Eelgrass commonly occurs in shallow soft-bottom tide flats, along channels, and in the shallow subtidal fringe.

Factors that affect its distribution and growth along with the ranges that are optimal for eelgrass are shown in Table 4.

Location of Eelgrass

Eelgrass occurs from about +1 m to -5 m MLLW in the central Puget Sound area (Bulthuis 1994, Thom et al. 1998). The primary factor controlling distribution at the upper boundary is desiccation stress, and at the lower boundary is light penetration (Thom et al. 1998). Competition for light and nutrients with macroalgae species can also affect eelgrass distribution.

Table 4. Habitat factors controlling eelgrass growth.

FACTOR	
Light	3 M PAR d^{-1}; spring and summer
Temperature	7-13 ^{o}C
Salinity	10-13$^{o}/_{oo}$
Substrata	Fine sand to mud
Nutrient	Soil nutrients present moderate to low water column
Water Motion	Up to 3-m s^{-1} tidal 80-cm s^{-1} burst. Some motion is good

Source: Thom et al. (1988); unpublished data; Phillips (1984).

The current understanding of the range and distribution of eelgrass is limited because comprehensive surveys have not been performed in WRIA 8. The primary sources of distribution data are from surveys that included observations made during low tides and covered primarily intertidal and very shallow subtidal meadows and patches. These data include the Coastal Zone Atlas (Washington Department of Ecology 1979), which is more than 20 years old, and very recent estimates provided by the Washington State Department of Natural Resources (1999). The most comprehensive maps of eelgrass, which include subtidal meadows, have been developed for the region between Picnic Point and Shilshole Bay (Woodruff et al. 2000).

WRIA 8 Eelgrass Distribution

According to the Washington Department of Natural Resources (WDNR) ShoreZone database (WDNR 2001) and studies conducted by Woodruff et al. (2000), eelgrass covers approximately 25,548 meters (57 percent) of the shoreline in WRIA 8 (Figures 14 and 15). In reach 1, eelgrass ranges from dense to patchy, but is generally continuous. Between Picnic Point and Point Edwards at the northern end of WRIA 8, only patchy eelgrass has been recorded. However, surveys are needed to evaluate the condition of subtidal eelgrass. In reach 2, eelgrass is also dense to moderate and almost continuous. Eelgrass is generally continuous in reach 3 except for the break at Shilshole Marina. The ShoreZone database (WDNR 2001) also indicates that eelgrass meadows are found along 23,200 linear feet (4.4 miles) of the Elliott Bay nearshore, representing about 26.7 percent of the shoreline. The distribution of eelgrass is entirely outside of the highly developed Seattle waterfront with concentrations around West Point, along Magnolia Bluff adjacent to Discovery Park, and between Duwamish Head and Alki Point (Washington Department of Ecology [WDOE] 1979). The Duwamish/Alki beds occupy about 1.25 miles of shoreline (Thom and Hallum 1990). Little or no eelgrass is present within the Duwamish Estuary.

Eelgrass Density: Eelgrass density is highly variable but can reach in excess of 800 shoots m^{-2} in central Puget Sound (Thom et al. 1998). There are few published reports on density in WRIA 8. Mean densities that have been reported from specific studies range from about 50-400 shoots m^{-2} (Thom 1988, Thom and Hallum 1989); (Thom 1990, Thom and Albright 1990)).

Stressors: Stressors to eelgrass are those things that negatively affect the factors that control eelgrass growth or directly affect eelgrass itself. There are two broad categories of stressors: natural stressors, and anthropogenic stressors. This section discusses each in turn.

Natural Stressors

Natural stressors to eelgrass include the following:

- Increased turbidity
- Foraging
- Black rot disease
- Rhizome exposure
- Hydrogen sulfide in soils

Increases in turbidity caused by suspended sediments or phytoplankton blooms reduce water clarity. A persistent reduction in water clarity would result in less light, and could cause eelgrass, especially those plants at the lower (deeper) edge of the distribution, to die. Some organisms, including invertebrates and black brant geese, forage upon eelgrass.

As previously detailed, black rot disease was responsible for killing almost all eelgrass on the eastern United States in the 1930s. Black rot disease has been recorded and confirmed for Puget Sound, but systematic surveys for the disease are not available in WRIA 8 (Bulthuis 1994).

Increases in turbidity caused by suspended sediments or phytoplankton blooms reduce water clarity. A persistent reduction in water clarity would result in less light, and could cause eelgrass, especially those plants at the lower (deeper) edge of the distribution, to die.

Hydrogen sulfide (H_2S) develops in highly organic sediments. Eelgrass is susceptible to high H_2S levels and will die if H_2S is a persistent feature of the sediment conditions (Goodman et al. 1995). There are no documented cases of loss of eelgrass due to high hydrogen sulfide levels in WRIA 8.

Waves and currents can expose eelgrass rhizomes. Extended exposure, especially during low tides, can result in damage to the plants because of desiccation of the roots and rhizome. There is no documentation of excessive exposed rhizomes in WRIA 8.

Anthropogenic Stressors

Stressors to eelgrass caused or exacerbated by human activities include the following:

- Clam harvesting;
- Propeller scour and wash;
- Eutrophication;
- Physical disturbances from shoreline armoring;
- Shading from overwater structures; and
- Physical disturbances from dredging and filling

In the study region, clam harvesting has been observed to disturb the benthic community, at least temporarily. However, no systematic quantification of this effect has been attempted. Physical disturbance by excessive propeller wash can gouge sections of eelgrass meadows. These gouges are commonly observed in heavily used beaches, especially where geoduck harvesting is popular. However, no cases of this problem are documented in WRIA 8.

Eutrophication has been shown to result in the growth of massive amount of epiphytes on eelgrass leaves, which can result in the death of the eelgrass host. There is little information on epiphyte loads in the region. It appears from the work conducted at Seahurst Park that epiphytes were not overly abundant there (Thom and Albright 1990).

Figure 14. Eelgrass distribution in WRIA 8 (southern)

See Appendix B for Figures

Figure 15. Eelgrass distribution in WRIA 8 (northern**)**

See Appendix B for Figures

Eutrophication in Puget Sound is believed to influence the buildup of massive ulvoid mats that grow in the intertidal and shallow subtidal zones. Ulvoids detach during windy periods, and pile up in thick mats over eelgrass, which can smother and kill the eelgrass (Thom et al. 1998). There is no evidence that this is a problem in eelgrass beds in WRIA 8.

Shoreline armoring impedes sediment supply to nearshore habitats, and this sediment starvation can lead to changes in nearshore substrates. Typically, sediment changes from sand or mud to coarse sand, gravel, and finally hardpan. If sediment becomes too coarse, eelgrass may be driven out. Also, construction of shoreline armoring devices can cover or destroy eelgrass meadows (Williams and Thom, in prep.). Overwater structures can deprive eelgrass of the light they need to thrive (Simenstad et al., 1998; Nightingale and Simenstad In Prep). Dredging operations can excavate eelgrass meadows or cause detrimental increases in turbidity, and filling can smother eelgrass meadows permanently.

Historic Distribution

Comprehensive historical records of eelgrass distribution are lacking in WRIA 8. Eelgrass information comes from site-specific studies, which are incomplete in terms of providing a historical picture of distribution.

In an attempt to document changes in eelgrass, Thom and Hallum (1990) compiled all known records of eelgrass. The oldest records came from marks on U.S. Coast and Geodetic Survey navigation charts that were developed for several bays in Puget Sound, including Padilla Bay. These charts date back in some cases to the period of 1850-1890. No records on these charts showed eelgrass in any portion of WRIA 8. Other site-specific records on eelgrass include dive work done by Ron Phillips in 1962 at about 100 locations throughout Puget Sound and Hood Canal.

Intertidal eelgrass may have declined at the southern end of reach 1 (WRIA 8). The historic data in Thom and Hallum show eelgrass in this area, whereas the WDNR maps show no eelgrass. WDNR records best document eelgrass from very shallow water to intertidal areas. Subtidal eelgrass appears to remain in this area, however (Figure 13) eelgrass may have increased, although it remains patchy, in reach 3 near West Point.

Reasons for Change

We hypothesize that eelgrass occurred in most shallow water areas in the region, and that disturbances such as overwater structures, bulkheads, marinas, groins, and dredging and filling have resulted in loss of eelgrass in the region. Areas where intertidal eelgrass may have declined (e.g., reach 1, Lincoln Park) are in regions of extensive shoreline armoring. Areas where eelgrass has increased may be related to increased fine substrata (e.g., from fill at Lincoln Park). However, the mapping records were conducted at different scales and with various methods, and it is difficult to draw strongly defensible conclusions.

Data Gaps

Gaps in our knowledge of eelgrass within WRIA 8 include the effects of shoreline armoring and bivalve harvest (Table 5) on eelgrass meadows. We also do not know enough about the historical distribution and abundance of eelgrass to draw any meaningful conclusions. Monitoring of eelgrass beds eventually would show trends in density and abundance, and perhaps allow scientists to distinguish natural variability from adverse effects of human activities. Better data on fish use of eelgrass, and the effects of urban runoff on eelgrass, would contribute to improved management efforts.

Table 5. Data gaps for eelgrass.

DATA GAPS	LOCATIONS in WRIA 8
Complete maps, including measurements of area	Northern portion of reach 1 and southern portion of reach 3
Monitoring of eelgrass beds	All reaches
Incidence, causes, and effects of ulvoid blooms	All reaches
Effects of nutrient loading and urban runoff on eelgrass	All reaches
Anoxic sediment impacts	All reaches
Clam harvesting impacts and recovery rates	All reaches
Effects of shoreline hardening	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches

A.2. Kelp Forests

Kelp Functions within the Ecosystem

Bull kelp, *Nereocystis luetkeana* (Mertens) P. & R., is the largest brown algae found in the Pacific Northwest. It forms small patches to large forests in the shallow subtidal zone in Puget Sound. Other large brown algal species common in the study region include *Costaria costata* (Turner) Saunders, *Laminaria saccharina* (L.) Lamouroux, and *Sargassum muticum* (Yendo) Fensholt. These latter species are often found associated with bull kelp forests. *S. muticum* is a non-native species that was introduced by the Japanese (Pacific) oyster mariculture industry to the Northwest in the 1930s (Anderson 1998) (see Non-Native Species).

There is no comprehensive evaluation of the functions of kelp in Puget Sound, but the following list highlights functions typically associated with kelp:

- Primary production;
- Habitat for fish, especially rockfish, but also salmon;
- Contributor to pelagic food webs through particulate and dissolved carbon;
- Herring spawning substrate;

- Wave and current buffering (Duggins 1980) (Harrold et al. 1988) (Jackson and Winant 1983);
- Substrate for secondary production; and
- Extraction of chemicals for commercial use (Whyte and Englar 1980)

A kelp forest provides a three-dimensional habitat. This is important for many fish whose larvae use the kelp as settlement habitat. Adult fish feed on and hide in the kelp fronds. Many invertebrates such as crabs, snails, bryozoans, sponges, tunicates, anemones, and shrimp use the blades as living habitat (Foster and Schiel 1985).

Primary production has been estimated as growth rates in only a few areas in the Pacific Northwest. Production rates for bull kelp at West Point (WRIA 8, reach 3) were reported to be 0.6-4.2 cm d^{-1} (Thom 1978). Bull kelp can grow at rates up to approximately 2.4 cm d^{-1} during the spring and early summer (Duncan 1973). Growth rates of other kelp species are slower than bull kelp (Thom 1978).

Processes that Maintain Kelp: Kelp grows attached to bedrock or pebble to larger sized gravel in the very low intertidal and shallow subtidal zone. Growth is dependent on light and temperature (Rigg 1917, Vadas 1972, Druehl and Hsiao 1977). Limited experimental evidence indicates that *N. luetkeana* photosynthesis is limited by carbon during summer (Thom 1996). Because of this, all of the kelps exhibit a dynamic seasonal cycle with a period of maximum growth rate in spring and early summer. Winter is a period of low biomass. The stipe and fronds of bull kelp die completely in winter, and exists as a microscopic phase until spring. None of the kelps are resistant to drying. Hence, plants that colonize the intertidal zone early in spring are generally lost to desiccation later in spring. Because it forms a dense canopy, bull kelp can exhibit major control over the abundance of the other kelp and algal species (Thom 1978).

Kelp forests are subject to herbivory. Sea urchins graze on kelp, generally feeding on drift material, but sometimes removing entire plants by grazing through their holdfasts (Foster and Schiel 1985). Gastropods graze on the plant tissue, but do not remove entire kelp plants.

Variations in the amount of rocky substrata can result in gains and losses of kelp. Expansion and contraction of the kelp forest at Lincoln Park can be explained by changes in sediment deposition resulting from construction of the seawall in the mid-1930s (Thom and Hallum 1990). Landslides can affect early spring development of kelp through excess siltation (Shaffer and Parks 1994).

WRIA 8 Kelp Distribution

Kelp occurs in small to large meadows throughout WRIA 8. Maps are available for *N. luetkeana* and *L. saccharina*.

Figure 16. Bull kelp distribution in WRIA 8

See Appendix B for Figures

According to the ShoreZone database (WDNR), kelp was recorded at more than 5,433 m (12 percent) of shoreline in WRIA 8. Bull kelp occurs in small patches in reach 1, but has not been reported from the northern half of reach 1 (Figure 15). Bull kelp is limited to a small area at the north end of reach 2. Kelp occurs along the breakwater of Shilshole Marina and on the north side of West Point in reach 3 (Figure 15). *L. saccharina* distribution is highly discontinuous (Figure 15). Locations where this species has been mapped occur in reach 2.

Kelp Density

The stipe density of bull kelp has been reported from West Point (WRIA 8, reach 3) to range between 0.9-3.8 stipes m^{-2} (Thom 1978). These fall within the range reported elsewhere in the Pacific Northwest (Rigg 1917, Foreman 1984).

Stressors

There are no investigations on the overall health or indicators of health for kelp in Puget Sound. Some potential health indicators are:

- Degree of tissue bleaching
- Epiphyte loads
- Changes in distribution and density
- Physical disturbances from shoreline armoring, marina construction, and harvesting
- Shading from overwater structures

Spilled oil can cause bleaching of kelp tissue, which results in death of the plant (Antrim et al. 1995). Epiphytes normally occupy kelp plants (Markham 1969, Thom 1978). Where abrasion has damaged the epidermal tissue, infection by epiphytes appears to be more pronounced (Thom 1978). Heavy epiphyte loads have been noted at West Point and Lincoln Park. Although not tested, this type of damage may affect the growth and survival of the plant.

Physical disturbances from kelp harvesting may have occurred at a kelp bed near Alki Point in the late 1980s. Harvesting before kelp developed sori reduced the size of kelp beds at Alki Beach and reduced recruitment (Thom and Hallum 1990).

Beach nourishment also can disturb kelp. At Lincoln Park, the addition of finer sediments altered the substrate from hardpan to coarse sand and gravel, covering the hard bottom sites used for bull kelp attachment (Williams and Thom, in prep.).

Nutrient loading can adversely affect kelp growth. For example, Thom (1978) found that brown algal cover was negatively related to increasing sewage volume at Seattle beaches. Shading from overwater structures in Elliott Bay has also been observed (Thom, personal observations) as a potential stressor.

Historical Distribution of Kelp

It is likely that kelp distribution has changed in the study area based on maps produced by the Department of Agriculture in 1911-1912 and maps produced for the Coastal Zone Atlas in the mid-1970s (Thom and Hallum 1990). In reach 1 in WRIA 8, kelp was previously reported to occur along a greater length of shoreline than it has recently been reported (Figure 15).

Reasons for Change

There is one documented case of changes in kelp distribution in WRIA 8. Experimental manipulations and growth rate studies at West Point and Lincoln Park indicate that kelp growth may be enhanced at West Point. Because nutrients from sewage effluent were suspected of reaching the beach, it was hypothesized that the altered kelp bed structure and growth was driven partially by greater nutrients there (Thom 1978).

WDNR monitoring of kelp forests along the Strait of Juan de Fuca indicates that kelp forest abundance and distribution changes annually to some degree. Year to year variation of thirty percent is common (B. Bookheim, WADNR, personal communication). Annual variability, driven by natural factors (e.g., climate), probably occurs in Puget Sound as well.

Data Gaps

The general lack of historical and recent studies of kelp in Puget Sound results in numerous gaps in our knowledge. Mapping distribution and monitoring over time, studies of kelp forest ecosystems and species interactions, and the impacts of development and changes in water chemistry would prove invaluable for enhancing our understanding and improvement of our management of kelp and kelp dependent species. The most critical data gaps in our knowledge of kelp are provided in Table 6.

Table 6. Data gaps for kelp.

DATA GAPS	WRIA 8
Complete maps of kelp forest area	Reach 3
Monitoring of kelp forests	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches
Role of kelp in the food web	All reaches
Harvest impacts	All reaches
Effects of shoreline hardening	All reaches
Ecological tradeoffs of kelp forest expansion due to shoreline armoring	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches
Role of nutrients, temperature, and chemical contaminants on kelp growth and health	All reaches
Effects of anthropogenic discharges on kelp	All reaches
Effects of *Sargassum muticum* competition in disturbed kelp forests	All reaches

A.3. Flats

Functions within Ecosystem

Flats can be variously defined, but generally include gently sloping sandy or muddy intertidal or shallow subtidal areas. Mudflats consist of unconsolidated sediment with particles that are smaller than stones and are predominantly silt (0.0625 to 0.00391 mm) and clay (0.00391 to 0.00024 mm) (Simenstad et al. 1991b). The substrate is usually high in organic content with anaerobic conditions existing below the surface. Sandflats have unconsolidated sediment with particles that are smaller than stones and are predominantly sand (2.0 to 0.074 mm) (Simenstad et al. 1991b). The substrata on flats can also be composed of a mixture of pebbles and cobble. There is no comprehensive assessment of the functions of flats in the Pacific Northwest. Studies conducted in Puget Sound and other Washington estuaries have proven the following list of functions for flats:

- Primary production
- Nutrient cycling
- Habitat/support for juvenile and adult fish
- Bivalve production
- Prey production for juvenile salmon, flat fish, and shorebirds
- Detritus sink
- Predator protection for sand lance
- Wave dissipation for salt marsh

There is commonly a dense flora of microalgae, primarily diatoms, which inhabit the fine sediments of flats. Chlorophyll a concentration, an indicator of the density of microalgae, is reported to range from 140-380 mg m^{-2} on flats in Puget Sound (Thom 1989). Published rates of primary production measured for flats range from 22-59 g C m^{-2} $year^{-1}$ (Thom 1984, Thom 1989). Inorganic nutrient flux rates can be substantial on flats, especially muddy flats (Thom et al. 1994a). Flats with more organic matter and higher densities of benthic infaunal invertebrates tend to have higher respiration rates and associated nutrient flux rates. Nutrient flux from flats may be an important source of nutrients to primary producers in the general vicinity of the flats, although this has not been conclusively shown.

Juvenile salmon prey species have been shown to be seasonally abundant on flats and their distribution is linked to the benthic microalgal abundance (Thom et al. 1989). Prey abundance at Seahurst Park ranged from 90,000-230,000 individuals m^{-2} in 1982-1983.

Processes that Maintain Flats

Sediment required to maintain flats is primarily supplied by rivers, streams, and eroding bluffs. Nearshore currents and waves, along with river flow dynamics, act in concert to distribute and rework sediments on flats. While sediment composition as well as sediment dynamics exert primary control over the biological community that develops on flats, seasonal abundance of algae and invertebrate prey species also appears to be driven by variations in light and temperature (Thom et al. 1989). In addition, detritus sources help maintain levels of

organic matter that are an important component of flats and support biotic communities that utilize flats.

Location of Flats

Flats are generally located at the mouths of streams and rivers where sediment transported downstream is deposited. They are also located in embayments, below the swash/backwash zone and other areas of low wave and current energies where longshore currents and waves deposit sediment. According to the ShoreZone database (WDNR), tidal flats cover 2,862 m (6 percent) of shorelines in WRIA 8. The ShoreZone definition of flats is unidirectional, horizontal, or gently sloping surfaces of less than 5˙. This definition, or the resolution of mapping methods, does not capture all flats in the study area.

Sediment Characteristics of Flats

Flats generally include gently sloping sandy or muddy beaches, but can also include a mixture of pebbles and cobble. Limited sediment grain size data from flats in WRIA 8 show that flats are primarily composed of fine sand (69-77 percent), with lesser amounts of coarse sand and silt (Thom et al. 1984).

Stressors

There are no comprehensive studies on the health of flats in WRIA 8. Health indicators include, but are not limited to the following:

- Unnatural erosion or deposition of sediment
- Harvesting of shellfish and other marine life
- Overabundance of organic matter loading including ulvoid mats
- Fecal and chemical contamination
- Physical disturbances from shoreline armoring, marina construction, and upland development practices
- Shading from overwater structures
- Competition from non-native species
- Loss of emergent and riparian vegetation

All of these indicators are suspected of occurring throughout WRIA 8, based on site-specific studies (Matches et al. 1984, Thom et al. 1984, Thom et al. 1988).

Historic Distribution

There are no maps of the distribution of flats other than what can be deduced from Coast and Geodetic Survey nautical charts developed in the mid-to-late 1800s. These charts are available for larger deltaic flats such as the Duwamish River delta, but are not for nearshore areas and smaller stream deltas. The linked bathymetry-topography maps developed by the University of Washington's Puget Sound Regional Synthesis Model (PRISM) are based on

records from the mid-1950s and later. Based on these maps, flats occur in most embayments (e.g., reach 2).

Reasons for Change

Shoreline armoring, dredging, and filling have caused loss of flats in parts of WRIA 8.

Data Gaps

Data gaps for flats are identified in Table 7 below.

Table 7. Data gaps for flats.

DATA GAPS	WRIA 8
Complete maps of flat area	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches
Role of flat production in the food web	All reaches
Bivalve harvest impacts	All reaches
Effects of shoreline hardening	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches
Comparison of fish use of disturbed and undisturbed flats	All reaches
Role of nutrients, temperature and chemical contaminants on benthic plant and animal growth and health	All reaches

A.4. Tidal Marshes

Functions within Ecosystem

Tidal marshes include salt and freshwater marsh habitats that experience tidal inundation. General marsh functions include those commonly listed for wetlands, which include: fish and wildlife support, groundwater recharge, nutrient cycling, flood attenuation, and water quality improvement. Functions demonstrated for tidal marshes in the Pacific Northwest are as follows:

- Primary production
- Juvenile fish and invertebrate production support
- Adult fish and invertebrate foraging
- Salmonid osmoregulation and overwintering habitat
- Water quality
- Bird foraging, nesting, and reproduction
- Wildlife habitat
- Detrital food chain production
- Wave buffering

Primary production rates for regional tidal marshes range from 529-1,108 g C m^{-2} yr^{-1} (Thom 1981). Juvenile salmon have been shown to reside in tidal marshes in the Puyallup River

estuary and Grays Harbor. Salmon forage on prey resources produced in, and imported to, the marsh system (Shreffler et al. 1992). Significant growth of juvenile salmon residing in these systems has also been reported. Prey resource production has been documented in small, restored tidal marshes in the Duwamish Estuary (Simenstad and Cordell 2000).

In a diel study of fluxes of dissolved and suspended matter between the Gog-le-hi-te marsh and the Puyallup River, it was shown that the marsh exported organic matter and imported some invertebrates (Simenstad and Thom 1996). The water entering the marsh was warmed and salinity increased in the system. Dissolved oxygen was also increased in the system. It should be noted, however, that the Gog-le-hi-te system is a restoring tidal marsh, likely to be short of reaching equivalency, and does not necessarily represent other tidal marsh systems in other parts of Puget Sound.

As an example of tidal marsh habitat utilization, the Gog-le-hi-te system was shown to be used by 118 bird species within the first five years of its existence (Simenstad and Thom 1996). Grazing of marsh vegetation by waterfowl was noted, as was foraging of fish by great blue heron and kingfishers. In general, shorebirds procure invertebrate prey and raptors feed on small mammals, amphibians, and reptiles. In addition, passerines such as red-winged blackbirds and marsh wrens nest in tidal marshes (Simenstad et al. 1991b).

Processes that Maintain Tidal Marshes

Marshes accrete sediment and organic matter and thereby build land both upward and outward. They are maintained primarily by adequate hydrology as well as sediment supply. Marshes generally occur in more protected areas where waves and currents do not erode the marsh. Salinity effects saltmarsh plant species composition and the lower limits of distribution. In addition, surface (river and stream channel) and groundwater (seepage) discharge influence salinity, thereby influencing plant species composition and distribution. Alterations in hydrology, sediment supply, sea level, or marsh plant production can affect the maintenance of the marsh.

Location of Tidal Marshes

The current distribution of marshes in WRIA 8 is extremely limited due at least in part due to historic filling, diking, armoring, and other anthropogenic intrusions. A small tidal saltmarsh located in Edmonds between the area immediately east of the railroad tracks and south of the Edmonds ferry terminal is connected to Puget Sound. In WRIA 8 the ShoreZone database (WDNR 2001) does not show any tidal marsh habitats in WRIA 8.

Stressors

There have been no reports on health indicators of tidal marshes in the region. Some potential health indicators are as follows:

- Disturbed community structure
- Disturbed plant growth
- Presence of non-native species

- Buffer encroachment
- Runoff scour
- Elevated soil contaminant concentrations
- Presence of man-made debris
- Physical disturbances from shoreline armoring, marina construction, and harvesting
- Chemical contamination

These systems are vulnerable to physical disturbances by human actions (e.g., filling, dredging, hydrologic constriction, boat wakes) as well as chemical contamination. Debris, such as plastics and other man-made materials, can accumulate in tidal marshes, which can bury and smother marsh plants (Thom et al. 2000).

Historical Distribution

Tidal marshes in the Puyallup River-Commencement Bay area develop over the elevation range of 3-5 m MLLW (Thom et al. 2000). It is reasonable to infer that marshes in WRIA 8 would have formed at similar elevations.

Reasons for Change

The primary causes for change include dredging, filling, changes in freshwater input and overwater structures.

Data Gaps

Significant data gaps in marsh ecology, such as the extent of interannual variability, role of upland buffers in marsh migration, and interactions between marshes and riparian zones, also exist. The significance of marshes in groundwater recharge, the role of periodic disturbance in marsh ecology, and the importance of large woody debris as habitat structure in marshes also are not well studied. Table 8 lists the identified data gaps.

Table 8. Data gaps for tidal marshes.

DATA GAPS	LOCATION IN WRIA 8
Complete maps of marsh area	All reaches
Interannual variability and natural vs. human-influenced controls of variability	All reaches
Role of reduced or altered upland buffers in allowing marshes to migrate inland with sea level rise	All reaches
Role of marsh production in the food web	All reaches
Fish (especially juvenile salmon) and invertebrate use	All reaches
Interactions between marshes and riparian zones	All reaches
Role of marshes in groundwater recharge	All reaches
Role of periodic disturbance in marsh ecology	All reaches
Role of large woody debris as habitat in marshes	All reaches
Carrying capacity of disturbed and undisturbed marshes	All reaches
Role of nutrients, temperature, and chemical contaminants on benthic plant and animal growth and health	All reaches

A.5. Subestuaries (River Mouths and Deltas)

Subestuaries are those areas of river and stream mouths that experience tidal inundation, including their deltas and any associated marshes. Fresh and salt water mix here, providing a range of salinities. These are the areas where rivers broaden, attenuating localized flooding. Like marshes, subestuaries provide juvenile salmonid rearing and feeding areas, can support eelgrass beds if salinities are high enough, and provide refuge, feeding, and production areas to a wide variety of birds, fish, mammals, invertebrates, and reptiles.

The following discussion includes a general overview of all stream and river subestuaries in WRIA 8.

Functions

In their natural condition, the river mouth and delta are areas where the river spreads out, attenuating floodwaters. The following list highlights functions typically associated with subestuaries:

- Floodwater attenuation
- Critical transition areas for anadromous salmonids
- Water quality improvement
- Rearing areas for juvenile salmonids and other estuarine dependent species of fish and wildlife
- Supports eelgrass
- Refuge for multiple species

Often subestuaries are associated with wetlands , which further slow peak flows. Vegetated wetlands (emergent marshes and forested flood plains) that persist along margins of river deltas can trap sediments and uptake nutrients, or other contaminants, which might otherwise be delivered by the river to the nearshore environment.

Subestuaries, particularly salt marshes, are important rearing areas for juvenile salmonids, providing refuge and food before they leave for open waters. Provided salinities are not too low, these areas can also support eelgrass, an important habitat for many species. Additionally, freshwater outlets are used by birds for bathing and drinking, particularly in the late summer months when freshwater is more limited (Norman 1998).

Like tidal marshes, a wide variety of birds, fish, mammals, amphibians, reptiles, and invertebrates use subestuarine marshes for refuge, food, and reproduction.

Processes that Maintain Subestuaries and Deltas

River deltas develop as a result of downstream sediment transport, with the rate of delta growth related to the amount of annual freshwater discharge (Downing 1983). In protected bays, freshwater and saltwater are stratified in the water column at the river mouth, providing a means for sediment to settle out of the river plume. This process forms the mud shoals and tidal flats that exist at the heads of protected bays. The small streams that are located along the shoreline of Puget Sound may form small deltas if the mouths are located in areas protected from waves and tidal currents. Over time wetland accretion occurs on the deltas as marsh vegetation slows the water and settles out fine sediments.

Location of Subestuaries

The only large outlet in WRIA 8 is the Lake Washington Ship Canal, which empties into Shilshole Bay. There is no floodplain or river delta associated with this outlet, which was historically a small bay and was developed into a ship canal for navigation. The canal is extremely important for anadromous fish migration because it is the only way into and out of the Lake Washington/Cedar/Sammamish System. Aside from this large subestuary, there are six small streams (classification information not available) in WRIA 8, located approximately every 10 km along the shoreline, with three in reach 1 and three in reach 2. Some of these have deltas.

Stressors

Many of the streams in the study area are in urbanized areas and have been altered by development, resulting in fish habitat loss, water pollution, erosion and sedimentation, landslides, and flooding (King County 1990). Many of the small wetlands that were once associated with the small streams are degraded or gone as a result of filling and other development practices. The primary cause of small stream degradation in the region is impervious surface development within the watershed. Vegetation removal and covering of land surface by human infrastructure leads to a decrease in the amount of precipitation that soaks into the soil, and a subsequent increase in the amount of water delivered directly to the

stream. These changes, in turn, cause a greater frequency and higher peaks for flood events, upsetting the processes that naturally sustain stream channels, greater inputs of sediment and contaminants to the stream system, and ultimately, the nearshore environment.

Historic Distribution

The general locations of most of the small streams are probably the same as they were historically. However, channelization and upland development have likely changed their natural flows, floodplain, and riparian characteristics. Unfortunately, the lack of historical monitoring results in an inability to accurately assess historical conditions of small streams. The most obvious and greatest changes have occurred in larger systems, such as when the White River and Cedar River were diverted out of the Green/Duwamish, reducing the basin by more than two-thirds. This had a corresponding effect on the river mouth and delta. In WRIA 8, the greatest change was to the Sammamish River, with the construction of the Lake Washington Ship Canal. The Sammamish once had a fairly large river delta and associated wetland system.

Reasons for Change

Development activities, particularly diversions of rivers and dredging and filling activities, have significantly altered the WRIA 8 subestuary.

Data Gaps

More information regarding salmon use of small streams could be gathered. As of 1990, when the last sensitive areas map was constructed, there were several small streams that had not been classified because salmonid use had not been determined. However, City of Seattle streams have recently been assessed for stream type, habitat, fish type and salmon barriers and spawning (report in preparation, Gail Arnold, SPU, personnel communication). Data gaps for subestuaries are listed in Table 9.

Table 9. Data gaps for subestuaries.

DATA GAPS	LOCATION IN WRIA 8
Information on juvenile salmonid use of small streams	All reaches
Extent of impervious surface development in small stream watersheds	All reaches
Relationship between impervious surface and subestuary degradation	All reaches
Importance of subestuaries to migrating salmonids and other fish and wildlife	All reaches
Effects of degraded water quality and habitat loss on subestuarine carrying capacity	All reaches

A.6. Sand Spits

Functions within Ecosystem

Sand spits may enclose (partially or totally) intertidal estuarine areas. Substrata are typically sand, silty sand, or gravelly sand. Functions of sand spits in the Pacific Northwest include:

- Foraging areas for waterfowl and shorebirds
- Prey production for shellfish, marine fishes, and macroinvertebrates
- Infauna production (e.g. bivalves, burrowing worms)
- Primary production
- Spawning habitat for forage fishes

In general, pickleweed *(Salicornia virginica)* dominates the upper zones of these estuarine, intertidal marsh areas, forming dense mats. Other halophytes such as *Distichlis spicata* and *Atriplex patula* may be present (Dethier 1990).

Processes that Maintain Sand Spits

In the Pacific Northwest, sediment particles contributing to sand spit formation originate primarily from fluvial, rather than marine, sources (Simenstad et al. 1991b). However, in the Puget Sound region, sediments deposited on sand spits may also originate from eroding bluffs. Waves and currents transport this material along the shoreline until it settles out near an embayment, forming a spit. Changes in river sediment load, ocean currents, and wave action can affect the maintenance of sand spits.

Location of Sand Spits

The current distribution of sand spits in WRIA 8 is extremely limited. The ShoreZone database (WDNR) does not include spits. However, documentation of shore-drift patterns indicates that several small spits do exist in reach 3 (Washington Department of Ecology 1991).

- Reach 3: Two spits are documented. The most obvious is the large symmetrical spit at West Point. The West Point spit is classified as a triangular cuspate foreland, formed by material eroding from feeder bluffs (Magnolia Bluff) and carried by local longshore transport and nearshore currents (MacDonald et al. 1994). The convergence of two drift cells occurs at the West Point spit (Schwartz et al. 1991). The second is a drift-aligned sand and gravel intertidal spit oriented toward the southwest and located northeast of West Point.

Stressors

These systems are vulnerable to filling, dredging, boat wakes, and changes in sedimentation rates such as those caused by shoreline armoring. They also are vulnerable to physical disturbances caused by shoreline development.

Because of potential for fecal coliform and pathogen contamination, the beaches (including sand spits) of WRIA 8 are closed to commercial shellfish harvesting (Puget Sound Water Quality Action Team 2000). Chemical contamination is likely in WRIA 8, but few studies have focused on sand spits.

There have been no reports of health indicators specific to sand spits in the region. However, general health indicators that have been reported, or can be assumed to effect areas that contain sand spits include the following:

- Unnatural erosion or deposition of sediment
- Fecal and chemical contamination
- Alteration of natural habitats
- Overharvesting of shellfish

Historic Distribution

Very little information is available on the historical distribution of sand spits in WRIA 8. However, sand spits enclosing salt marsh subestuaries were once present at Elliot Point and at Edwards Point at the north and south ends of reach 1, respectively. Prior to the development of the Elliott Bay Marina in 1992, a zone of drift divergence on the southeast shore of Magnolia Bluff created an intertidal sand and gravel spit near Pier 91. The marina eliminated the net shore drift that created this spit. No information on the Alki Point spit was identified.

Studies have found that the West Point spit appears stable, despite shoreline armoring along Magnolia Bluff. In comparing distance and area measurements from aerial photographs between 1936 and 1977 with original surveys conducted in 1883, it was determined that the spit changed less than 40 feet. The construction of a sludge lagoon along the spit in 1962 interrupted littoral drift and caused rapid modification to the shoreline both up and downdrift. However, the sludge lagoon was removed in 1980 and replaced by a gravel beach. After the first year of construction, about 14 percent of the beach material moved around the point to the north side of West Point. About 60,000 square yards of beach grass were planted in the sand fill to aid stabilization of the backshore. Since 1981, the beach has remained relatively intact (Macdonald et al. 1994).

Reasons for Change

Shoreline armoring, shoreline development, dredging, and filling are likely the major causes for loss of sand spits and associated habitat.

Data Gaps

Little current and historical information on sand spits is available for WRIA 8, and we do not know conclusively how natural and human-influenced forces affect them. Table 10 shows gaps in our knowledge of sand spits, including their role in the food web and as habitat for fish and invertebrates.

Table 10. Data gaps for sand spits.

DATA GAPS	LOCATION IN WRIA 8
Natural interannual variability vs. human-influenced controls of variability	All reaches
Role of sand spit production in the food web	All reaches
Fish ,invertebrate, and wildlife use of existing spits	All reaches
Cumulative and site-specific effects of shoreline armoring and other development practices on spits	All reaches
Carrying capacity of disturbed and undisturbed spits	All reaches

A.7. Beaches and Backshore

Functions within Ecosystem

Beaches include boulder, cobble, gravel, sand, and silt areas that comprise most of the shoreline of Puget Sound. They are generally steeper than tide flats described above. Backshore areas are immediately landward of beaches and are zones inundated only by storm-driven tides. A typical profile of an undisturbed shoreline in Central Puget Sound would have an upper backshore or storm berm area that collects logs and algae and other debris during storms. The intertidal portion of the beach, between OHW and about MLW, is typically relatively steep and comprised of a mixture of cobbles and gravel in a sand matrix. At about MLW the beach slope typically breaks to a relatively flat low-tide sand terrace.

Functions supported by beaches are numerous, and are generally similar to those described above for tide flats. However, the level of each function differs from tide flats. Ecological functions of beaches that have been documented in the region include:

- Primary production
- Nutrient cycling
- Refuge for multiple species
- Prey production for juvenile salmon and other marine fishes
- Fish habitat, including forage fish spawning
- Infaunal and epifaunal production

Organisms in these habitats are diverse, with both epifauna and infauna. Beaches are used as feeding areas by cutthroat trout, juvenile salmon, piscivorous birds such as cormorants, grebes, loons, mergansers, and great blue herons, bivalve-eating birds such as scoters and goldeneye (Dethier 1990), and shorebirds that probe into the substrate, or sweep the shallow water with their bills for invertebrate prey.

Backshore areas have not been studied well for their ecological functions. However, we do know that woody debris accumulates in this zone through transport at extreme high tides. It is generally believed that this woody debris can help stabilize the shoreline, trap sediments and

organic matter, and provide microhabitats for invertebrates and birds. Backshore areas also support a unique assemblage of vegetation tolerant of wind, salt spray, and shifting substrate.

Processes that Maintain Beaches and Backshore

Like tide flats, beaches and backshores are maintained by the dynamics of erosion and deposition of sediment. Large woody debris and vegetation contribute to the formation and maintenance of beaches and backshore areas.

Location of Beaches and Backshore

Beaches and backshore areas occur within all reaches of WRIA 8. A beach is an accumulation of unconsolidated material formed by waves and wave-induced currents in the zone that extends landward from the lower low water line for large (spring) tides, to a place where there is a marked change in material or physiographic form, usually the effective limit of storm waves. Backshore areas are those where water reaches only during extreme high tides that occur during major storms. Based on the ShoreZone database (WNDR), the total shoreline length that contains beaches is presented in Table 11.

In WRIA 8, the ShoreZone database (WNDR) shows 36,959 meters of beaches.

Table 11. Shoreline lengths where various beach types were recorded in the ShoreZone database (WDNR 2001)**.**

TYPE	Length (m)	Percent of Total WRIA 8 Shoreline
Beach – Total	36,959	82.8
Boulders	464	1.0
Diamicton*	0	0
Pebbles	0	0
Sand	13,439	30.1
Sand/pebbles	5,684	12.7
Sand/boulder	1,955	4.4
Cobble/pebbles	698	1.6
Sand/fines	0	0
Sand/pebbles/cobble	10,019	22.5
Sand/pebbles/boulder	1,977	4.4
Cobbles/pebble/boulder	498	1.1
Sand/cobble/boulder	0	0
Cobble/pebble/boulder/sand	2,225	5.0

* Diamicton is a non-sorted to poorly sorted mixture of sand and larger rounded and angular particles in a matrix of silt and clay.

Two taxa of seaweed, *Ulva* spp. and *Fucus gardneri*, dominate beaches in the region, but several other algal species may be locally common. *F. gardneri* (rockweed) is always found attached to more stable rocks ranging from small cobbles to boulders or to artificial substrata such as pilings or riprap. *Ulva* (sea lettuce) typically attaches to pebble or larger substrata, but may also be found in viable free-floating patches deposited along beaches. The distribution of

rockweed provides a good indication of the general distribution of intertidal pebble-to-boulder substrata. The widespread distribution of rockweed and sea lettuce is illustrated in Figure 16.

Stressors

Beaches are subject to the same stressors affecting flats (see Flats above). These include overabundance of ulvoids, physical disturbances as a result of shoreline armoring, contamination by organic matter and fecal coliform, *Spartina* conversion to monoculture marshes, and overwater structures and marinas. Shellfish harvesting can also be particularly damaging to these systems.

Some indicators of the health of beaches include the following:

- Fecal contamination
- Chemical contamination
- Alteration of natural habitats
- Alteration of resource use of natural habitats
- Alteration of sediment supply
- Presence of non-native species

Shoreline armoring is particularly harmful to recruitment of new beach materials. Shoreline armoring likely reduces recruitment of new beach materials throughout WRIA 8.

Historic Distribution

No comprehensive historical maps are available for assessing historical distribution. In areas where development has occurred, such as at Shilshole Marina, it has likely resulted in loss of beaches and beach functions.

Reasons for Change from Historical Distribution

Shoreline armoring, overwater structures, dredging, filling, and resource harvesting are likely the major causes for loss of beach habitat.

Data Gaps

Although massive urbanization have occurred on the throughout the WRIA 8 shorelines, the cumulative effects of development on beaches and backshore are not well understood. Table 12 lists some of the gaps in our knowledge of beaches and backshore.

Table 12. Data gaps for beaches and backshore.

DATA GAPS	LOCATIONS IN WRIA 8
Role of production in the food web	All reaches
Bivalve harvest impacts	All reaches
Effects of shoreline hardening and other development practices	All reaches
Fish (especially juvenile salmon and forage fish) and invertebrate use	All reaches
Role of woody debris in nearshore ecosystem	All reaches
Carrying capacity of degraded and undisturbed beaches and backshore areas	All reaches

Figure 17: Distribution of rockweed and sea lettuce in WRIA 8

See Appendix B for Figures

A.8. Banks and Bluffs

Functions within Ecosystem

Banks and bluffs are typically steep areas of varying heights, located between the intertidal zone and the upland. They are a part of the riparian zone and act as an important transition area in this aquatic/terrestrial interface. The ShoreZone database (WDNR) identifies cliffs as those areas with a slope of more than 20 percent grade. Banks and bluffs can be composed of sediments of varying grain sizes as well as rocks and boulders. Functions performed by banks and bluffs include the following:

- Source of sediments to beaches
- Habitat for bluff-dwelling animals
- Support of marine riparian vegetation (and associated riparian functions)
- Source of groundwater seepage into estuarine and marine waters

Processes that Maintain Banks and Bluffs

These habitats are formed and maintained by the dynamics of numerous factors including soils, wind, erosion, hydrology, and vegetative cover.

Location of Banks and Bluffs

Based on the ShoreZone database (WDNR), the distribution of cliffs of various types are shown in Table 13. As the table shows, bluffs in WRIA 8 are primarily high and steep.

Table 13. Shoreline lengths where various cliff types were recorded in the ShoreZone database (WDNR 2001).

TYPE	WRIA 8 Length (m)	Percent of Total WRIA 8 Shoreline
Cliff –Total	2,115	4.7
Inclined/low (20-35°; <5m)	0	0
Inclined/moderate (20-35°; 5-10m)	472	1.1
Inclined/high (20-35°; >10m)	0	0
Steep/moderate (>35°; <5m)	0	0
Steep/moderate (>35°; 5-10m)	0	0
Steep/high (>35°; >35m)	1,643	3.7

Stressors

The "health" of banks and bluffs is difficult to assess. We do know that stressors include shoreline armoring, vegetative cover reduction, shoreline development, overwater structures, dredging, filling, sediment extraction, and hydrology changes.

Residential development has caused some erosion and stability problems in a variety of places, including along the lower bluff southeast of Discovery Park. In general a change in the erosion rate of these areas would affect not only the protection of the upland area, but also the sediment composition and elevation of beaches and other intertidal and shallow subtidal habitats. Hence, where bank erosion rates have been increased or where erosion has been interrupted by artificial means (e.g., a seawall), the health of the adjacent habitats that are dependent on sediment from the bluffs is affected. Additional information on these types of problems can be found in the Shoreline Conditions section of this report.

Historic Distribution

The historical distribution of banks and bluffs has not been mapped. Obvious, but unquantified, changes have occurred in Shilshole Bay, Seahurst Park, and other areas where shoreline development has been extensive.

Reasons for Change

The major obvious changes are likely due to shoreline armoring and coastal development that directly affects bluffs and their maintenance processes.

Data Gaps

Within WRIA 8, massive shoreline development and armoring activities have taken place over the last 125 years. However, the total impact this urbanization has on banks and bluffs is not well understood. Table 14 lists some of the gaps in our knowledge of bluff and bank habitats.

Table 14. Data gaps for banks and bluffs.

DATA GAPS	LOCATIONS IN WRIA 8
Incidence of drainage/stability problems on bluffs	All reaches
Effects of shoreline armoring and other development on banks and bluffs	All reaches
Portion of beach sediment budget contributed by bluffs	All reaches
Groundwater input from bluffs and banks	All reaches

A.8. Marine Riparian Zones

Functions within the Ecosystem

Riparian zones are those areas on or by land bordering a stream, lake, tidewater, or other body of water (Hall 1987) that constitute the interface between terrestrial and aquatic ecosystems (Swanson et al. 1982). They perform a number of vital functions that affect the quality of aquatic and terrestrial habitats as determined by their physical, chemical and biological characteristics. Riparian-aquatic interactions are now recognized by scientists as so important that riparian buffers have been established as a central element of forest practice rules and watershed restoration efforts (Spence et al. 1996). Riparian vegetation composition, density and continuity are some of the most important characteristics of riparian systems. In general, healthy riparian systems have the following characteristics (Brennan and Culverwell in prep):

- long linear shapes
- high edge to area ratios
- microclimates distinct from those of adjacent uplands
- standing water present all or most of the year, or a capacity to retain water
- periodic flooding which results in greater natural diversity
- composition of native vegetation differing somewhat from upland systems

Most of what we know about riparian functions and values comes from investigations of freshwater systems, which have been the subject of extensive research. Although marine riparian zones have not been subject to the same level of scientific investigation, increasing evidence suggests that riparian zones serve similar functions regardless of the salinity of the water bodies they border (Desbonnet et al. 1994) and are likely to provide additional functions unique to nearshore systems (Brennan and Culverwell in prep). Riparian functions that are known or likely to contribute to nearshore ecosystem health include protection of water quality, and bank stability; provision of wildlife habitat, microclimate, and shade; and input of nutrients and large woody debris. Each of these functions is briefly reviewed below.

Water Quality

The use and effectiveness of vegetated buffers for pollution abatement and the protection of aquatic ecosystems has been well documented (e.g., Phillips 1989; Groffman et al. 1990; U.S. EPA 1993; Desbonnet et al., 1994; Lorance et al., 1997; Bernd-Cohen and Gordon 1998; Rein 1999; and, Wenger 1999). Vegetation binds soils, retains and absorbs contaminants, and reduces overland flow volume and velocity. The effectiveness of riparian buffers for pollution and sediment control depends on a number of factors, including (Brennan and Culverwell in prep):

- soils
- geomorphology
- hydrology
- biological processes (i.e., microbial activity)
- vegetation type

- slope height and angle
- annual rainfall
- level of pollution loading
- types of pollutants
- surrounding land uses
- buffer width

The degradation of urban waterways is directly linked to urbanization and has been exacerbated by the lack of adequate runoff storage, treatment and filtration mechanisms (Brennan and Culverwell in prep). The major pollutants found in urban runoff include sediment, nutrients, road salts, heavy metals, petroleum hydrocarbons, herbicides, pesticides, pathogenic bacteria and viruses (U.S. EPA 1993). The loss of vegetation and resultant increase of contaminants in the system are the result of human activities, such as clearing, grading, compaction of soils, landscaping practices, and the installation of impervious surfaces such as roads, buildings, sidewalks, and parking lots. Pesticide, herbicide, and fertilizer application also contributes to nutrient and contaminant loading. Vegetation removal and the introduction of sediments, nutrients and other contaminants into the aquatic environment can result in eutrophication and reduce plant and insect food sources for fish and wildlife species (Knutson and Naef 1997). In addition to these indirect effects, contaminants can have direct effects on aquatic organisms including increased mortality in adults, juveniles and embryos, reduced reproductive success, birth defects, anorexia and loss of body weight, retarded growth, and changes in species or community composition.

Many of the contaminants introduced into the nearshore are passed through the food chain and are found in higher trophic levels. For example, Calambokidis (1995) and others have found excessively high levels of PCBs in harbor seals and orca whales in Puget Sound. Water quality is also a human health and safety issue. Most of the beaches in King County have been closed to shellfish harvest, and some to finfish harvest, as a result of high contaminant levels found in sediments, aquatic organisms, and the water column. Although this action is a good precautionary measure for human health and safety, much remains to be learned about direct and indirect cause and effect relationships between urbanization and the health of individual species and the ecosystem.

Wildlife Habitat

Healthy riparian areas along marine shorelines support abundant and diverse assemblages of wildlife. For example, Brennan and Culverwell (in prep) identified 205 animal species (5 amphibians, 4 reptiles, 153 birds, and 43 mammals) in a review of animal species known or expected to have a direct association with riparian habitat along the marine shorelines in Central Puget Sound. This represents approximately 70 percent of the 292 animal species known to inhabit all of King County. Animal species diversity and abundance is greatly influenced by the composition and continuity of vegetation and the proximity of riparian areas to Puget Sound, which offers a moderate climate, greater habitat complexity and increased opportunities for feeding, foraging, cover and migration.

Wildlife habitat requirements in freshwater riparian zones are complex and have received a significant amount of review and analysis. However, few studies have focused on wildlife habitat requirements in marine riparian areas and we must depend upon wildlife studies and studies of riparian support functions elsewhere to begin to understand the potential of marine riparian areas. For example, Brown (1985) reports that 359 of 414 (87 percent) species of wildlife in western Washington and western Oregon use riparian areas and wetlands during some season or part of their life cycle (Cedarholm et al., 2000). In a review of riparian buffers needed to support wildlife in Washington State, Knutson and Naef (1997) determined that the average width reported to retain riparian functions for wildlife habitat was 287 feet (88 meters). In their review of the literature on wildlife habitat protection, Desbonnet et al. (1994) offer recommendations of 198-330 feet (60-100 meters) for general wildlife habitat, 304 feet (92 meters) for protection of significant wildlife habitat, and 1980 feet (600 meters) for the protection of critical species. It is suspected that buffer requirements for freshwater systems may be significantly less than for some marine and estuarine riparian systems because of the influences of wind, salt spray, desiccation, and general microclimate effects on vegetation and associated wildlife (Klaus Richter, personal communication).

Aside from direct habitat loss, one of the greatest impacts of urbanization on wildlife comes from habitat fragmentation (Stenberg et al. 1997; Knutson and Naef 1997). The isolation of remnant habitat parcels makes utilization and recolonization difficult or impossible (Knutson and Naef 1997). This is of particular concern for species with low mobility such as amphibians (K. Richter, KCDNR 1995; Knutson and Naef 1997). Because many wildlife species depend upon wide, continuous corridors, vegetative cover, climate, food, and separation from the disturbance of urbanization, the loss and fragmentation that results from urbanization greatly limits wildlife species distribution, diversity and abundance. Developing a better understanding of wildlife species' life history requirements and their utilization of marine riparian zones, and the effects of habitat loss, alteration, and fragmentation will require additional directed studies in these areas.

Microclimate

Riparian plant and animal communities are greatly influenced by their proximity to marine waters. Physical influences on these communities include temperature and moisture regulation, tidal inundation, wind exposure, and salt spray. Marine littoral communities are, in turn, influenced by riparian condition, with overhanging vegetation and organic litter, moisture, and soils playing important roles in species distribution and abundance. In both environments, many organisms, such as amphibians and upper intertidal invertebrates, depend upon cool, moist conditions for survival. Many of the habitat-forming processes and much of the habitat structure is due to the presence of vegetation. Riparian vegetation provides shade and organic matter, retains soils and moisture, and reduces the effects of wind and salt spray.

The removal of riparian vegetation increases the exposure of the land and water to the sun, wind, and precipitation. The resultant effects are increased temperatures, decreased moisture and humidity, increased runoff and elevated water temperatures entering marine systems, desiccation or erosion of soils, and increased stress for organisms dependent upon cool, moist conditions. As marine shorelines have become developed, many of these habitat features have

been replaced with concrete, rock, asphalt, and other impermeable structures that displace habitats and species. It is assumed that the effects of alteration or elimination of microclimates in marine riparian areas as a result of urbanization are similar to the impacts that have been demonstrated in freshwater riparian areas. Further investigation is needed to quantify the relationship between marine riparian vegetation, microclimates and the impacts of urbanization.

Shade

In freshwater streams, riparian vegetation moderates the amount of solar radiation that reaches the stream channel and runoff entering the stream, thereby dampening seasonal and diel fluctuations in stream temperature (Beschta et al. 1987). In estuarine areas that receive tidal exchange and flushing of larger volumes of water, the effect of shading on water temperature would likely be substantially less than in small stream environments. However, shade may be important for regulating water temperatures in tidal channels and for direct drainages (i.e., streams, springs, and seeps) to marine waters. Furthermore, shade has long been recognized as an important factor in reducing desiccation from solar radiation in marine intertidal organisms (Calvin and Ricketts 1968; Connell 1972). In a literature review of the causes of spatial and temporal patterns in intertidal organisms, Foster et al. (1986) found that the most commonly reported factor responsible for setting the upper limits of intertidal animals is desiccation.

In Puget Sound, there are few studies that show the direct linkage between shade and nearshore species composition, or dependence. However, Penttila (1978) suggests that shade can increase the success of surf smelt spawning by reducing the mortality attributed to thermal stress and desiccation. A recent study comparing shaded and unshaded summer spawning sites found that shaded sites had significantly lower egg mortality (Penttila, 2001). Surf smelt are obligate beach spawners and are also an important source of prey in the nearshore ecosystem. Ongoing studies by the University of Washington may provide additional data that reveals the contribution of riparian vegetation in thermal regulation and species composition in supralittoral zones. However, additional information is needed to fully understand the importance of shading in the nearshore.

Nutrient Input

Riparian areas act as both sources of organic matter and sinks for trapping and regulating the flow of nutrients. Although the amount of input and level of importance to the marine system have not been quantified, riparian vegetation has the potential of producing significant amounts of organic matter. The organic matter that falls to the forest floor and becomes a part of the soil, or enters the aquatic environment, directly or indirectly, contributes to the detrital food web. Organic detritus is the principal energy source for food webs in estuarine and shallow marine benthic portions of the ecosystem; the principal source of this detrital carbon is debris from macrophytes in the system (Gonor et al. 1988). Nutrients, such as nitrogen, are also fixed by roots of some plants and metered out to the aquatic system through runoff, leaf and stem litter, or large woody debris.

Riparian vegetation also makes indirect contributions of nutrients to the nearshore system in the form of prey resources. The organic debris produced by riparian vegetation often collects on beaches and combines with marine-derived plant material to form beach wrack. The structure and decomposition of beach wrack attracts a diverse array of terrestrial insects and marine invertebrates. Many riparian plants attract insects that become prey for terrestrial and aquatic consumers. For example, a number of studies have identified terrestrial insects as a significant dietary component of juvenile chinook and chum salmon diets in subestuaries and other nearshore waters throughout Puget Sound (Fresh et al. 1979; Fresh et al. 1981; Pearce et al. 1982; Levings et al. 1991; Shreffler et al. 1992; Levings et al. 1995; Miller and Simenstad 1997; Cordell et al. 1999a,b; Cordell unpublished data). In addition, other invertebrates, such as mysids and amphipods, are connected to vegetation via detritus-based food webs and serve as important prey for salmonids and other fishes, birds, and invertebrates in the nearshore.

Current nearshore food web analysis by the University of Washington has identified important habitats and food web connections for chinook salmon in Puget Sound, including (Cordell et al. unpublished data):

- Intertidal and shallow subtidal areas that produce amphipods and other epibenthic crustaceans. As has been established for juvenile chum salmon, these probably include intertidal flats as well as vegetation and areas of high detritus buildup.
- Nearshore vegetated terrestrial habitats that are the source of terrestrial insects in the diets.
- Feeding on planktonic grazers such as euphausids, shrimp, and crab larvae, planktonic amphipods, and copepods.
- Feeding on other secondary pelagic consumers such as herring and other fishes.

Due to the limited sampling and dietary analysis of juvenile salmonids and other species in the nearshore environment, additional studies are needed to quantify and understand the contribution of riparian vegetation to nearshore food webs and the impacts of vegetation loss along marine shorelines. However, it is clear that as vegetation is eliminated, the food supply and the thus the carrying capacity of the nearshore ecosystem is reduced (Brennan and Culverwell in Prep).

Bank Stabilization

Vegetation is well recognized as an effective tool in reducing erosion and increasing slope stability by intercepting and extracting moisture through the canopy and roots, mechanical reinforcement of soils and restraint by the roots and stems, and adding structure to beaches that traps sediments and protects the toe of slope (see Myers 1993; Menashe 1993; Macdonald and Witek 1994; Gray and Sotir 1996; Brennan and Culverwell in prep). Vegetation, once established, provides a self-perpetuating and increasingly effective permanent erosion control (Kittredge 1948; Menashe 1993). Soils, slope height and angle, drainage, and other factors are also very important in determining susceptibility to erosion. However, for all shorelines, and particularly those in areas with steep and eroding bluffs, native vegetation is usually the best (and most cost effective) tool for keeping the bluff intact and for minimizing erosion (Broadhurst 1998).

The loss or removal of shoreline vegetation can result in increased rates of erosion and higher frequency of slope failure. This cause-and-effect relationship can be demonstrated convincingly as a result of many field and laboratory studies reported in the technical literature (Gray and Sotir 1996). Land use practices such as commercial, industrial, and residential development, along with infrastructure such as roads, bridges, and railroads, have all had a dramatic effect on the volume, type, density, and extent of riparian vegetation that remains along the shoreline. Removal for development, landscaping and view corridors has greatly decreased the amount of vegetation available to perform slope stabilization functions. These activities also result in increased impervious surfaces. Combined, these alterations have resulted in increased erosion and, often, the subsequent installation of armoring, or bank stabilization structures, which typically results in additional vegetation removal. While many recommendations and efforts have been made to utilize vegetation management and alternatives to structural solutions for controlling shoreline erosion (see Macdonald and Witek 1994; Zelo et al. 2000), current regulations do not make use of these alternatives mandatory.

Large Woody Debris (LWD)

One of the primary roles of riparian vegetation relative to aquatic ecosystems is the contribution of habitat structure in the form of LWD. The mechanisms for delivery of LWD into the nearshore include natural and human-induced erosion of banks and bluffs, erosion of wooded riverbanks and delivery through the estuary, and drift logs delivered by the tides. The role of LWD in freshwater lotic systems has been well documented and has led to increasing efforts to utilize LWD for bank stabilization and habitat restoration (e.g. Johnson and Stypula 1993; WDFW 1998). Coarse woody debris is also an important part of estuarine and oceanic habitats (Gonor et al. 1988) and plays important roles for both fish and wildlife (Brennan and Culverwell in prep). Cedarholm et al. (2000) recognized the importance of LWD in increasing habitat complexity and heterogeneity, serving particularly important benefits to salmonids in estuarine marshes and nearshore environments. Weitkamp (1982) observed juvenile salmon feeding on biota attached to boom logs near Pier 90 in Elliott Bay. In Tillamook Bay, Oregon, large stumps were placed on the mud flats at the mouth of the Tillamook River with the intent of increasing fish habitat (Tillamook Bay National Estuary Project 2000).

Vegetation and woody debris provide nutrients to the aquatic environment and refuge for fishes and wildlife, and function as hydraulic buffers to flood and storm surges, or wave energies. Structurally, LWD provides potential roosting, nesting, refuge, and foraging opportunities for wildlife; foraging, refuge, and spawning substrate for fishes; and foraging, refuge, spawning, and attachment substrate for aquatic invertebrates and plants in the nearshore environment (Brennan and Culverwell, in prep). Logs that become imbedded in beaches serve to trap sediments that help to build the berm and backshore. The logs provide moisture and nutrients for the establishment of vegetation, which further stabilizes beaches. Once established, these features can be effective at reducing wave-induced erosion. In an effort to avoid the impacts of conventional shoreline armoring (bulkheads), a number of projects have selected alternatives that include the use of anchored logs and vegetation to decrease erosion (Zelo et al. 2000).

Location of Marine Riparian Vegetation

Marine riparian vegetation, defined as trees overhanging the intertidal zone, was found along 1335 ft. of shoreline in WRIA 8 (WDNR). This represents 1 percent of the shoreline. However, the width, species composition, continuity, density, and age structure of riparian vegetation have not been determined. These factors are important for determining riparian functions and values and for developing management and recovery options. Regardless, it is apparent that little riparian vegetation remains due to urbanization and shoreline development practices in WRIA 8.

Stressors

Stressors can be broken down into natural and anthropogenic causes. Natural stressors include earthquakes, slides, disease, parasitism, wave action during storms, and wind. Anthropogenic stressors include vegetation clearing, increased impervious surfaces and surface water runoff, air and water pollution, herbicides, and intentional changes in vegetation (i.e. landscaping). Vegetation removal and the introduction of exotic species change community structure, increase the chance of competitive interactions, change soil chemistry and microclimate, and increase solar and wind exposure.

Historic Distribution

Macdonald and Witek (1994) provide a brief historical description of vegetation type and distribution :

> *Historically, western Washington included the most densely forested region in the United States. Temperate coniferous forests predominated and the size and longevity of the dominant species was unrivaled elsewhere in the world (Franklin and Dyrness 1988). Explorers and early pioneers describe old-growth forest coming right down to the shore – an occurrence now limited to scattered inaccessible sites along the outer ocean coast of the Olympic Peninsula (Egan 1990; Dunagan 1991; Kruckeberg 1991).*

Historic photographs and other historic accounts of northwest estuaries (e.g. Sedell and Duval 1985; Maser et al. 1988; Dunagan 1991) suggest that the above description is representative of WRIA 8.

More recent changes may be represented by a study conducted by American Forests, a Washington D.C.-based non-profit organization. They analyzed satellite imagery of 3.9 million acres of land on the east side of Puget Sound to determine how forest cover in the basin changed from 1972 to 1996. The analysis showed that dense vegetation and tree canopy coverage declined by 37 percent. The decline in coastal areas is likely to have occurred earlier and in greater amounts due to high development pressures and land use practices in these areas.

Reasons for Change

Vegetation clearing occurs with most development projects, including those at the water's edge. Most Puget Sound shorelines were logged off around the turn of the century (Macdonald and Witek 1994). Timber on the shorelines was some of the first cut due to the ease of access and transport (Dunagan 1991) and for land development (Brennan and Culverwell in prep). Over time, vegetation has been removed for timber, housing and other land development, roads, railroads, port development and other commercial and industrial development, view corridors, shoreline armoring, landscaping, beach access, and other land use practices. While much research, attention, and protection have been given to freshwater riparian areas, very little attention has focused on the potential importance of marine riparian areas. Some local governments provide limited guidelines for the removal of vegetation in their shoreline master programs, but most regulators admit it is extremely difficult to enforce (Broadhurst 1998) and regulations and enforcement have been woefully inadequate to protect this critical element of the nearshore ecosystem (Brennan and Culverwell in prep).

Data Gaps

Relatively little research has been conducted on marine riparian areas compared to freshwater systems. Some research has occurred in other parts of the country on the effects of marine riparian vegetation on pollution abatement, soil stability, wildlife habitat, and fish habitat. However, little research has focused on Pacific Northwest systems. Additionally, regulations regarding functional buffer widths and riparian protection are not in place compared to freshwater systems. The functions and values of marine riparian vegetation need to be better documented in the scientific literature in order to provide a better understanding of riparian functions in marine ecosystems and to create adequate policies for protection and restoration. Table 15 provides a list of identified data gaps for marine riparian habitats.

Table 15. Data gaps for marine riparian zones.

DATA GAPS	LOCATIONS IN WRIA 8
Complete maps of marine riparian vegetation, including extent (width, continuity), type, density, composition	All reaches
Percent impervious area and type of cover (e.g., concrete, asphalt, structures)	All reaches
Role of MRV in food web (contribution of organic carbon, insects, etc.)	All reaches
Role of MRV in providing water quality functions, especially non-point source pollution	All reaches
Importance of MRV in providing shade to fish & wildlife	All reaches
Role of MRV in providing microclimates	All reaches
Role of MRV in providing wildlife habitat	All reaches
Role of MRV in providing fish habitat	All reaches
Role of MRV in increasing slope stability	All reaches
Cumulative impacts of shoreline armoring and other shoreline development and land use practices on MRV and MRV functions	All reaches

Key Findings

Distribution of Habitat Types

- Nearshore marine habitats in WRIA 8 are diverse and include marine riparian vegetation, banks and bluffs, beach and backshore, tidal marshes, tidal flats, eelgrass meadows, kelp forests, and water column habitats.
- These habitats act together to create the productive Puget Sound ecosystem by providing the physical, chemical and biological processes that form habitats and drive critical functions.
- Historical maps of nearshore marine and estuarine habitats are lacking in WRIA 8; only recently have comprehensive mapping efforts (WDNR Washington State ShoreZone Inventory 2001) been undertaken that adequately assess the region's nearshore marine resources.
- Eelgrass productivity exceeds that of most other aquatic plants. Organic carbon produced by eelgrass is especially important in driving the nearshore marine food web of Puget Sound.
- Overwater structures, shoreline armoring, fecal contamination, climate change, dredging, filling, resource exploitation, contamination, ship wakes and propellers have all contributed to major losses of habitat area and their functions in the region
- Monitoring programs have not adequately addressed long-term changes in habitat distribution.
- There is no comprehensive understanding of the effects of multiple stressors on the viability of nearshore marine habitats in the region.

Eelgrass

- Eelgrass meadows are highly productive habitats that support primary production, process nutrients, provide wave and current energy buffering, supply organic matter, and provide invaluable fish and wildlife habitat.
- Eelgrass meadows are found along approximately 57 percent of the WRIA 8 shoreline.
- Stressors to eelgrass include natural factors such as disease and overgrazing, as well as human influences such as shoreline armoring, overwater structures, dredging, and filling.
- Anecdotal observations suggest that the Alki meadow has been declining since the 1960s.

Kelp Forests

- Kelp supports primary production, provides fish and wildlife habitat, contributes organic and particulate carbon to the food web, provides wave and current buffering, and is a substrate for secondary production.
- Kelp is found along 12 percent of the WRIA 8 shoreline.
- Kelp forests in the study area may have been reduced since the 1980s due to harvest practices. However, there is evidence of increased abundance and distribution in the whole of Puget Sound compared to early in the century. Other stressors include nutrient loading and shading from overwater structures.
- Apparent increases in kelp may be the result of shoreline armoring and subsequent hardening of shallow subtidal substrates, which favors kelp attachment, recruitment, and growth.

Flats

- Flats are invaluable habitats that support primary production, process nutrients, provide habitat for fish and wildlife, produce prey for fishes and shorebirds, and buffer wave and current energy.
- The ShoreZone database indicates that flats are found along 6 percent of WRIA 8.
- Stressors to flats include filling, dredging, overwater structures, and over harvest of flat species.
- The health of flats is not clear.

Tidal Marshes

- Marshes support primary production, provide nursery areas for fish and invertebrates, produce prey resources for adult fish and invertebrates, support other wildlife, protect water quality, buffer waves, and shelter salmonids as they osmoregulate and overwinter.
- The distribution of marshes in WRIA 8 is extremely limited due to historical diking, filling, armoring, and other human intrusions.

Subestuaries (River Mouths and Deltas)

- Subestuaries attenuate floodwaters, provide transition areas for salmonids, improve water quality, provide rearing areas for juvenile fishes, support eelgrass, and provide refuge for fish and wildlife.
- Most subestuaries in WRIA 8 are at the mouths of small streams. There were historically approximately 33 in WRIA 8. Currently, some of these streams enter the marine environment through the railroad line and appear as bank storage.
- The major stressor to subestuaries is development, which results in filling, dredging, increases in impervious surfaces, water pollution, and erosion and sedimentation.
- Historically, the river mouth and delta were shaped by different hydrology patterns than today.

Sand Spits

- Sand spits provide foraging areas for wildlife, produce bivalves, and support primary production.
- In WRIA 8, there is a spit at West Point.
- Sand spits are vulnerable to filling, dredging, boat wakes, and changes in sedimentation rates such as those caused by shoreline armoring and development.
- West Point has a prominent sand spits that is formed by the convergence of two drift cells.

Beaches and Backshore

- Beaches and backshore areas support primary production, cycle nutrients, provide refuge for multiple species, produce prey for fishes, and support bivalves.
- There are almost 37,000 meters of beaches in WRIA 8.
- Major threats to beaches include shoreline armoring, overwater structures, shellfish harvesting, and contamination with organic matter and bacteria.
- Shoreline armoring is particularly harmful to recruitment of new beach materials. This likely occurs throughout WRIA 8.
- Seawalls are present for approximately 13,000 linear ft from Pier 91 to Magnolia Bluff. Only 5,580 linear ft from Magnolia Bluff to West Point are free of shoreline armoring.

Banks and Bluffs

- Bluffs provide sediments to beaches, habitat for wildlife, marine riparian
- vegetation, and groundwater seepage.
- Bluffs in WRIA 8 are primarily high and steep.
- In WRIA 8, almost 5 percent of the shoreline is banks and bluffs.
- Stressors include shoreline armoring, reduction of vegetative cover, shoreline
- development, overwater structures, dredging, filling, sediment extraction, and hydrology changes.

Marine Riparian Vegetation

- Very few data have been collected on the functions of riparian vegetation in estuarine and nearshore areas. However, marine riparian vegetation likely protects water quality, bank stability, microclimate, and shade; and provides wildlife habitat, nutrients and large woody debris.
- There is marine riparian vegetation along only 1 percent of the WRIA 8 shoreline.
- Stressors to marine riparian vegetation include earthquakes, landslides, storm waves, wind, clearing for development and landscaping, and shoreline armoring.
- Along Magnolia Bluff, much of the riparian zone likely provides high quality riparian function. Most of the vegetation is adult deciduous trees that extend uninterrupted for more than 300 ft up the bluff. Landslides and instability along southern portions of the bluff have been observed in areas developed for residential use.

B. SELECTED FISH SPECIES

B.1. Forage Fish

Forage fish, as the name implies, are a significant part of the prey base for marine mammals, sea birds, and fish populations, including salmonids, in Puget Sound. They rely upon a variety of shallow nearshore and estuarine habitats and are a valuable indicator of the health and productivity of our marine environment (Table 16).

The five species of forage fish are herring, surf smelt, longfin smelt, eulachon, and sand lance. These small, schooling fish most likely use shorelines within WRIA 8.

Table 16. Forage fish: Status in South Puget Sound and indication of nearshore marine and estuarine habitat use.

		Nearshore and Estuarine Habitat Use		
Common Name	**Scientific Name**	**Spawn**	**Adult Resid.**	**Juven. Rear.**
Pacific Herring	*Clupea harengus pallasi*	**X**	**X**	**X**
Surf Smelt	*Hypomesus pretiosus*	**X**	**X**	**X**
Longfin smelt	*Spirinchus thaleichthys*	**X**	**X**	**X**
Eulachon	*Thaleichthys pacificus*			
Sand Lance	*Ammodytes hexapterus*	**X**	**X**	**X**

Source:(Lemberg et al. 1997, Musick et al. 2000)
Notes: Anadromous eulachon pass through nearshore and estuarine habitats during spawning migrations; patterns of habitat use are poorly known.

Pacific Herring (*Clupea harengus pallasi*)

Juveniles

After transformation from their larval form, juvenile Pacific herring usually stay in nearshore marine waters until fall, when they disperse to deeper marine waters (Emmett et al. 1991). They feed primarily on euphausids (J. Brennan, personal communication), copepods and small crustacean larvae (Hart 1973, Emmett et al. 1991).

Adults

Pacific herring do not make extensive coastal migrations, but rather move onshore and offshore in schools as they feed and spawn (Emmett et al. 1991). Some Puget Sound herring may summer off Cape Flattery (W. Palsson, WDFW, personal communication). Adult Puget Sound herring stocks move onshore during winter and spring to holding areas prior to moving to inshore spawning grounds (O'Toole 1995, Lemberg et al. 1997). Adults appear to consistently return to their natal spawning grounds, and during spawning migrations may greatly reduce or stop feeding (Emmett et al. 1991, Lemberg et al. 1997). Most spawning in Puget Sound takes place from late January through early April in lower intertidal and upper subtidal habitats (O'Toole 1995). Adhesive eggs are primarily deposited on native eelgrass and a variety of marine algae (Lemberg et al. 1997). Pacific herring in shallow nearshore habitats of Puget Sound feed primarily on copepods, decapod crab larvae, (Fresh et al. 1981) and euphausids (D. Penttila, WDFW, personal communication).

Current Distribution and Use

At least 18 Pacific herring stocks, defined by spawning ground, occur inside Puget Sound (Lemberg et al. 1997). Pacific herring use the nearshore environment for feeding and spawning. Currently, there are two commercial herring fisheries in Washington; the principal one is in south-central Puget Sound and has annual average landings (1992-96) of 510 tons (Lemberg et al. 1997). Currently, Puget Sound herring are fished at a conservative level (O'Toole 1995). Although Puget Sound herring stocks have declined over the past 20 years, the National Marine Fisheries Service decided they did not warrant listing under ESA in 2001. It is probable that Pacific herring of all ages pass through WRIA 8 nearshore habitats, especially as juveniles rearing during the summer months and as adults migrating to holding areas near natal spawning grounds

Within WRIA 8 there are no documented herring stocks that spawn within the nearshore. However, not every beach has been comprehensively surveyed and herring are widespread within Puget Sound and use these habitats for feeding and migration.

Historical Distribution and Use

Pacific herring stocks in Puget Sound have undergone significant fluctuations, and some stocks have declined over the past 20 years.

Within WRIA 8 the distribution data for Puget Sound fishes compiled through 1973 show clusters of Pacific herring records within the nearshore area (Miller and Borton 1980). According to several isolated records, Pacific herring occurred near Edwards Point (reach 1), with a group off Meadow Point and Golden Gardens beach (reach 2), and in Shilshole Bay (reach 3). Pacific herring were rare to common (331 fish total) in monthly beach seine collections made off West Point in 1975 (Miller et al. 1976).

Surf Smelt (*Hypomesus pretiosus*)

Juveniles

Juvenile surf smelt reside in nearshore waters and may use estuaries for feeding and rearing (Emmett et al. 1991, Lemberg et al. 1997).

Adults

Adult surf smelt are pelagic, but remain in nearshore habitats over a variety of substrates throughout the year (Emmett et al. 1991). They feed on a variety of zooplankton and epibenthic organisms, including planktonic crustaceans and fish larvae (Emmett et al. 1991); (Fresh et al. 1981). Spawning occurs during much of the year on mixed sand-gravel beaches at a tidal elevation between approximately +2 meters and the mean higher-high water line (Lemberg et al. 1997), or higher. Adults school offshore and may return to the same spawning ground each year (Lemberg et al. 1997). Surf smelt are an important trophic link in nearshore marine food webs.

Current Distribution and Use

Surf smelt are a widespread and important member of the nearshore fish community throughout Puget Sound. Although surf smelt movements within Puget Sound are unstudied, a number of genetically distinct stocks are thought to occur. Because no stock assessment studies have been done, the status of Puget Sound surf smelt populations is currently unknown (Lemberg et al. 1997). The initial studies of surf smelt in the Puget Sound basin in the 1930's mapped no spawning beaches in WRIA 8. Subsequent discoveries of spawning sites in this region are presumably due to increased sampling effort, not an expansion of the range of this species (D. Penttila, WDFW, pers. comm.). Limited periodic surveys of surf smelt spawning beaches have documented about 210 linear miles of spawning habitats (Lemberg et al. 1997).

In WRIA 8, four surf smelt spawning beaches have been documented along the shoreline; the north side of Picnic Point; north of Point Edwards, the south shore of Point Wells, and Richmond Beach (Lemberg et al. 1997) (Figure 18). Lack of documented spawning in an area does not mean that spawning does not occur there. Not all beaches have been surveyed and those that have do not always include data for multiple years. All currently known surf smelt spawning beaches in WRIA 8 have been discovered since 1991 (D. Penttila, WDFW, pers. comm.).

Figure 18. Location of known forage fish spawning beaches in WRIA 8

See Appendix B for Figures

Historic Distribution and Use

No reliable estimates of historic surf smelt distribution and habitat use exist for Puget Sound since spawning beach surveys were begun in 1972 (Pentilla 1978, Lemberg et al. 1997).

The historic distribution data for Puget Sound fishes compiled through 1973 shows clusters of surf smelt records within the nearshore area of WRIA 8 (Miller and Borton 1980). Most records indicate surf smelt occurrence near Edwards Point (reach 1), with some off Meadow Point and Golden Gardens beach (reach 2), and in Shilshole Bay (reach 3). Surf smelt were rare to common (54 total fish) in monthly beach seine collections made off West Point in 1975 (Miller et al. 1976).

Longfin Smelt (*Spirinchus thaleichthys*)

Juveniles

Juvenile longfin smelt are most commonly associated with pelagic estuarine habitats. They are carnivorous planktivores and eat a variety of small crustaceans (Emmett et al. 1991).

Adults

Adult longfin smelt are abundant in estuarine habitats from Puget Sound to San Francisco Bay. Spawning occurs in freshwater areas at night during winter over sandy areas with aquatic vegetation; most adults die soon after spawning (Emmett et al. 1991). Adults are carnivorous zooplanktivores and are consumed by numerous marine and estuarine vertebrates (Emmett et al. 1991).

Current Distribution and Use

Little information exists on longfin smelt habitat distributions and use in Puget Sound. However, longfin smelt are likely found in estuarine habitats within WRIA 8.

Historic Distribution and Use

One historic record of longfin smelt exists within WRIA 8 nearshore habitats. Longfin smelt were rare (2 total fish) in monthly beach seine collections made off West Point in 1975 (Miller et al. 1976).

Eulachon (*Thaleichthys pacificus*)

Juveniles

Newly hatched eulachon larvae are 5-7 mm long and rapidly drift out of rivers and estuaries to marine waters (Hart 1973, Emmett et al. 1991). Juveniles eat planktonic crustaceans such as

euphausids and copepods (Hart 1973, Emmett et al. 1991). They are found at various depths in marine habitats.

Adults

The eulachon is an anadromous species, and adults spawn in freshwater rivers once a year during the late winter/early spring (Emmett et al. 1991, Striplin Environmental Associates, Battelle Marine Sciences Laboratory, and King County Water and Land and Resource Division 2000). Adults spend most of their lives in the marine environment before making spawning migrations, when they may be found near the bottom of river and estuarine channels (Emmett et al. 1991).

Current Distribution and Use

Eulachon are considered rare within Puget Sound (Emmett et al. 1991) and little current information exists on their nearshore distributions within WRIA. Puget Sound eulachon populations were designated a candidate species for listing under the ESA in 1999 (National Marine Fisheries Service, National Oceanic and Atmospheric Administration 1999).

Historic Distribution and Use

Few records document the historical distribution and use of Puget Sound nearshore habitats by eulachon.

Historical distribution data for Puget Sound fishes compiled through 1973 show only three records of eulachon within the nearshore area of WRIA 8, and all of these occur near Meadow Point (reach 2) (Miller and Borton 1980).

Pacific Sand Lance (*Ammodytes hexapterus*)

Juveniles

Pacific sand lance juveniles are pelagic and schooling, but may burrow into unconsolidated sediments at night to rest and escape predators (Emmett et al. 1991). Juvenile sand lance are primarily planktivorous carnivores (Emmett et al. 1991). Juveniles rear in bays and nearshore waters (Lemberg et al. 1997) and are commonly found in eelgrass beds (King County, unpublished data).

Adults

Adult sand lance likely move into coastal and estuarine waters during spring and summer for feeding and refuge from predators (Emmett et al. 1991). Spawning occurs once a year from November to February at tidal elevations from +1.5 m to about the mean higher-high water line on sand to gravel beaches (Pentilla 1995, Lemberg et al. 1997). Adult sand lance are planktivorous carnivores and prey heavily upon calanoid copepods (Fresh et al. 1981). In turn, sand lance are a highly important prey item for many marine vertebrates and seabirds.

Current Distribution and Use

The Pacific sand lance (known locally as "candlefish") is a common but poorly known nearshore schooling baitfish in Washington waters (Pentilla 1995). However, they are highly abundant and widely distributed throughout Puget Sound bays and nearshore habitats (Emmett et al. 1991, Pentilla 1995). Over 140 miles of Puget Sound shoreline have been documented as sand lance spawning habitat (D. Penttila, WDFW, pers. comm.).

Within WRIA 8, documented sand lance spawning beaches exist near Elliot Point, north Picnic Point, and north Edwards Points (reach 1), south Point Wells (reach 2), and south of Meadow Point (reach 3) (Lemberg et al. 1997) (Figure 18). However, just because spawning is not documented in an area does not mean it does not occur there.

Historic Distribution and Use

No data were available regarding sand lance spawning habitats in Puget Sound before 1989 (Pentilla 1995). No sand lance spawning sites were documented in WRIA 8 prior to 1991. Historic abundance and habitat distribution and use are virtually unknown.

The historic distribution data for Puget Sound fishes compiled through 1973 show sand lance distributed throughout the nearshore area of WRIA 8 (Miller and Borton 1980). Sparse records of sand lance occur from Elliot Point (reach 1) south past Edwards Point and Richmond Beach (reach 2), with a higher frequency of sand lance catches near Golden Gardens (reach 2), Meadow Point, and Shilshole Bay (reach 3). Sand lance occurred rarely (240 fish total) in monthly beach seine collections made off West Point in 1975 (Miller et al. 1976). During 1975-76 beach seine netting, 247 sand lance were caught off West Point (Striplin Environmental Associates, Battelle Marine Sciences Laboratory, and King County Water and Land and Resource Division 2000).

ALL FORAGE FISH

Reasons for Change

Increased natural mortality for herring over the last 20 years has been attributed to increased predation pressure (Lemberg et al. 1997). Individual herring stocks vary greatly in relative size and may undergo significant fluctuations in recruitment and adult survival due to variations in marine ecological conditions and prey resources, alterations in nearshore habitats, and fishery over harvest (Lemberg et al. 1997, West 1997).

No data are available for smelt, longfin, eulachon, and sand lance.

Stressors

Commercial over harvest of herring to supply bait needs and for sac-roe occur and have resulted in fisheries closures (Bargmann 1998). There is a relatively consistent *in situ* egg

mortality at certain locations in Quartermaster Harbor (Lemberg et al. 1997). The causes of these egg mortalities are as yet unknown. Surf smelt also are affected by large commercial and recreational harvests that average more than 200 tons annually (Lemberg et al. 1997). Pollution, thermal stress, and desiccation can result in egg and larval mortality (Emmett et al. 1991).

Herring, surf smelt, and sand lance have specific spawning habitat requirements, which make them especially vulnerable to shoreline development activities (Lemberg et al. 1997, Pentilla 1978, Pentilla 2000). For example, shoreline armoring has been implicated in the loss and alteration of beach substrate that supports eelgrass and forage fish spawning (Thom and Hallum 1990; Thom and Shreffler 1994). Loss of overhanging riparian vegetation along shorelines may reduce shading and result in reduced survival of these species' eggs and larvae (Pentilla 2000).

Longfin and eulachon are affected by the loss of estuarine habitats and alteration of freshwater flows (Emmett et al. 1991). All life stages are sensitive to changes in temperature and industrial pollution (Emmett et al. 1991).

Data Gaps

Reasons for increased natural mortality in herring are unclear, especially in light of the relatively low recent abundance levels of most Puget Sound herring predators.

Smelt migrations and movements of surf smelt are unstudied, and it is unclear if adults return to natal spawning beaches or exhibit fidelity to specific spawning beaches. In fact, little basic biological information exists for all forage fish in Puget Sound. Stock assessments, dietary studies, additional spawning surveys, and information about other life history requirements are needed for all forage fish (Table 17) (Bargmann 1998).

Table 17. Data gaps for forage fish.

DATA GAPS	LOCATIONS IN WRIA 8
Reasons for increased mortality of Pacific herring	All reaches
Water quality effects on nursery grounds and young-of-year	All reaches
Complete life history requirements of forage fish species	All reaches
Information on forage fish stocks and biomass	All reaches
Complete spawning ground surveys	All reaches
Quantitative data on the effects of shoreline armoring and other shoreline development on spawning grounds	All reaches
Complete spawning ground surveys	All reaches

Key Findings

- Forage fish found within nearshore marine habitats of WRIA 8 include herring, surf smelt, Pacific sand lance, eulachon, and longfin smelt. Forage fish use these habitats for feeding, migration, spawning, and rearing.
- Forage fish represent a significant component of the Puget Sound food web.

- Herring return to natal spawning grounds; egg attachment sites include firm substrates such as eelgrass and macroalgae. Sand lance and surf smelt spawn on upper intertidal beach habitats with sand/gravel sediments. All of these habitats are especially vulnerable to shoreline development.
- Within WRIA 8, there are no known herring spawning areas and only a limited number of documented surf smelt and sand lance spawning beaches. Regular spawning surveys and stock assessment are needed throughout the study area.

C. SHORELINE CONDITIONS

C.1. Shoreline Armoring

Although the term shoreline armoring is often used in reference to bulkheads and seawalls, it is used more broadly here to describe a number of different structures. Shoreline armoring is, in a general sense, the placement of structures in the nearshore in an attempt to intercept wave energy and/or control the movement of sediment. Because these structures typically are constructed of rock, concrete, wood, or metal, the practice is sometimes referred to as shoreline hardening.

Property owners armor their shorelines for a variety of reasons, including the following:

- To create areas of calm water, such as for a marina
- To stabilize entrances to harbors, rivers, and inlets
- To trap sand in an effort to control beach width
- To protect upland property from wave-induced erosion
- To retain or stabilize unstable banks and bluffs
- To create shoreline real estate by retaining fill
- To establish moorage for vessels
- To enhance property values
- To protect foundations of structures

However, shoreline armoring often fails to accomplish these goals, and can have serious unintended adverse effects upon nearshore habitats and species. Even so, shoreline armoring is widespread in Puget Sound: the recent increase in the population of Puget Sound has resulted in the armoring of more than 29 percent of the shoreline, with an additional 1.7 miles of shoreline armored each year (Canning and Shipman 1995). More than half of the shoreline of the Main Basin of Puget Sound, and 79 percent of the eastern shoreline of the central basin, have been modified as a result of shoreline armoring (Puget Sound Water Quality Action Team 2000).

Types and Distribution

There are six main types of shoreline armoring structures:

- *Breakwaters* are self-supporting structures intended to deflect or absorb waves, creating areas of calm water (Mulvihill et al. 1980;(U.S. Corps of Engineers 1984). Most breakwaters are placed in high-energy environments, are generally parallel to the shore, and are commonly built up from the seafloor with rough stone, pre-cast concrete, sheet piles, or pilings.
- *Jetties* are built perpendicular to shore, often starting landward of the high water mark and extending into the subtidal (Mulvihill et al. 1980). Jetties are constructed in an effort to stabilize entrances to harbors, bays, and rivers (U.S. Corps of Engineers 1981).
- *Groins* are similar to jetties, but serve a slightly different purpose. Property owners install groins to trap sediments, usually to increase the width of a beach (U.S. Corps of Engineers 1981).
- *Bulkheads* are vertical or near-vertical structures built parallel to the shoreline (U.S. Corps of Engineers 1981), usually of concrete or rock. Property owners construct bulkheads in an effort to protect upland property from wave-induced erosion, to stabilize banks and bluffs, to retain fill, and to create moorage for vessels (ACOE 1981).
- *Seawalls* are more massive bulkheads and generally are built in areas of moderate to high wave energy (U.S. Corps of Engineers 1981).
- *Revetments* are built either to protect foundations of structures such as bulkheads and piers or as a form of bulkhead, and most often are constructed of large rocks called riprap.

Marine shorelines of WRIA 8 are heavily armored. The ShoreZone database shows that 87 percent of the WRIA 8 is armored (WDNR, 2001). In WRIA 8, almost the entire shoreline from Shilshole Bay north is armored as a result of the Burlington Northern railroad tracks being built on the shoreline. Bulkheads and seawalls are the most common shore protection technique used in Puget Sound. Of the 87 percent of the WRIA 8 shoreline that is armored, 85 percent has a bulkhead. There are no inventories of bulkheads or seawalls with revetments in Puget Sound.

In WRIA 8, breakwaters form the outer boundaries of marinas. Edmonds and Shilshole Bay marinas have breakwaters. There are no jetties in WRIA 8. Although groins can no longer be built in Washington State, there are a few in WRIA 8. Those identified include one in Edmonds (Brackett's Landing Park) and several along the shoreline of the Magnolia neighborhood in Seattle.

Physical Effects of Armoring on the Nearshore

The WDOE Coastal Erosion Management Studies (MacDonald et al. 1994) present an excellent description of the impacts of armoring on physical processes of the nearshore environment. Much of this section is drawn from their work.

The most prominent effects of shoreline armoring on nearshore physical processes are as follows (after Macdonald et al., 1994):

- Loss of beach area from placement of structures
- Impoundment of sediment behind structures
- Modifications of groundwater regimes
- Lowering of beach elevations
- Redirection and intensification of wave energy
- Alterations of substrate
- Loss or riparian vegetation and associated functions

Each of these impacts is described below.

Shoreline armoring structures often are built at or below the high water mark, on or across the beach itself, and/or out into the intertidal and subtidal zones. One obvious effect of such construction is that these beach, intertidal, and subtidal habitats are permanently lost. Furthermore, the processes and functions that feed into, or are provided by these altered areas are interrupted.

Shoreline armoring structures, especially bulkheads, seawalls, revetments, groins, and jetties, trap sediments. Bulkheads, seawalls, and revetments often prevent sediments from moving from banks and bluffs to the beach, where longshore currents can entrain them. Groins and jetties, if built properly, interrupt longshore transport, causing sediment to accumulate on their updrift sides and be redirected offshore. As a result, shoreline armoring interrupts sediment delivery and transport in drift cells, thereby starving downdrift beaches of necessary sediments.

If shoreline-armoring structures are impermeable, they can cause alteration of local groundwater regimes. An impermeable structure such as a bulkhead can cause the water table behind it to rise, thereby increasing pore pressure in the beach material and rendering it more susceptible to wave erosion (Macdonald et al., 1994). Changes in groundwater regimes also can exacerbate landslides.

Longshore transport of sediment is a natural and healthy process in Puget Sound. However, if waves and currents remove sediments from beaches that are sediment starved, the beach will retreat landward and erode. If a seawall is built on a retreating beach, the beach in front of the seawall will continue to erode and steepen. In turn, the water in front of the seawall will deepen, gradually changing the environment from beach to intertidal or subtidal.

If shoreline-armoring structures are placed below the ordinary high water mark, they will interact with waves more frequently. Vertical structures such as bulkheads reflect waves back into the surf zone, where their energy adds to that of incoming waves to increase the rate of the erosion in front of the structure (Tait and Griggs, 1991). As a result, the beach in front of the structure narrows, and ultimately can disappear. If the structure has an end wall that anchors it to the uplands, the end wall will reflect wave energy onto the adjacent beach, causing it to erode as well. This increased erosion often encourages adjacent property owners to construct shoreline-armoring devices, creating a domino effect (MacDonald et al., 1994).

The installation of shoreline armoring does not halt the processes of erosion; as described above, armoring can intensify erosion. Waves continue to entrain sediments in front of such structures, particularly fine sediments such as silt, clay, fine sands and gravel. As a result, finer sediments are removed from areas in front of bulkheads and seawalls, leaving behind coarser sediments such as gravel and cobble. Over time this process results in a change in overall substrate character from fine to coarse sediments. Many of the beaches in Puget Sound are composed of only a thin veneer of finer sediments, underlain by a coarse material, or hardpan. Thus, the erosion of a sand/gravel beach can result in a complete loss of natural beach characteristics and associated fauna.

Many of these effects can take years or even decades to become apparent, so studying and documenting them is very difficult and rarely attempted. In addition, because many of these effects occur at locations downdrift of armored areas establishing cause and effect relationships is challenging.

Biological Effects of Armoring on the Nearshore

The physical effects of shoreline armoring discussed above lead to shifts in habitat structure and species assemblages, changes in ecological processes, and direct and indirect impacts on nearshore species and communities. Thom and Shreffler (1994) provide an excellent overview of these effects; unless otherwise cited, the information in this section is drawn from their work.

Shoreline armoring causes sediment starvation, and intensifies wave energy so that fine sediments are winnowed away, leaving behind coarse sediments and eventually bedrock, or hardpan. These changes amount to a shift in habitat structure. As a result, the species assemblages also change, from ones that favor finer sediments to those that favor coarse sediments and rocky substrates. For example, such a shift in the most common beach habitat type in Puget Sound, a mix of sand and gravel would change from an assemblage of small crustacea, bivalves, and eelgrass to rocky/hardpan communities composed of barnacles, seaweed, and other associated flora and fauna. In addition, the structures bury the organisms and habitat under the footprint of the structure, potentially reducing prey production and organic reduction for higher trophic levels.

Shoreline armoring also affects ecological processes. Because armoring can increase erosion rates on beaches, it removes areas for organic matter to accumulate. The composition of such matter also changes if armoring displaces vegetation. This organic matter provides habitat for insects and amphipods, and provides nutrients as it is converted through reduction and decomposition. Shoreline armoring can alter nutrient dynamics further if it interrupts the flow of streams to a beach or changes the groundwater regime. Freshwater carries nutrients and inorganic compounds to beaches and the intertidal zone. Shoreline armoring can affect the migration of animals, including fish. Groins and jetties that jut into the subtidal zone force juvenile salmonids and other fish into deeper waters where they may experience increased predation. Armoring also alters shade on beaches, as discussed under Marine Riparian Zones. Loss of shade on surf smelt spawning sites reduces egg survival (Penttila, 2001).

Shoreline armoring has a number of direct and indirect effects on finfish and wildlife Loss of riparian cover leads to decreases in the shade, cover, detrital input, and terrestrial prey upon which juvenile salmonids depend. Loss of wetland vegetation such as tidal marshes eliminates critical refuge, forage, and osmoregulation areas. Alterations in marine riparian vegetation lead to loss of habitat complexity, refuge, and nutrient sources. Shifts in intertidal and subtidal communities reduce nutrients and food sources for juvenile and adult fishes, such as salmonids, birds and other wildlife. Loss of shallow-water habitat and changes in intertidal communities degrade migratory corridors.

Changes in habitat structure eliminate spawning sites for forage fish and rock sole. For example, surf smelt require high intertidal sites with particular sediment sizes for spawning. They are therefore particularly vulnerable to direct loss of habitat from the construction of shoreline armoring as well as changes in substrate caused by armoring.

Aquatic vegetation, shellfish and other invertebrates also are affected by shoreline armoring. When shoreline armoring increases erosion at one point, those sediments are deposited downdrift, or offshore, and can smother aquatic vegetation and benthic infauna, changing community composition.. For example, changes in substrate can render habitat unsuitable for clam recruitment, or for the establishment of eelgrass. Habitat functions supported by eelgrass or other substrate types, such as foraging, spawning and refuge are, in turn, lost.

Cumulative Effects of Shoreline Armoring on the Nearshore

Site-specific effects of individual bulkheads include burial, beach erosion, transference of wave energies, which can result in erosion of adjacent lands, reduction of sediment input, reduced riparian functions and other associated system processes and functions. While these individual, site-specific effects may not have a dramatic impact on the overall system, the cumulative impacts within the site and throughout the system (or subsystem such as a drift cell) are likely to be much more severe. Because shorelines in WRIA 8 are heavily armored, these cumulative effects are a major concern.

Unfortunately, there currently are no quantitative studies of the cumulative effects of shoreline armoring on the ecology of the nearshore ecosystem in Puget Sound (Thom et al., 1994). Studies elsewhere have quantified some of the physical effects (e.g., Tait and Griggs 1991). The principles of landscape ecology and conservation biology should be incorporated into any future assessment.

Data Gaps

Although there is qualitative evidence for many of the effects of shoreline armoring on the nearshore ecosystem, there is little quantitative data linking shoreline armoring to physical and biological changes. Ecological changes within drift cells should be quantified, as well as the cumulative effects of these changes on WRIA 8. Table 18 lists some specific data gaps that need to be filled to better understand the effects of shoreline armoring.

Table 18. Shoreline armoring data gaps.

DATA GAPS	LOCATIONS IN WRIA 8
Quantified relationships between shoreline armoring and changes in sediment budgets	All reaches
Quantified relationships between shoreline armoring and changes in substrate	All reaches
Quantified relationships between shoreline armoring and loss of shallow-water habitat	All reaches
Quantified information on cumulative effects of shoreline armoring on intertidal and subtidal benthic communities	All reaches
Quantitative studies of the effects of shoreline armoring on juvenile salmonid feeding opportunities	All reaches
Quantitative studies of the effects of shoreline steepening on vulnerability of juvenile salmonids to predation	All reaches
Carrying capacity of armored versus undisturbed shorelines	All reaches
Effective and ecologically sound alternatives to conventional shoreline armoring	All reaches

C.2. Overwater Structures

Types and Distribution

Overwater structures in marine waters include floating docks, covered moorages, houseboats, boathouses, houses, piers, pilings, marinas, barges, rafts, booms, mooring buoys, and floating breakwaters (Nightingale B. and Simenstad C. 2000).

There is limited information on the distribution and abundance of overwater structures in Puget Sound. Floating docks, covered moorages, and mooring buoys are common around Puget Sound, but they are more common in protected embayments than along exposed shorelines. This is evidenced by the average of two docks per mile of shoreline on the eastern shore of WRIA 8 (WDNR 1999). According to the Shoreline Management Act, houseboats are not allowed anywhere in the state except limited locations in Lake Union and Portage Bay. Boathouses and overwater houses are typically associated with floating docks. Piers often serve as a connection between floating docks and the upland. Pilings are widely scattered around Puget Sound, some associated with docks and others relics of long abandoned shoreline activities. A recent survey of the Puget Sound shore found 54 piers and docks and three marinas are located along the eastern shoreline of WRIA 8. Barges, rafts, and booms are typically associated with overwater industrial activities and often are relocated to various worksites.

Effects Upon Nearshore Ecosystem

Overwater structures are typically located in the nearshore. They change the levels of light, shoreline energy regimes, substrate type and stability, and water quality (Nightingale B. and Simenstad C. 2000). These changes result in altered abundance and diversity of species in nearshore marine ecosystems. Light levels may be reduced to levels below those necessary

for photosynthesis, fish feeding, predator avoidance, schooling, and migration. Overwater structures can alter wave energy and sediment dynamics, affecting substrate size, type and stability, plant propagation, fish foraging, spawning and migration, and shellfish settlement and rearing. Overwater structures can affect the seabed, disturbing or destroying benthic organisms and vegetative growth. Construction materials can leach contaminants into the environment and boats, boathouses, houseboats, and marinas are sources of water pollution.

Docks, piers, and pilings can interfere with the light for plant growth and propagation (Simenstad et al. 1998). The area of shade created by overwater structures is related to the structure size, height, height above the water, orientation to the sun, and the construction materials ((Olson et al. 1996). Covered moorages, houseboats, boathouses, and houses can cover relatively large areas of the water surface, constantly shading the area below the structure. Fixed floating docks completely block the light to the surface, creating constant shade for an unchanging area while those anchored by chains move and allow for light penetration to areas as they are uncovered (Pentilla and Doty 1990). Marinas are groupings of individual piers, often behind a breakwater, where large areas of light reduction can occur. Barges, rafts, booms, and floating breakwaters block light and can affect plant reproduction within one week (Pentilla and Doty 1990).

Studies of marinas found fish near the shoreline and perimeter of the marina, but not in dark areas under the docks and moored boats (Nightingale B. and Simenstad C. 2000). Avian predation on fish in marinas did not appear to be related to the floating docks and moored vessels. Studies have found fewer juvenile fish under piers than in surrounding open waters and reveal that piers supported by piles interfere with the migration of fish (Able et al. 1998); (Nightingale B. and Simenstad C. 2000). The construction of piers increases turbidity and the sound of pile driving can influence fish behavior. Floating breakwaters allow for improved fish passage over conventional solid breakwaters, but their impacts on fish behavior are not fully understood (Nightingale B. and Simenstad C. 2000). When barges, rafts, vessels, and booms ground into the nearshore bottom, this can kill benthic and intertidal organisms and plants and disrupt the substrate habitat.

On the eastern shore of WRIA 8 marinas are typically located behind a breakwater, and changes in wave energy and sediment transport occur with their presence. Elsewhere, marinas may be located in embayments with low wave energy where a breakwater is unnecessary, or limited to a floating breakwater. The chains that anchor mooring buoys can scour the substrate and destroy vegetation and benthic organisms. Marinas create waters with low tidal exchange and, if phytoplankton blooms occur, low DO concentrations can result in fish kills.

In addition to the effects of overwater structures, additional impacts may occur as a result of vessels temporarily or permanently moored to those structures. Covered moorages, houseboats, and boathouses are associated with cleaning, pesticide, herbicide, paint, petroleum and maintenance products that can enter the water. Boats add additional shading, and props can scour the bottom affecting benthic organisms and plants. Boat discharges introduce contaminants and nutrients, changing the habitat that plant and animal species require (Nightingale B. and Simenstad C. 2000). The water quality of marinas is affected by

boat engine exhaust, fuel spills, sewage discharge, and contaminated stormwater runoff coming from parking lots close to the marina.

Construction and maintenance practices associated with overwater structures also result in adverse effects to aquatic habitats and species. Dredging, filling and pile driving can result in short-term and long-term disturbance, or modification of physical and biological processes. For example, dredging and construction materials (e.g. creosote treated piles) used in marine construction result in contaminant releases. Pile driving, dredging, and other practices create noise that may result in avoidance behavior by some species. Dredging and the placement of inwater structures alters sediment distribution and composition, hydrology, and biological community composition as a result of habitat alterations that occur with each construction or maintenance event. A more extensive discussion of these individual effects may be found in other sections of this report.

Data Gaps

There is limited information on the distribution and abundance of overwater structures in Puget Sound. Additional information on the effects of overwater structures on plant and animal communities is needed. Table 19 lists specific data gaps for overwater structures.

Table 19. Overwater structures data gaps.

DATA GAPS	LOCATIONS IN WRIA 8
Cumulative and site-specific effects of overwater structures on nearshore processes and biological communities	All reaches
Effective alternatives to and mitigation measures for docks and piers	All reaches
Assessments of risk to juvenile salmonids posed by delays in migration caused by disorientation, lack of schooling in refugia, and changes of migratory route to avoid overwater structures.	All reaches
Quantified relationships between overwater structures and predation rates on juvenile salmonids	All reaches

C.3 Dredging

Dredging is conducted to create and maintain slips and channels for berthing and navigation. Dredging and disposal are regulated through state and federal permit systems. Dredged material containing low levels of contaminants may be disposed at designated open water disposal sites under the Puget Sound Dredged Disposal Analysis (PSDDA) program. Dredged material that cannot be placed at an open water disposal site is required to be treated or disposed at a confined facility. Confined disposal sites are generally located in upland (i.e., landfill) or nearshore areas.

Current and Historic Dredging Sites

Very few nearshore areas of WRIA 8 are dredged. There may be maintenance dredging at Shilshole Bay Marina located in Seattle, just north of the entrance to the Lake Washington Ship Canal.

It is likely that dredging is required to maintain safe navigation at Shilshole Marina (reach 3). However, there is no record of recent dredging at this marina under the PSDDA program. The marina could have been dredged before 1988 or outside of PSDDA requirements if sediments were disposed at an upland location.

Effects On the Nearshore Ecosystem

Disruption and loss of benthic communities in the dredged area is an unavoidable impact of dredging, although recolonization generally occurs within three to five years. Benthic habitat characteristics such as elevation and grain size may be changed by dredging and result in a different biological community than that originally present. Dredging impacts on fish and mobile species that can avoid the dredging activity and turbidity plume are likely to be limited. However, the turbidity plume may contain chemical contaminants that are resuspended and may make their way into the food web. In addition, the siltation of nonmobile species can result in a loss (e.g. mortality) and disturbance of benthic communities can affect community composition and fish food supply. Possible impacts on fishes are reduced by dredging during periods when they are not likely to be present in nearshore areas.

One potential environmental impact of dredging in nearshore areas is a temporary increase in turbidity due to sediment resuspension. While mechanical dredging generally maintains most of the dredged material in the bucket in a cohesive clump, some sediment loss and resuspension into the water column occurs. Since marinas are protected from strong currents and have reduced water circulation, the majority of suspended sediment generated in the Des Moines Marina dredging projects, for example, likely remained in the immediate vicinities of the marina. While this reduced sediment dispersion into Puget Sound, it may also have lengthened the period that turbidity impacts within marinas.

Sediments at the Des Moines Marina in both 1983 and 1994 were sampled and analyzed and showed very low levels of the contaminants in question. For both projects, the dredged material was approved for disposal at a designated PSDDA open-water disposal site. Since chemical concentrations in the sediments were low, loss of contaminants during dredging was not a major concern at this marina.

Data Gaps

While the effects of dredging on nearshore habitats and species are known in a general sense, little quantitative data links dredging to changes in habitats and species. Data gaps are summarized in Table 20.

Table 20. Data gaps for dredging.

DATA GAPS	LOCATIONS IN WRIA 8
Quantitative information on the effects of dredging on benthic habitat and communities.	All reaches
Quantitative information on the potential to entrain salmonids including bull trout	
Quantitative information on the effects of dredging on other nearshore species.	All reaches

C.4. Filling

Historically, outright filling of nearshore areas was conducted to create new upland areas for development and frequently resulted in loss of wetlands, beaches, riparian zones, and other habitat. Another major historical and current source of nearshore fill is shoreline armoring, which buries nearshore habitat and sometimes retains additional fill. Beach nourishment also is a type of fill, but usually is done to restore lost nearshore habitat. Modern filling projects usually are conducted to create or restore habitat, or to cap contaminated sediments.

Current and Historic Filling Sites

In WRIA 8 the greatest source of nearshore fill has been shoreline armoring. As discussed above, WRIA 8 is 87 percent armored. Therefore, filling has occurred along the majority of WRIA 8 shorelines.

Other types of filling projects are habitat restoration and beach nourishment projects. Beach nourishment is the intentional placement of sediments in order to recreate or widen a beach. Beach nourishment restores and protects the natural beach and represents an increasingly popular "soft" alternative to traditional shoreline armoring techniques such as bulkheads and seawalls. Beach nourishment has been a key component of park enhancement in several locations within WRIA 8 including West Point in Discovery Park (reach 3-4), Meadow Point at Golden Gardens (reach 2-3), and Seacrest Park on West Seattle's Elliott Bay shoreline (reach 4).

Effects Upon Nearshore Ecosystem

The potential environmental impacts of nearshore filling include the following:

Changes in the Physical Environment

- Elevation
- Currents and circulation
- Profile or morphology (slope, angle)
- Substrate type and size

Because filling involves placement of additional materials in the nearshore environment, bathymetry and topography are altered at the site. For example, in the case of shoreline armoring, the topography of the beach changes abruptly at a bulkhead and more gradually at a revetment. These changes in bathymetry also can alter currents and circulation at the site.

Filling changes beach profile or habitat morphology. Addition of beach nourishment material widens the beach and often makes its slope gentler. Filling of habitats such as marshes eliminates the complex morphology of channels and intervening lands. If fill materials are different from the original substrate at the site, substrate types and/or sizes will change.

Changes in the Biological Community

- Displacement of and changes to existing biological communities.
- Alterations in intertidal or shallow subtidal habitat.
- Short-term exposure of plants and animals to suspended solids and reduced dissolved oxygen.

Fill materials bury existing organisms. If the changes in bathymetry or topography are significant enough, these organisms may not be able to recolonize the site and will be displaced. If the fill changes the substrate type or size, alterations in intertidal and shallow subtidal habitats ensue. As a result, the plant and animal communities on the site may shift. During emplacement of fill, plants and animals experience increased turbidity and reduced dissolved oxygen.

Beach Nourishment and Restoration Projects

It is important to note that some types of fill may have beneficial effects upon the nearshore environment. Beach nourishment projects usually are undertaken to protect upland property, and if done properly, consist of sediments similar to those that naturally would be at the site. As a result, beach nourishment projects can restore beach habitats, and as sediments erode away from the project, can provide downdrift beaches and habitats with much-needed sediments. Although nourishment projects change beach elevation and profile, and alter sediments, if done properly they restore the beach and sediments to their natural condition. Beach nourishment projects do have the same negative effects as other fill projects: they bury existing organisms, and subject plants and animals to short-term construction impacts. However, it is likely that their beneficial effects outweigh their negative impacts.

Similarly, many nearshore habitat restoration or sediment remediation projects involve some placement of fill. Because the purpose of these projects is to restore lost habitats such as marshes or to enhance existing ones, in time their beneficial effects could outweigh the negative impacts of fill.

Data Gaps

There are very few studies of the changes in physical and biological environments that may have occurred as a result of historical fill activities. In addition, few studies have quantified

the potential beneficial effects of beach nourishment and restoration projects. Data gaps are summarized in Table 21.

Table 21. Data gaps for filling.

DATA GAPS	LOCATIONS IN WRIA 8
Monitoring of beach nourishment sites to determine the effects of nourishment on sediment budgets and biota	All reaches
Assessment of beach nourishment as an option for restoring beach habitat and protecting upland property	All reaches
Quantitative estimates of the amount of nearshore habitat filled for shoreline armoring and other development purposes	All reaches
Cumulative effects of loss of nearshore habitats to filling on biota, especially juvenile salmonids	All reaches

C.5. Sewage Discharges

In WRIA 8, the primary source of untreated sewage discharges to the nearshore are from Combined Sewer Outfalls (CSOs). CSOs are discharges of untreated sewage and stormwater that flow directly into the nearshore, lakes, or streams during periods of heavy rainfall (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). These systems consist of one sewer that carries both sewage and stormwater away from development, and were built before the 1950s, when separated sewers for stormwater and sewage became mandatory. Subsequently, Metro (now King County) built pipelines to capture and transport the combined sewage to new treatment plants. CSOs remain as relief valves for when heavy rainfalls overwhelm the capacity of the sewage system. Sewage is then discharged into the nearshore in order to protect the sewer infrastructure and prevent sewage from backing up into homes, streets, and wastewater plants (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000).

Within WRIA 8, nine marine CSOs are found within the City of Seattle and King County (see Table 22). King County operates two of the nine CSO locations within the City of Seattle. The City operates the remaining seven. However, the City's pipes drain smaller basins than the County pipes do, so overflows from the City systems tend to be smaller in volume and shorter in duration than overflows from the County system.

Since the early 1980s, King County has undertaken a program to reduce the frequency and volume of CSOs. Between 1981 and 1983, King County's combined sewers discharged almost 2.3 billion gallons of combined sewage each year. As a result of several CSO control projects, King County has reduced the annual volume of CSOs to about 1.5 billion gallons (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). The ultimate goal of the program is to reduce CSOs to an average of one untreated discharge event per site per year. The City of Seattle has also done a significant amount of CSO reduction work.

Table 22. CSO Volume and Frequency: 1983, 1999 and 2005 (Based on historic CSO events and modeling completed in 1999) (Source: King County Wastewater Treatment Division and the Seattle Public Utilities Resource Planning Division).

Location	DSN[2]	Service Area	Volume Revised 1981-3 Baseline Volume (MGY)	Revised 1981-3 Baseline Frequency[1] (events/yr)	1999 Average Annual Volume (MGY)	1999 Average Annual Frequency[1] (events/yr)	2005 Average Annual Volume (MGY)	2005 Average Annual Frequency[1] (events/yr)
(2) King County Outfalls								
Carkeek Treated CSO	046	Carkeek	na	na	51	9	53	9
North Beach	048	Carkeek	6	17	6	17	6	17
(3) City of Seattle Outfalls								
Seaview NW at NW 71st St.	S056	Ballard	Unk	Unk	0	0	This aspect Has not been modeled by King County	
Seaview NW at NW 68th St	S057	Ballard	Unk	Unk	0	0		
Seaview NW at NW 57th St	S059	Ballard	Unk	Unk	0	0		
W Cramer St. at 39th Ave, NW	S060	Ballard	Unk	Unk	NA	3		
24th Ave NW at NW Market St	S150	Ballard	Unk	Unk	Not	Unk		
24th Ave NW at NW Market St	S151	Ballard	Unk	Unk	Monitored	Unk		
28th Ave NW at NW Market St	S152	Ballard	Unk	Unk	0	0		

(1) Based on 48 hour inter-event interval.
(2) DSN is the Discharge Serial Number, a unique identifier listed in the NPDES permit.

Types and Distribution

There are nine discharge points to Puget Sound north of the West Point Treatment Plant outfall (Table 22). King County operates two of the discharges and the City of Seattle operates the remaining seven. The largest of these is the Carkeek Park CSO Treatment Plant (reach 2). Discharges from this CSO Treatment Plant were modeled in 1999 and the results indicated that on average, there could be discharged as much as 51 million gallons/year (MGY) of treated effluent into the Sound during nine separate discharge events. If the trends modeled in 1999 continue it is projected that by 2005 the average volume could increase to 53 MGY in nine discharge events (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). The 1999/2000 year was actually a low rainfall year and the measured volume from the plant was actually 8 MGY during six events. The County considers this controlled. The North Beach CSO is located to the south of Carkeek Park. In the 1999 modeling exercise results indicated that there could be an average of 6 MGY discharged during 17 events. This trend was expected to continue into 2005 (King County Department of Natural Resources and Brown & Caldwell, Inc., 2000). In actuality there was 1.5 MGY discharged during 12 events.

The four City of Seattle CSOs are pumping stations. These are monitored for CSO discharge frequencies, but not volumes. Seattle considers these CSO discharges controlled. Seattle is now in the process of determining CSO discharge volumes from pumping stations by upgrading monitoring systems.

Effects Upon Nearshore Ecosystem

There have been very few studies that have dealt specifically with the effects of CSOs on the nearshore environment. Most programs conducted in WRIA 8 were further offshore and related to effluent discharges (Word et al. 1981), Cominski et al. 1984, KC DNR 1999) or to baseline studies and the potential for siting a discharge in the deep subtidal (Thom et al. 1978), (Word and Ebbesmeyer 1984).

There are five types of effects that occur as a result of CSO discharge events. The severity of the effect depends on the volume and duration of the event. These five types of effects are scouring, smothering of benthic communities, short-term pulses of bacteria, chemical contamination of water column, and chemical contamination of sediments. Scouring occurs as a result of the high volumes and velocities of discharges. If the CSO has a high organic content, this material may settle out and smother organisms in the lower portion of the nearshore immediately adjacent to the scoured area. CSOs also carry human pathogens, including protozoa, bacteria, viruses, and possibly tapeworms and round worms (Parametrix, Inc., and King County Department of Natural Resources, 1999). Elevated levels of these pathogens persist in the nearshore environment for short periods following CSOs. Chemical impacts will be discussed in general terms under Sediment Contamination.

Data Gaps

Few studies have identified and documented in a comprehensive manner the effects of discharges on the nearshore environment. Not only are studies of the effects of discharges on these ecosystems lacking, there is also a lack of basic baseline data for these habitats in general. Without this baseline information it is difficult to identify and separate impacts caused by human activity from the natural variation inherent in the nearshore. An effort should be made to identify and categorize the baseline condition of these habitats. Site-specific studies then should be conducted to examine the condition of the habitats adjacent to different types of discharges to determine if cause and effect relationships can be drawn. Data gaps are summarized in Table 23.

Table 23. Data gaps for sewage discharges.

DATA GAPS	LOCATIONS IN WRIA 8
Effects of sewage discharges on the nearshore ecosystem	All reaches
Baseline data for habitats surrounding CSOs	All reaches

C.6. Sediment Contamination

Types and Distribution

King County routinely monitors sediment quality at a variety of locations in the area north of West Point (reach 3). Table 24 presents the results of analyses for metals and organic compounds at four intertidal stations in 1997. The organic compounds reported here represent four of the primary classes of chemicals of concern. These include bis (2-ethylhexyl) phthalate (phthalates), high molecular weight polycyclic aromatic hydrocarbons (HPAH), low molecular weight polycyclic aromatic hydrocarbons (LPAH), and total polychlorinated biphenyls (PCB aroclors). The results are presented for each compound in mg/kg dry weight for metals and ug/kg dry weight for the organic compounds (Table 24). A comparison of the data to the Washington State Sediment Management Standards, Sediment Quality Standard (SQS) value for each metal and to the Washington State Lowest Apparent Effects Threshold (LAET) value indicates that concentrations are well below levels believed to be harmful to benthic ecosystems and in fact most were at or below the method detection limit.

Table 24. Data for two intertidal stations showing concentrations of selected metals and four classes of organic compounds.

		North of West Point (WRIA 8)	
Parameter	**WA SQS (1) LAET (2)**	**Richmond Beach JSWX01**	**Carkeek Park KSHZ03**
Percent Fines	NA	1	4.6
TOC (mg/kg)	NA	234	693
Arsenic	57(1)	3U	3.2U
Cadmium	5.1(1)	0.2U	0.2U
Copper	390(1)	11.4	6.7
Lead	450(1)	9.8	3.7
Silver	6.1(1)	0.2U	0.3U
Zinc	410(1)	30.9	26.1
Phthalates	1300(2)	16.7U	19.9U
LPAH	5200(2)	44.9U	53.4U
HPAH	12000(2)	44.9U	53.4U
T PCBs	130(2)	14U	16U

(1) Washington State Sediment Management Standards Chapter 173-204 WAC
(2) Washington State Sediment lowest apparent effects threshold (LAET)

Effects Upon Nearshore Ecosystem

Impacts to the nearshore community as a result of chemical contamination arise from two causes. These include organic enrichment and physiological effects of the chemicals themselves. Organic enrichment is caused by the presence of excess amounts of organic carbon, which acts as a food source for invertebrate communities. If a benthic community is inundated with a large amount of organic carbon at least two events could occur. The first is that the benthic community could be directly smothered by the excess organic carbon. The portion of the community that is not smothered will undergo the second of two events - organic enrichment. It could also result in DO depletion in near bottom waters. The effects of organic enrichment have been studied for 50 years and much is known about how enrichment affects benthic communities. If the nearshore habitat consists of sand there will be a shift in community structure from a suspension or surface detrital feeding community to one dominated by surface or subsurface deposit feeding organisms. Sensitive species (amphipods, echinoderms) will decrease in abundance while tolerant species capable of exploiting the high organic carbon availability will increase. If the nearshore habitat consists of fine silts and clays, the community may still undergo a change. There would be an increase in abundance of tolerant species that may lead to the habitat being dominated only by those species that thrive in habitats with a high organic carbon content.

Changes in nearshore communities caused by chemical contamination are more difficult to document. These effects can be masked by the presence of organic carbon, which can have a stimulatory effect on the nearshore community. Catastrophic input of chemicals into the nearshore environment will have an immediate, acute impact on the community resulting in the immediate loss of all but the most tolerant individuals. Little is known about the chronic input of low levels of chemicals to this habitat. Evidence suggests that sensitive species will decrease in richness and abundance (as described above) while there may be no change in the condition tolerant species (Word et al. 1981). However, this inference was based on an examination of the deep subtidal benthic community in the erosional environment off the West Point outfall, rather than a true nearshore community.

Data Gaps

There is a lack of basic knowledge on community-level effects from the mixtures of chemicals found in the environment (Table 25). Much is known about the effects of specific chemicals on individual species from toxicity testing, however the complex mixtures found in sediment habitats make it difficult to separate the effects of one chemical from another. This is an emerging science and rudimentary tests are available; however, their cost make them prohibitive for use in monitoring studies.

Table 25. Data gaps for sediment contamination.

DATA GAPS	LOCATIONS IN WRIA 8
Community-level effects of mixtures of chemicals	All reaches
Sublethal effects of single contaminants and mixtures of contaminants	All reaches
Relationships between sublethal effects and survival of organisms, particularly salmonids	All reaches
Characterization of sediment contamination in the subsurface	All reaches

C.7. Non-Point Pollution

Definition and Types

The U.S. Environmental Protection Agency (EPA) defines non-point pollution as pollution that does not have a single point of origin or one that is not introduced into a receiving stream from a specific outlet (EPA 2000). Residential and commercial development creates non-point pollutants that are generally carried off the land by stormwater. When land that would naturally soak up rain and natural runoff is cleared of vegetation and then covered with an impervious surface, more surface water is generated during storms. Impervious surfaces in developed areas include roofs, sidewalks, driveways, parking lots, and even lawns. Pollutants, such as nitrates, phosphates, pesticides, petroleum, sediments from cleared soil, and fecal coliform bacteria from

onsite sewage systems, are washed from the land into streams and eventually into marine waters.

Residential non-point pollution sources are associated with everyday activities such as operating motor vehicles, washing equipment and structures, fertilizing home gardens, and controlling pests. Leaking septic tanks also allow contaminants to enter groundwater that can eventually enter nearshore waters. Examples of commercial non-point pollution sources include industrial waterfront facility roofs, storage yards, and parking lots; agriculture activities; strip malls; and gas stations. Non-point pollution also results from vessel use on the surface waters of WRIA 8. Exhausts and spills associated with these activities enter the water directly. WRIA 8 has one ferry terminal (Edmonds) and three large marinas.

Effects upon Nearshore Ecosystems

Non-point pollution affects nearshore ecosystems in several ways. Pollutants contained in untreated runoff enter nearshore marine waters and degrade water quality. Clearing nearshore land may cause turbid nearshore waters. Leaking septic tanks and other non-point sewage sources contaminate shellfish beds. Exhaust, maintenance waste, and spills associated with boating activities pollute waters directly.

Some of the contaminants in surface water runoff increase levels of organic nutrients in receiving water bodies. This may lead to local eutrophication, which can intensify algal blooms, increase turbidity, and reduce DO levels, especially in estuaries. Increased growth of macroalgae species such as *Ulva* may degrade nearshore habitat by limiting eelgrass *(Zostera* spp.) distribution through competition. Eelgrass beds are ideal habitat for many nearshore species including juvenile salmonids and spawning forage fish.

Residential and commercial development may directly disturb or alter the nearshore if vegetation is cleared, reducing the filtration of non-point source pollution by riparian vegetation. Clearing vegetation along the shoreline may destabilize bluffs and, through the process of erosion, increase sediment loads into the nearshore system. In the past, pier construction for a single-family house was not tightly regulated, but cumulative effects of pier construction by many homeowners along the shoreline may harm the nearshore system through contaminant releases from construction materials and boat operations.

Almost 40 percent of Washington's shellfish beds have been closed as a result of environmental contamination. Failing septic systems, animal waste, stormwater runoff, and discharge from boats are the primary non-point pollution sources (WDOE 1998).

Commercial marinas affect nearshore habitat by increasing boat traffic and decreasing water quality. Boaters affect water quality in several ways. Small amounts of leaking oil can contaminate many gallons of water, and paint scrapings and many boat solvents are toxic to nearshore fish and wildlife (Puget Sound Water Quality Action Team 2000). Untreated sewage that is pumped overboard introduces bacteria and viruses to the

nearshore and may contaminate shellfish. Altogether, these additional forms of non-point pollution can have large negative impacts on the nearshore ecosystem.

Data Gaps

The primary data gaps of non-point pollution effects on the nearshore environment are related to the location, timing, identification, and quantification of contaminants. More investigation is needed to identify how organisms respond to contaminants. In situ monitoring using mussels and the eggs or larvae of herring and sea urchins can be used to gain insight into the sub-lethal impacts of various pollutants. Investigations related to the synergistic effects of combinations of various levels of contaminants would also be helpful in prioritizing mitigation measures and regulation enforcement.

Table 26. Data gaps for non-pollution.

DATA GAPS	LOCATIONS IN WRIA 8
Location, timing, identification, and quantification of contaminants	All reaches
Sublethal effects of single contaminants and mixtures of contaminants	All reaches

C.8. Non-Native Species

Definition

Plants and animals that are introduced into habitats in which they do not naturally occur are called non-native species. They are also known as non-indigenous, exotic, introduced, or invasive species. Non-native species have been introduced to the Puget Sound through shipping (attached to ship hulls and through discharge of ballast water), aquaculture, commercial fisheries of various kinds, and other human activities. Introductions of non-native species have been known to profoundly affect ecosystems. By competing with native species for food and habitat as well as preying on them, non-native species can reduce or eliminate populations of native species.

Distribution and List

The Puget Sound Expedition Rapid Assessment survey for non-native marine organisms, based on techniques developed in San Francisco Bay, was conducted September 8 through 16, 1998. This study found 39 non-native species in the samples collected. Of these, 11 were new records for Puget Sound and five were known but had no information previously published about them. Five species were found in Elliott Bay (the bryozoan species *Bowerbankia gracilis*, *Schizoporella unicornus*, and a *Bugula* sp., and the urochordates *Botryllus schlosseri* and *B. violaceus)* and two of the bryozoan species found at Elliott Bay.

Table 27 provides a list of 39 non-native species collected by the 1998 Puget Sound Expedition. It includes information about species' native range, first record on the Pacific Coast and in Puget Sound, and possible means of introduction.

Table 27. Origins, first records and mechanisms of introduction of 39 non-native species collected by the 1998 Puget Sound Expedition.

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Seaweed				
Sargassum muticum	Japan	1944	* 1948	OJ
Grass				
Spartina anglica	England	1961-1962	1961-62	MR
Eelgrass				
Zostera japonica	W Pacific	1957	* 1974	OJ
Foraminifera				
Trochammina hadai	Japan	* 1971	* 1971	BW, SF, OJ
Cnidaria - hydroid				
Cordylophora caspia	Black Sea and Caspian Sea	ca. 1920	ca. 1920	BW, SF
Cnidaria - anemone				
Diadumene lineata	probably Asia	1906	< 1939	OA, SF
Annelida				
Hobsonia florida	NW Atlantic	1940	1940	?
Annelida				
Pseudopolydora paucibranchiata	* Japan	* 1950	* 1993	* BW, SF
Mollusca - snail				
Batillaria attramentaria	Japan	1924	1924	OJ
Mollusca - snail				
Crepidula fornicata	NW Atlantic	1905	1905	OA
Mollusca - snail				
Myosotella myosotis	Europe?	1871	1927	OA (SB, SF)
Mollusca - bivalve				
Crassostrea gigas	Japan	1875	1875	OJ
Mollusca - bivalve				
Mya arenaria	NW Atlantic	1874	1888-1889	OA
Mollusca - bivalve				
Nuttallia obscurata	Japan, Korea (China?)	* 1991	* 1993	BW
Mollusca - bivalve				
RudiVenerupis (Ruditapes) phillippinarum (Tapes japonica, Venerupis philippinarum)	NW Pacific	1924	1924	OJ
Copepoda				
Choniostomatid copepod	?	?	1998	?
Cumacea				
Nippoleucon hinumensis	Japan	1979	* mid-1990s	BW
Isopoda				
Limnoria tripunctata	?	1871 or 1875	* 1962	SF
Amphipoda				

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Ampithoe valida	NW Atlantic	1941	* 1966	BW, OA, SF
Amphipoda				
Caprella mutica	* Sea of Japan	1973-1977	1998	BW, OJ
Amphipoda				
Corophium acherusicum	* N Atlantic	1905	1974-1975	OA, SF
Amphipoda				
Corophium insidiosum	N Atlantic	1915	* 1949	OA, SF
Amphipoda				
Eochelidium sp.	Japan or Korea ?	* 1993?	1997	BW
Amphipoda				
Grandidierella japonica	Japan	1966	* 1977	BW, OJ, SF
Amphipoda				
Jassa marmorata	NW Atlantic	1941	* 1990?	BW, SF
Amphipoda				
Melita nitida	NW Atlantic	1938	* 1998	BW, OA, SB, SF
Amphipoda				
Parapleustes derzhavini	* W Pacific	1904	1998	SF
Entoprocta				
Barentsia benedeni ?	Europe	1929	1998	OJ, SF
Ectoprocta (Bryozoa)				
Bowerbanki gracilis	NW Atlantic?	<1923	<1953	OA, SF
Ectoprocta (Bryozoa)				
Bugula sp. 1	?	?	1993	?
Ectoprocta (Bryozoa)				
Bugula sp. 2	?	?	1998	?
Ectoprocta (Bryozoa)				
Bugula stolonifera	NW Atlantic	<1978	1998	SF
Ectoprocta (Bryozoa)				
Cryptosula pallasiana	N Atlantic	1943-1944	1998	OA, SF
Ectoprocta (Bryozoa)				
Schizoporella unicornis	NW Pacific	1927	1927	OJ, SF
Urochordata (Tunicata)				
Botrylloides violaceus	Japan	1973	1977	OJ, SF
Urochordata (Tunicata)				
Botryllus schlosseri	NE Atlantic	1944-1947	* 1970s	OA, SF
Urochordata (Tunicata)				
Ciona savignyi	* Japan	1985	1998	BW, SF
Urochordata (Tunicata)				
Molgula manhattensis	NW Atlantic	1949	1998	BW, OA, SF
Urochordata (Tunicata)				
Styela clava	China to Sea of Okhotsk	1932-1933	1998	BW, OJ, SF

Source: Cohen et al. 1998
* = Correction to information in Cohen et. al. 1998, the Puget Sound Expedition Report.
< = First records consisting of written accounts that do not state the date of planting, collection, or observation.
( ) = Parentheses indicate less likely mechanisms.
OA = with shipments of Atlantic oysters
OJ = with shipments of Japanese oysters
SF = in ship fouling or boring
SB = in solid ballast
BW = in ship ballast water or seawater system
MR = planted for marsh restoration or erosion control

Table 28 lists non-native species known to be established in Puget Sound, but that were not collected by the 1998 Puget Sound Expedition. This list is incomplete and is not intended to be an all-inclusive list.

Table 28. Origins, first records and mechanisms of additional non-native species in Puget Sound.

General Taxon	Native Range	First Pacific Coast Record	First Puget Sound Record	Possible Mechanism of Introduction
Grass				
Spartina alterniflora	NW Atlantic	1910	1910	MR, SB
Grass				
Spartina patens	NW Atlantic	< 1930	?	MR
Cnidaria - hydroid				
Bougainvillia muscus (= B. ramosa)	N Atlantic	1975	1981	SF
Cnidaria - hydroid				
Cladonema radiatum	NW Atlantic and Mediterranean	1988	1988	SF, BW
Platyhelminthes				
Pseudostylochus ostreophagus	Japan	1954	1954	OJ
Annelida				
Neanthes succinea (cosmopolitan)	?	1896	1998	OA, SF
Annelida				
Streblospio benedicti	N Atlantic	1932	1998	OA, BW, SF
Mollusca - snail				
Cecina manchurica	Japan, China	1961	1961	OJ
Mollusca - snail				
Ceratostoma inornatum	Japan	1924	1924	OJ
Mollusca - snail				
Crepidula plana	W Atlantic	1901	1930s	OA
Mollusca - snail				
Urosalpinx cinerea	NW Atlantic	1890	1929	OA
Mollusca - bivalve				
Musculista senhousia	Japan, China	1924	1924	OJ
Mollusca - bivalve				
Mytilus galloprovincialis	NE Atlantic Mediterranean	1940s	1980s	SF
Copepoda				
Mytilicola orientalis (= M. ostreae)	W Pacific	1938	1946?	OJ
Copepoda				
Pseudodiaptomus inopinus	Asian N Pacific	1990	1991	BW

Source: Cohen et al. 1998
< = First records consisting of written accounts that do not state the date of planting, collection, or observation.
OA = with shipments of Atlantic oysters
OJ = with shipments of Japanese oysters
SF = in ship fouling or boring
SB = in solid ballast
BW = in ship ballast water or seawater system
MR = planted for marsh restoration or erosion control

Selected Species

Zostera japonica

Known as Japanese eelgrass, *Zostera japonica* reproduces like many other seagrasses. Flowering and pollination occur underwater. Seeds are produced, often in great quantities. The growth of an eelgrass meadow occurs by vegetative spread with the extension of the rhizome and the germination and growth of seedlings. A seagrass must have four properties to exist in the sea. It must be adapted for life in a saline medium, be able to grow when completely submerged, have an anchoring system to withstand wave action and tidal currents, and have a capacity for hydrophilus pollination.

While Japanese eelgrass colonizes previously unvegetated mud flats, improving grazing opportunities for waterfowl, it also competes to a degree with native eelgrass (*Zostera marina*) and changes the structure and diversity of the invertebrate community within the sand or mud. *Z. japonica* is found in WRIA 8.

Spartina spp.

Commonly known as cordgrass, *Spartina* is an invasive grass that is well established in many areas of Puget Sound. Three species of *Spartina* have been introduced to Western Washington. *Spartina* grows tenaciously in the intertidal area of mud, sand, or mixed sand/pebble marine beaches. It reproduces both with seeds and massive runners, which makes it a difficult plant to control.

Spartina grows in dense colonies that trap sediments and raise the elevation of tideflats, thereby reducing and/or changing the invertebrate population and eliminating the availability of the area for feeding by shorebirds and fish. *Spartina* chokes out native vegetation, does not provide food or habitat for many native animals, and can even increase flooding. It occurs at a few locations along the shorelines of WRIA 8.

Copepods

Copepods are tiny shrimp-like creatures that live throughout the ocean and on the ocean floor, as well as in association with other animals. Because they are so small, free-living copepods can feed only on small food items such as bacteria, diatoms, or other unicellular forms. Eggs produced by the female copepod are carried in clusters in one or a pair of egg sacs attached to the base of the abdomen. Males often have a modified first antenna that is used in copulation. Copepods live relatively long lives for their size (weeks-months). They can be grazers of phytoplankton when small, carnivorous when large, and a few are parasites. Eleven molts take place between 12 different life stages: 6 naupliar, 5 copepodite, and a single reproductive adult stage. In general, for each copepodite stage, another body segment is added.

Copepods are key organisms in the food chain. If non-native copepods out-compete or prey on native species, it may weaken other species that depend on native copepods for

food. For example, juvenile fishes depend on copepods during critical stages of their life histories.

Sargassum

Commonly known as Japweed, *Sargassum muticum* is a brown algae that originates in Asia. It is tolerant of wide temperature and salinity ranges. This species has both male and female parts in the same individual and is self-fertile. Fertile branches of adult algae produce gametes. When the ova are released, they are not broadcast into the surrounding water like most algal gametes, but remain attached to the receptacle. After fertilization, the zygotes continue to grow on the parent for several days before dropping to the ocean floor. The enveloping mucilage protects them from environmental stress. Their large size also allows them to settle rapidly, and the well-developed rhizoids adhere quickly to the substrate. This results in young plants settling near the parent (within 3 meters), where conditions are likely to be favorable (Monterey Bay Aquarium Research Institute 1999). A holdfast can also regenerate fronds. Fertile branches lead to long range dispersal. *Sargassum muticum* is a bushy plant that can shade out competitors.

For five decades *Sargassum* species have been known for their invasive colonization that competes with native perennial brown algae. Faunal communities on *S. muticum* were compared with those on *Laminaria saccharina*, a native alga displaced by *S. muticum* (Osborn 1999). *S. muticum* is able to support a more abundant and species-rich community than the native alga *L. saccharina* because of its high degree of morphological complexity. Only two species never occurred on *S. muticum* that were common on *L. saccharina,* whereas 15 species were common on *S. muticum* but never found on *L. saccharina*. Abundance of fauna increased as *S. muticum* biomass increased over time. The particulate load on *S. muticum* was heavy and consisted primarily of diatoms. Epibiont diversity and abundance increase in areas invaded by *S. muticum* because of the increased habitat, productivity, and complexity that *S. muticum* provides. Furthermore, it should be noted that *Sargassum* is commonly used by herring as spawning substrate throughout the Puget Sound basin (D. Penttila, WDFW, personal communication). For these reasons, eliminating *S. muticum* is not recommended based on the impact *S. muticum* has on epifauna and its potential for providing herring spawning substrate. However, *S. muticum* may negatively affect water movement, light penetration, sediment accumulation, and anoxia at night. Further research is needed before management decisions can be made regarding *S. muticum*, which occurs in WRIA 8.

Other Species

Other significant non-native species include the oyster drill (*Ceratostoma inornatum*), varnish or dark mahogany clam (*Nuttalia obscurata*), and the European green crab (*Carcinus maenas*).

The oyster drill preys upon young oysters, significantly decreasing oyster survival and profits from oyster beds. The varnish clam was introduced into the Strait of Georgia around the early 1990s and is now widespread there; however, its impact on native

bivalve species remains unassessed. The green crab, reported in Willapa Bay in 1998, is a voracious predator that feeds on many types of organisms, particularly bivalve mollusks (clams, oysters, and mussels), polychaetes, and small crustaceans. If it becomes established, it may have a significant impact on the state's clam and oyster culture industries, as well as the commercially important Dungeness crab fishery.

Data Gaps

The Puget Sound Expedition was conducted over only a brief period, and much of its work is provisional. Additional taxonomic work and review is needed. There is a need to do more sampling in low salinity areas and to expand research into the waters of British Columbia. Additional information is needed on smaller organisms, such as amphipods. Relationships of these organisms to the native food chain and microhabitats need further understanding. Much work needs to be done to understand the nature of these invasions and potential solutions to impacts.

NEARSHORE CONCLUSIONS AND RECOMMENDATIONS

The objective of this study was to provide a reconnaissance-level understanding of the nearshore ecosystem on the eastern shore of WRIA 8 for the purpose of guiding nearshore watershed planning and salmon recovery actions in WRIA 8. Because this was a reconnaissance-level effort, it is likely that not all of the published and unpublished literature on the region was covered. Furthermore, the general lack of nearshore ecosystem data limited our ability to provide a more in-depth review and analysis.

Where necessary, information from sources outside of WRIA 8 was included for the development of a more complete understanding of the nearshore environment. Most of the species, ecosystem processes, habitat types, and stressors found in WRIA 8 occur in other areas as well and, in some cases, have been better studied in other areas. Furthermore, the nearshore ecosystem is only a part of a larger landscape that requires looking beyond watershed and geopolitical boundaries for an understanding of how it functions, what influences natural functions, and how that translates into an understanding of ecosystem health.

The conclusions and recommendations sections of this chapter were developed by members of the Nearshore Technical Committee to summarize and interpret the meaning of this reconnaissance-level assessment and to provide recommended actions that are likely to lead to improved ecosystem health, based on an understanding of the ecosystem and influences of anthropogenic stressors. In order to draw conclusions and recommendations from the report, and for interested parties to understand the context, it is important to understand the approach used in preparing the report and the guiding principles and assumptions made in the development of conclusions and recommendations. The approach used is provided in the introductory section of the report. The assumptions used to generate conclusions and recommendations include:

- The development of conclusions and recommendations uses “Best Available Science”, defined as a combination of direct studies, professional expertise and experience, and the application of fundamental ecological principles (e.g. the linkages between processes, structure, and functions).
- The nearshore ecosystem is an integral part of the watershed and is influenced by both upland/upriver processes and marine processes (it is viewed as a part of the continuum across the landscape).
- Humans exhibit an increasing power/ability to modify natural ecosystem processes, structure and functions to the detriment of living resources.
- Modification (e.g. introduction of chemical contaminants, habitat alteration, resource extraction) of natural ecosystem processes and structure is likely to result in shifts in species composition, viability, and productivity.
- Improving the nearshore ecosystem is likely to be good for salmon because of their dependence on properly functioning nearshore conditions for feeding, refuge, migration and physiological transition.
- Regional and global-scale factors, such as climate variability, also influence the nearshore ecosystem.

The objectives in developing conclusions and recommendations include the following:

- Elucidate what we know about the nearshore.
- Identify particular communities, populations, or other elements of the ecosystem that require special attention.
- Identify additional information that is needed to improve our understanding of the ecosystem.
- Recommend actions that will preserve, protect, and enhance the nearshore ecosystem.
- Recommend actions that will enhance our understanding of nearshore ecosystem processes, structure and functions.
- Provide an honest, meaningful and realistic assessment and predictions about the present and future health of the nearshore ecosystem. The assessment and predictions need to be revealing about the potential consequences of our actions and activities, or lack thereof, in light of our current understanding.

This chapter was written from a technical perspective to provide technical guidance. Therefore, every effort was made to avoid evaluation and interpretation of political, policy, and social considerations in both the report and in the conclusions and recommendations. However, some social values (e.g. human health and safety, commercial value) are identified but were not evaluated in this report. These considerations are the responsibility of other groups that may use this report in their planning and policy deliberations.

CONCLUSIONS

1) The nearshore ecosystem plays a critical role in support of a wide variety of biological resources, many of which are important to the people of the region for commercial, recreational, cultural, aesthetic, and other social values.

These resources include the physical characteristics as well as numerous species of shellfish, fin fishes, birds and other wildlife. Resources such as bivalves are common on beaches and flats. A large number of fish species use nearshore habitats for feeding, refuge, migration, and reproduction. Juvenile salmon preferentially feed on prey produced in the nearshore habitats including subestuaries, flats, beaches, riparian zones, kelp, and eelgrass meadows. These habitats are far removed from salmon spawning areas, which have been the focus of salmon life history and strategies for protection of critical salmonid habitat. However, nearshore habitat clearly plays an important role in the support of these highly migratory species through both direct and indirect mechanisms. For example, the riparian zone bordering the nearshore provides a direct source of prey for salmon and shade that enhances beach conditions for spawning forage fish and other species that use upper intertidal zones.

Temporal and spatial variability in habitat structure are controlled by a number of processes in the nearshore ecosystem. Similarly, nearshore biological resources are dependent upon a set of processes that regulates the abundance, diversity, and productivity of the various habitats that the resources use. For example, substrate composition plays a critical role in the abundance and distribution of infaunal bivalve populations and forage fish spawning. If sediment structure is significantly modified, bivalves and forage fish will no longer use these areas. Physical processes, such as erosion and deposition of sediments, are forced by wave and current energies that regulate sediment composition in an area. Modification of these force factors and other conditions will necessarily result in a modification of substrate and the species that utilize a particular habitat, or substrate type.

2) The viability of the nearshore system processes that support these resources has been damaged and continues to be threatened by a wide variety of human-induced changes.

The essential habitat-forming and many fundamental ecological processes have been severely damaged throughout much of the study area. Factors that have contributed include overwater structures, dredging, filling, shoreline armoring, shoreline vegetation removal, chemical and bacteria contamination, organic matter and nutrient loading, resource extraction (e.g. sport and commercial harvest, logging activities, mining), land-use practices (e.g. commercial and residential development, roads, bridges, transportation facilities), commercial activities (e.g. shipping, wastewater disposal), and recreational activities and support (e.g. boating, marinas). Major losses because of dredging and filling have occurred in Shilshole Bay, but losses have occurred in other areas as well as a result of development and land use practices. In many cases, multiple stressors are affecting shoreline areas.

Shoreline modifications have occurred over an exceedingly high percentage of WRIA 8 nearshore habitats, and represent one of the larger impacts on the nearshore ecology of the region. Numerous studies and reports have identified anthropogenic causes of habitat loss and degradation, species declines, and the needs for improving resource management and ecosystem health. While improvements have been made in some areas, the general condition of the nearshore environment continues on a downward trend due to a lack of attention, inadequate resources, and inadequate response to warnings and recommendations for improvement.

3) The cumulative effects of multiple stressors, or individual stressors over various temporal and spatial scales, on the nearshore system are unstudied in a systematic way.

Despite a good foundation for conceptual approaches and an understanding of the links between shoreline structural alteration, physical processes, and biological functions, there is a surprising gap in our documentation of ecological changes (Thayer et al. 1975). Furthermore, neither historical baseline nor current monitoring data provide the basis for understanding the magnitude of this change or threshold for cumulative impacts (Canning and Shipman 1995). In order to restore nearshore systems, it is essential to better understand the interaction of multiple stressors on the ecosystem.

4) The interactive effect of human-caused changes and natural variability on processes and resources has not been studied.

Consideration and documentation of natural versus human-induced stressors on the nearshore ecosystem are sorely needed. The underlying causes of poorly understood phenomena, such as widespread declines in herring stocks and reductions in salmon body size, may become clearer through such studies. The fact that both human and climate-related factors may play a role is only speculative at this time. In many circumstances, we lack the mechanistic understanding to judge what is natural versus what is not natural in forcing variations we see in the nearshore ecosystem.

Although generally not proven yet, natural variations in climate and water properties may have a strong influence on nearshore processes and resources. For example, the 1982-1983 El Nino produced dramatically different plant and animal species composition in the Seahurst area. This was documented only because there was an intensive baseline study under way at the time related to the siting of a new sewage outfall in the region. This study provided evidence that the nearshore ecosystem in Puget Sound is subject to broader factors, and that these factors may not be detectable without prolonged baseline monitoring in place.

5) Monitoring the performance of restored systems and baseline studies in reference areas are critical to the development of appropriate restoration strategies.

Although not a topic of this chapter, restorative actions are resulting in improvements to the nearshore ecosystem. Simenstad and Cordell (2000) summarize a limited, but important data set that proves restoration can yield positive results with regard to juvenile salmon. However, in general, restoration and enhancement monitoring have been inadequate for providing guidance on appropriate techniques and long-term successes. Few restoration and enhancement projects have been designed and monitored at the appropriate temporal and spatial scales. Furthermore, few projects integrate the full suite of ecosystem functions and processes into design and monitoring. This is often the result of inadequate information, funding, and an opportunistic approach to restoration. The end result is that the success and value of restoration efforts remains in question. Monitoring programs must be rigorous, set within the proper context and scale, and coordinated between agencies and other parties, and their results must be disseminated.

6) ***There are numerous data gaps in our understanding of the nearshore ecosystem that directly inhibit or weaken our ability to make informed decisions regarding management and restoration of the system. Monitoring programs are limited and have been inadequate for providing the level of scientific information necessary for informed resource management decisions.***

Resource monitoring is the responsibility of multiple entities that are often not adequately funded, or well coordinated. We cannot accurately assess what might be termed a "properly functioning estuarine or nearshore system" without filling many of the data gaps. Studies to refine metrics in an integrative way are decades behind efforts in freshwater streams and rivers. Recent work initiating the use of models (e.g.: Ecosystem Diagnosis and Treatment (EDT) model) for assessing the role of the nearshore system in the life history of salmon has revealed substantial uncertainties in our knowledge base. There is a clear need to conduct more studies on the use of nearshore systems by juvenile salmon and improve our understanding of how the nearshore integrates with freshwater, upland, and oceanic systems.

Specific information is necessary in developing habitat management plans and restoration projects. For example, while we have some understanding of the functions, we have no direct studies on the importance of large woody debris in the nearshore system, a topic of extensive study in stream and river ecosystems in recent years. Hence, there is limited information for generating recommendations on the restoration and management of backshore areas where woody debris is found. Additionally, in the Northwest, very little empirical information has been collected on the functions of riparian vegetation in estuarine and other nearshore areas. As a result, the related roles of LWD, shading, organic and litter recruitment, prey production, sediment and water filtration, and microclimates in the survival and growth of juvenile salmonids and other nearshore-dependent species have not been well defined.

7) There is a general lack of coordination in the collection, analysis, and dissemination of nearshore data.

Nearshore data must be coordinated and disseminated. Although a number of research and monitoring programs are being carried out (e.g. WDFW, PSAMP, various Tribes, and the University of Washington have collected data sets for nearshore fish species), there is rarely any synthesis and may be little coordination among components of the program. Sometimes data are collected and not analyzed. In other cases where data have been collected and analyzed, information dissemination to other resource agencies is often lacking, and accessibility and retrieval may be difficult. We cannot point to an integrated ecosystem monitoring program in WRIA 8 at this time. A conceptual model has been developed for Puget Sound (PSAMP 2000) that does include part of the nearshore system, but is lacking important elements of the upper intertidal and the terrestrial/aquatic interface (e.g. beaches, backshore, bluffs, and riparian areas). Furthermore, this model, along with other conceptual models, needs to be expanded and refined for describing the various elements and ecological relationships within the system. Such models, in conjunction with a larger management framework, are essential for developing monitoring and assessment programs. Most recently, the Nearshore PRISM working group has been developing a numerical model. This model, if developed fully, will greatly aid in our understanding and management of the nearshore system.

8) The nearshore system of Puget Sound needs more focused attention with funded research.

Basic information on ecology and population trends of many fish and invertebrate species is lacking, as is good historical baseline information on habitat conditions. Many scientists complain that they are pressed to answer very large and important questions about salmon recovery, but they lack the data to provide defensible responses due to a lack of context and availability of sufficient data. It is clear that until more attention is placed on the nearshore, there is a real risk that mistakes will be made in terms of management and the expenditure of funds for habitat restoration and salmon recovery.

9) The nearshore must be addressed from an ecosystem perspective.

The nearshore environment is influenced by a plethora of factors, both natural and anthropogenic, due to its placement in the larger landscape. Factors that effect oceanic, freshwater and terrestrial systems individually, all come together in a “great mixing bowl” to create a unique environment in the Puget Sound nearshore. Understanding all of the unique characteristics and complexities is a tremendous task that will take many years of dedicated, well-coordinated research and analysis. However, this will require a shift from our approach of single-species, or single-habitat management to an integrated ecosystem approach. For example, we need to understand that land-use practices along our shorelines have direct and indirect influences on the nearshore ecosystem (e.g. loss of vegetation, changes in sedimentation, water quality, and hydrology). These influences result in changes such as habitat structure, food supply and other elements that can reduce

the viability of multiple species within the system. Other factors, such as dams and water withdrawals, geographically far removed from the nearshore, can dramatically influence sediment supply and salinity in subestuaries, which in turn changes vegetation communities, habitat structure and species composition. The nearshore is therefore not only part of an individual watershed, but is also the thread that binds together multiple watersheds. Thus, it is imperative that we not only understand the nearshore ecosystem as a unique "marine" system, but that we also look across the landscape to determine how the nearshore interacts with influences from other distinct ecosystems.

10) Action is needed in the nearshore.

Numerous studies and reports have previously identified the problems facing the nearshore environment (e.g. PSWQA 1988a,b; Shreffler and Thom 1993; West 1996; WADOE 1994; Broadhurst 1998; Lynn 1998; PSWQAT 1998; WADNR 2000; PSWQAT 2000), and have drawn conclusions similar to this report. Yet, while state and federal agencies, tribes, and other stakeholders have long recognized the importance of Puget Sound resources and the effects of anthropogenic impacts, the response to previous recommendations for improved protection of resources has been lacking. Protection, restoration and recovery actions have lagged while the human population and development have increased dramatically. The lack of appropriate and adequate levels of protection has led to significant declines of nearshore species and habitats. The most obvious signs of loss include the Endangered Species Act listings of Hood Canal Summer Chum salmon, Puget Sound Chinook salmon, Bull trout, a petition to list Coho salmon and 18 marine fishes, and a proposal to list the system's top predator, the orca whale.

11) Particular attention and protective standards need to focus on communities, populations, or other elements of the ecosystem that require special attention.

Salmon populations are only one example. While salmon have become the major driver for our recent planning and assessment work, due to regulatory (i.e. ESA) and social demands, they are certainly not the only indicator of ecosystem health and may or may not be the best indicator. They may, however, be a useful indicator due to their complex life history and utilization of the landscape. While freshwater reproduction and rearing is critical to their survival, it is also important to emphasize that most Pacific salmon are marine fishes that are dependent upon good estuarine and marine habitat conditions and prey resources. This dependency requires us to pay particular attention to other elements in the ecosystem. For example, forage fishes (e.g. surf smelt, sand lance, herring) are important prey for salmon and a multitude of other marine species, yet we have no population data for surf smelt and sand lance and do little to protect their spawning habitat. Likewise, it has been suggested that harpacticoid copepods, another primary prey item of juvenile salmonids, may be an ecologically meaningful organism for determining environmental quality in nearshore environments (Cordell and Simenstad 1988).

Other examples of nearshore ecosystem elements that play important roles and should be protected include: eelgrass and macroalgae, which provide critical habitat functions for

multiple species; natural erosion of banks and bluffs, a critical habitat forming process; and crab, clam, and other invertebrate populations or communities that play important roles in the nearshore ecosystem, for which species composition and life history data are limited. These are but a few examples and, as in the rest of this report, are not intended to be exclusive of other species, populations, communities, and other elements of the ecosystem. As stated above, establishing more baseline monitoring and assessment, understanding ecosystem linkages, and understanding impacts of anthropogenic influences are critical to identifying the most important elements of the ecosystem and providing recommendations for protection. In other words, the selection of particular elements within the ecosystem, or other actions, must be made in the proper context.

RECOMMENDATIONS

Based on the findings and conclusions, it is apparent that there are a number of general and specific actions that need to be taken to better understand and protect individual elements within the ecosystem and the nearshore ecosystem as a whole. For example, it is clear that a number of anthropogenic influences are responsible for habitat loss and species declines. Yet, we lack adequate levels of scientific investigation to fully understand and describe all of the complex ecosystem linkages to provide specific remedies for maintaining or restoring "proper functioning conditions" for all elements, at all levels within the ecosystem. Therefore, it is imperative that we identify and prioritize the most critical data gaps, habitats, species, and ecosystem processes for in-depth analysis. This will require the development of criteria and protocols for evaluating each of these elements prior to analysis. In addition, it is also imperative that we take early actions to prevent further harm and not wait as additional scientific information is generated. Early actions come in many forms and range from the development of a coordinated technical framework and conceptual models to conservation, restoration, and protection actions or standards. It is apparent that historical protection measures have been inadequate. Therefore, protection is the most important early action that can be taken, for without it, degradation will continue and future restoration, scientific investigation, and other efforts to understand and restore the ecosystem will likely not reach recovery goals. Furthermore, the cost of protection, in terms of biological and economic costs, is low relative to the cost of restoration. This is a particularly important concern because restoration methodologies are not well studied and costly restoration projects are poorly monitored for success. Monitoring and adaptive management must be integral elements of both short-term and long-term action agendas to allow for the integration of new information.

The following action recommendations are divided into specific, non-prioritized categories. Many of these actions may be, and should be, taken simultaneously to restore the nearshore ecosystem. Although this report was written for a specific geographic area, many of these recommendations apply elsewhere and will require coordination and implementation on a larger scale to restore nearshore ecosystem conditions.

Monitoring and Research

- Develop, fund, and implement a coordinated monitoring and research program for the nearshore. This will require careful resource considerations (e.g. staff and funding at appropriate levels) and participation from entities outside of King County to address issues at the appropriate temporal and spatial scales.
- Develop a technical framework for understanding how the nearshore fits into the landscape of WRIA 8 and Puget Sound as a whole.
- Establish/support the development of a consortium of entities concerned with the nearshore environment and develop a long-term funding source for nearshore research and projects.
- Develop criteria and protocols for monitoring and assessment that may be used at various temporal and spatial scales that are widely accepted and may be used for research, protection, preservation, enhancement and restoration.

Habitat Protection, Enhancement, and Restoration

- Protect existing undeveloped shoreline areas in WRIA 8 from development practices that would be detrimental to the nearshore ecosystem. Develop protection, acquisition, and incentive strategies for lands that would contribute to maintaining or restoring ecosystem processes and functions to the benefit of nearshore ecosystem health.
- Protect eelgrass and macroalgae beds from the adverse effects of shoreline modifications such as dredging, filling, overwater structures, armoring, and pollution.
- Protect and enhance marine riparian vegetation. In the development of standards for protection, restoration, and enhancement, consider multiple functions.
- Protect forage fish spawning areas and other upper intertidal habitats and species. Concentrate restoration and enhancement efforts on areas with shoreline armoring and other development practices that reduce ecological processes and functions that support habitat quality.
- Develop a restoration strategy for the WRIA 8 nearshore that takes an ecosystem perspective within the landscape and helps to build our knowledge of the nearshore environment. Ensure that restoration projects and studies build upon a technical framework developed for the nearshore.
- Identify critical areas for protection, restoration, and enhancement in WRIA 8. Then protect, restore, and enhance them.
- Recreate intertidal acreage such as marshes, flats, and other habitats.
- Restore and recover estuarine intertidal flat and marsh habitat. Initial considerations should focus on appropriate salinity regimes and elevations, but should also consider other ecosystem processes in developing a functional design.
- Reduction of Shoreline Modifications

Shoreline Armoring

- Reduce the amount of existing shoreline armoring in WRIA 8, and prevent new installations of shoreline armoring.
- Restore natural physical and biological processes lost as a result of shoreline armoring and other bank stabilization practices.
- Determine and restore natural drift cell processes, specifically sediment budgets (e.g. rates, volumes, distribution). Feeder areas are particularly important. Where sediment supply is unimpeded, protect it. Where it is impeded, restore or enhance it at the appropriate temporal and spatial scale. Prevent the loss of sediment supply from armoring and other structures (e.g. jetties, groins) within the drift cell.
- Develop and implement technical guidance for alternatives to traditional shoreline armoring that maintain natural shoreline processes and functions.

Filling

- Reduce the amount of existing shoreline fill that has resulted from shoreline development practices and shoreline armoring.
- Prevent new fill in the nearshore.
- Where existing fill is removed, restore the area to low-gradient habitats such as flats, marshes, beaches and backshore.

Overwater Structures

- Protect and enhance light penetration in the nearshore, including areas under existing overwater structures.
- Reduce the amount of existing overwater and in-water structures.
- Eliminate the use of construction materials and construction practices that may release environmental contaminants into the aquatic environment (e.g. treated wood products such as pilings and other structural components of docks and piers).
- Remove existing sources of environmental contaminants (e.g. treated piles and old floats).
- Eliminate obstructions to migratory corridors in the nearshore, including both in-water and overwater structures.

Water Quality

- Identify and control non-point pollution sources.
- Reduce, or preferably, eliminate point-source contaminants.
- Develop innovative methods of stormwater treatment, such as projects that use plantings of native vegetation to filter stormwater and retain sediments while improving fish and wildlife habitat.

Non-native Species

- Monitor and prevent the introduction and spread of non-indigenous and invasive species. Identify and eliminate sources of introductions.

Recreational Impacts

- Eliminate habitat impacts associated with the harvest of nearshore species and other recreational uses of nearshore habitats.

As a final note, the ability to improve nearshore ecosystem health and address the recommendations contained in this report will require a number of changes in the way we as residents and stewards live in this system. Recognizing and acknowledging the influences that we have on the processes, structure and functions of this ecosystem are critical to the development of meaningful avoidance and protection standards. Providing adequate resources and a framework for the development of new information, management strategies, restoration, and preservation will require a large-scale, coordinated effort that integrates various management efforts and crosses jurisdictional boundaries. Taking an ecosystem approach to understanding and managing nearshore resources is essential. These are but a few of the necessary elements that are needed to improve the quality of the nearshore ecosystem for all that depend on it.

Despite the fact that there have been changes in regulatory and management practices, and our level of scientific knowledge has increased in recent years, the effects of urbanization have continued to take a toll on nearshore resources. It is revealing to review environmental regulations, or mitigation actions and compare them to the level of protection they have actually provided in the nearshore environment. Considering the levels of habitat loss and degradation in the nearshore, they have proven to be inadequate. These concerns are not new, as are most of the conclusions and recommendations found in this report. For example, upon review of past proceedings of Puget Sound Research Conferences (1988; 1991; 1995; 1998; 2001), these issues surface time and time again. Likewise, reports from the Puget Sound Water Quality Authority (1990), Puget Sound Water Quality Action Team (e.g., Broadhurst 1998; West 1997; Lynn 1999), Puget Sound/Georgia Basin Task Force (1994), WADNR (2000), and WDFW White Papers (e.g. Williams et al. in prep; Nightengale and Simenstad in prep), identify habitat losses and causes of habitat degradation. Interestingly, the problems, findings and recommendations contained in PSWQA (1990) apply just as much today as they did then. The list of problems and findings from this report are listed below:

PROBLEMS

- There is no systematic fish and wildlife habitat inventory for Puget Sound basin.
- Habitat protection in Puget Sound is frequently limited by gaps in interagency coordination and program integration.
- We lack an ecosystem approach to habitat management in the Puget Sound basin.

- We lack state and local goals and policies for habitat protection in Puget Sound with incentives to achieve that protection.
- The public lacks awareness, understanding, and involvement in habitat protection issues and programs.
- Enforcement of existing habitat protection laws in Puget Sound is inconsistent.
- We lack funding for current and new programs that protect fish and wildlife habitat in Puget Sound.

FINDINGS

- We lack clear state and local goals and policies for habitat protection in Puget Sound.
- A number of problems need to be jointly addressed and solved by a number of agencies, governments, tribes, organizations, and individuals currently involved in actions affecting the management and protection of fish and wildlife habitat.
- Agencies responsible for managing fish and wildlife habitats in Puget Sound do not have sufficient authority to adequately protect these habitats.
- The public lacks awareness and understanding of habitat protection issues and programs in the Puget Sound area.
- We lack adequate public involvement in issues relating the protection of fish and wildlife habitat in Puget Sound.
- The resources for staffing adequate habitat review, inventory, monitoring, enforcement, and education efforts are currently inadequate.

Hopefully, the integration of nearshore environments into watershed plans, the recent petitions to list marine species under the ESA, and the recent listings of salmonids (chinook salmon, summer chum salmon, and bull trout) under the ESA will bring additional attention, resources and efforts to preserving, protecting, and restoring the nearshore ecosystem.

HIRAM M. CHITTENDEN LOCKS and SALMON BAY

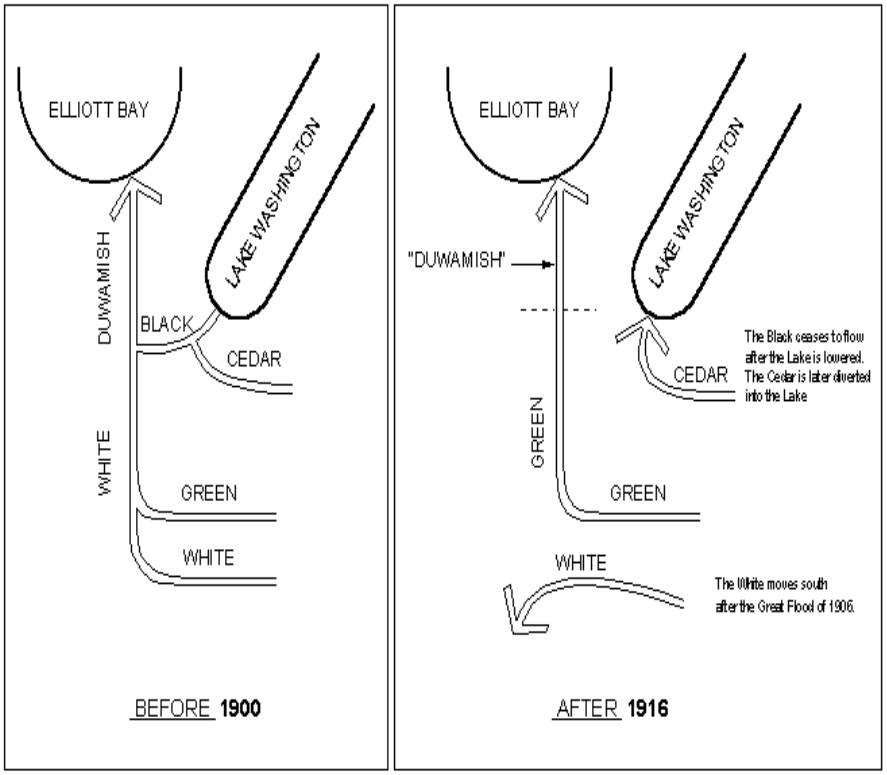
HIRAM M. CHITTENDEN LOCKS and SALMON BAY

A. Physical Description

Locks

In 1916 the Ship Canal was completed, resulting in the rerouting of the outlet of Lake Washington from the Black River through the Lake Washington Ship Canal (Ship Canal) and the Hiram M. Chittenden Locks (Locks). One of the results of this project was the lowering of the surface of Lake Washington an average of 9 feet from 30 feet to the mean elevation of Lake Union, 21 feet. Although completed in 1916, the U.S. Army Corps of Engineers (USACE) Seattle District did not officially authorize the Locks as a navigation project until 1917. The rerouting (Figure 19) resulted in moving the estuary outlet for Lake Washington from the Duwamish River to the Ship Canal and into Salmon Bay.

Figure 19. Configuration changes to freshwater input into Lake Washington prior to 1900 and after 1916 (Source: Dunne and Dietrich 1978).



The Locks is the outlet of the Lake Washington basin. The Lake Washington Basin is a sub-set of what is referred to as the Cedar - Sammamish Watershed. The Lake Washington Basin includes Lakes Union, Washington, and Sammamish, as well as their associated rivers, tributaries and landscape features. The Locks are located at the west end of the Ship Canal within the city of Seattle, King County, Washington. The Locks are located at the entrance to Salmon Bay, which is 1.2 miles from the Greater Puget Sound estuary. The Ship Canal includes Salmon Bay, the Fremont Cut, Lake Union, Portage Bay, the Montlake Cut, Lake Washington's Union Bay, and ends at Webster Point in the Laurelhurst Neighborhood of Seattle. Freshwater begins at the Locks and the adjacent dam, which controls the water levels Lakes Union and Washington.

The Locks were originally built with a log-weir fish ladder and included a series of six spillway bays to pass excess freshwater inflow. The spillways are used to maintain the elevations of Lakes Washington and Union between 20 and 22 feet above mean low low water (MLLW) within a historic reliability of 70 percent. Total storage between the normal operating levels of 20 and 22 feet is 46,424 acre-feet (ac-ft) of water, with a total water surface area of 23,464 acres and a shoreline of about 80 miles at the 22-foot elevation. Lake Washington alone is considered the second largest natural lake in Washington State with a surface area of 22,138 acres.

The Ship Canal is approximately 8.6 miles long. Below (west or marine side) the Locks is navigation channel that is 34 feet deep at MLLW and approximately 300 feet wide from Salmon Bay to the Burlington-Northern Railway Bridge located just west of the Locks. The passing basin from the Railway Bridge to the Locks is approximately 34 feet deep and 150 to 200 feet wide from the bridge to the Locks. Above the Locks (east of freshwater side), the designed channel is 30 feet deep at the Fremont and Montlake cuts at low pool, with bottom widths of 100 feet from the Locks to Lake Union through Fremont Cut; 200 feet wide through Portage Bay; 100 feet wide through Montlake Cut; and 200 feet wide through Union Bay to Lake Washington. Revetments protect the banks of both the Fremont and Montlake Cuts.

The Locks were constructed as a navigation project, with a small and large lock, to provide commercial boat traffic from the marine waters of Puget Sound to the protected freshwater waters of the Ship Canal and Salmon Bay. Currently, the Locks pass up to 70,000 vessels per year with peak passage occurring between May and October. The original project purpose and design did not include specific features to pass downstream migrating salmon and steelhead smolts.

Physical separation of the freshwater in Lake Washington for the marine waters of Puget Sound has resulted in one of the most modified estuary systems on the West Coast of North America.

Salmon Bay

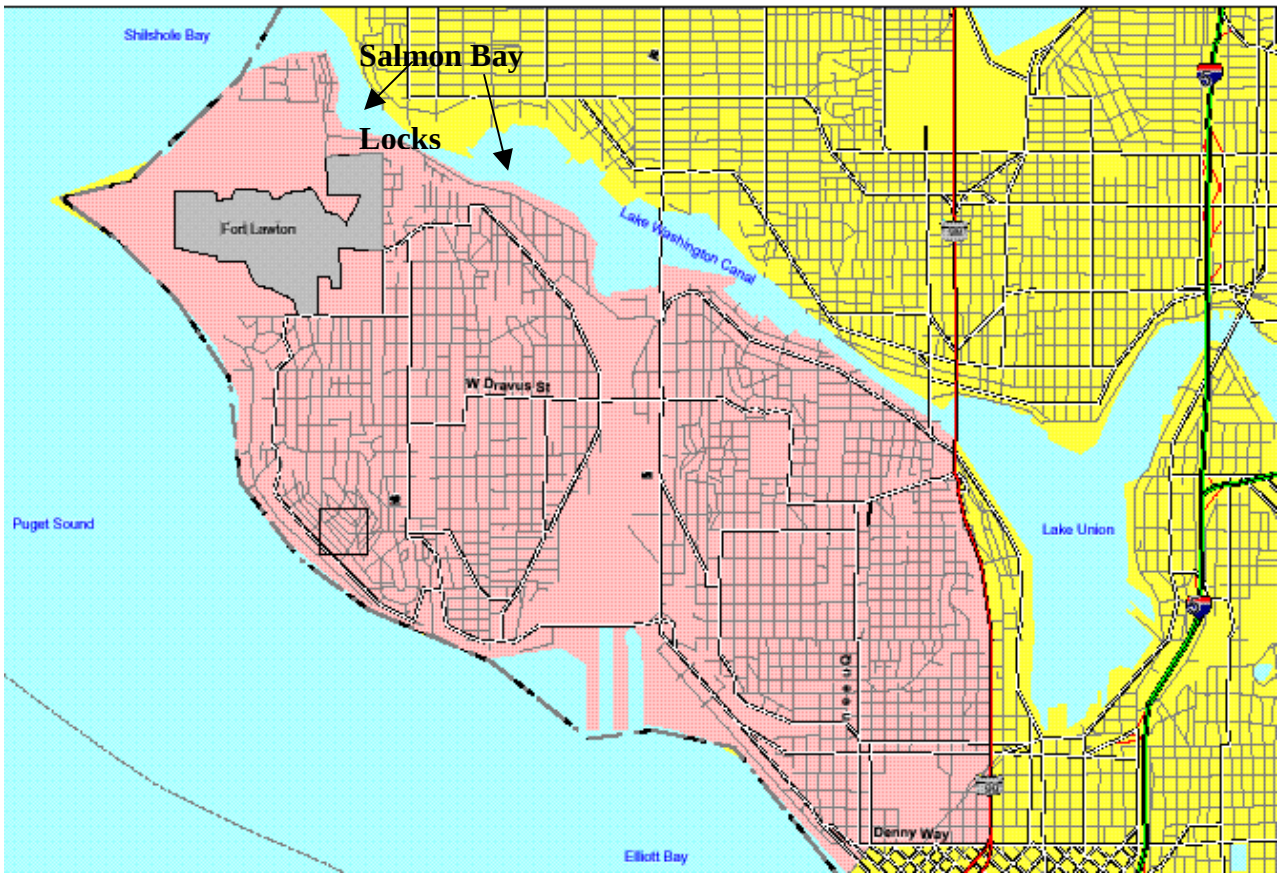
Salmon Bay, at the western end of the Locks, was originally a long, shallow, tidally inundated, saltwater bay that opened to the Puget Sound estuary. Early maps indicate a

small stream (now the Salmon Bay waterway) drained from Lake Union into Salmon Bay. In the late 1800's, this original stream had been dredged, straightened and widened to allow for the transport of logs between Salmon Bay and Lake Union. With completion of the Lake Washington Ship Canal, the Fremont Cut, and Salmon Bay waterway, a navigable connection between Lake Union and Salmon Bay was established (Weitkamp et al 2000).

Historically, Salmon Bay was a long, shallow, tidally inundated, saltwater bay that opened to Puget Sound and had tidal elevations equal with Puget Sound. At low tide, it was practically dry, the water level dropping as much as 20 feet (6.1 m) between extreme high and low tides (Williams 2000), but averaging 8 foot (2.4 m) fluctuations between high and low tide. Salmon Bay connected to Shilshole Bay through The Narrows, where the Locks were eventually placed. Early maps indicate a small stream (Ross Creek) drained from Lake Union into Salmon Bay. In the late 1800's, this original stream had been dredged, straightened and widened to allow for the transport of logs between Salmon Bay and Lake Union. With completion of the Lake Washington Ship Canal, the Fremont Cut, and Salmon Bay waterway, a navigable connection between Lake Union and Salmon Bay was established (Figure 20).

Today, the mile-long Salmon Bay waterway between the Locks and Shilshole Bay serves as the “estuarine” area with the Locks creating for migrating adult and juvenile salmon an abrupt transition between fresh and marine waters. This area is not an estuary formed by river action and associated deposition, but was historically influenced by tidal action up to the Fremont Cut. As a result, this area lacks the diversity of habitats and brackish water refuges characteristic of other (unaltered) river estuaries and over 1,300 acres of shallow water and wetland habitat were lost from the implementation of the Locks and Ship Canal (City of Seattle 2000).

Figure 20. Location of the Locks, Salmon Bay (Lake Washington Ship Canal) and Lake Union.



Physical Structures

The following section provides details on physical structures at the Locks (Figures 21-23). This discussion is considered necessary for the Locks sub-area as these structures are passageways, holding and rearing areas for all adult and juvenile salmon produced within the Cedar - Sammamish Watershed.

Large Lock. The large lock is 825 feet long between the upper and lower service gates, 80 feet wide, and divided into two chambers by an intermediate gate; the downstream (lower) and upstream (upper) chambers are 375 feet and 450 feet long, respectively (Figure 21). The intermediate gate can serve as either an upper or lower gate as needed when the entire lock is not required for ship transit. The filling and emptying of the lock chambers is achieved through the use of the side

Figure 21. Plan view of the Hiram M. Chittenden Locks Project**.**

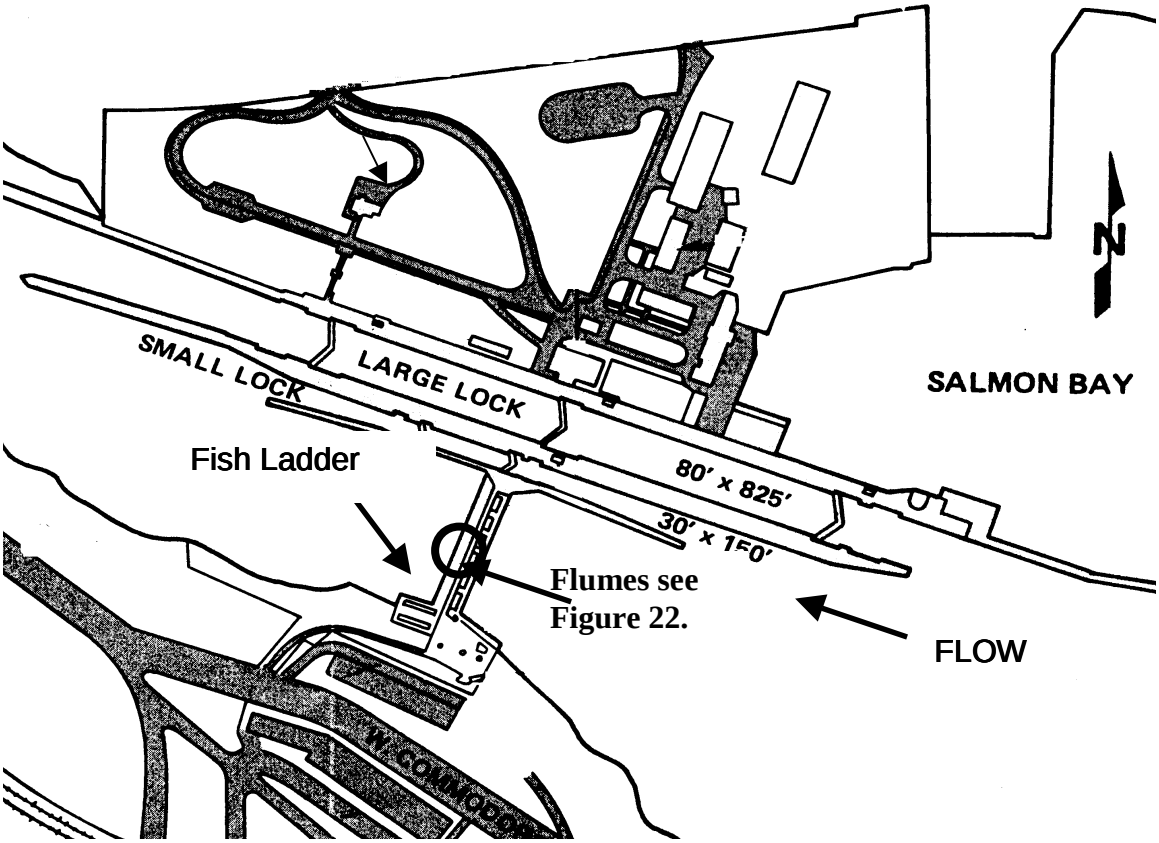


Figure 22. Plan view of the Locks including low flow volumes per outlet.

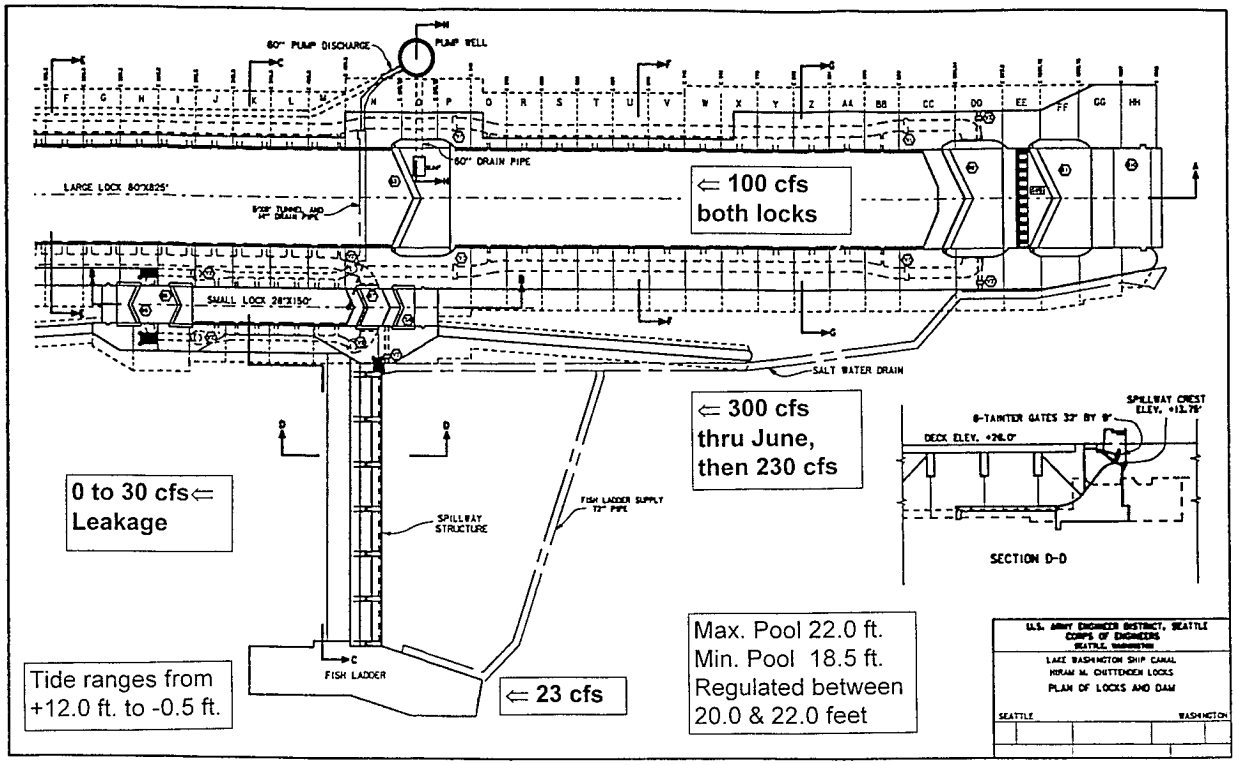
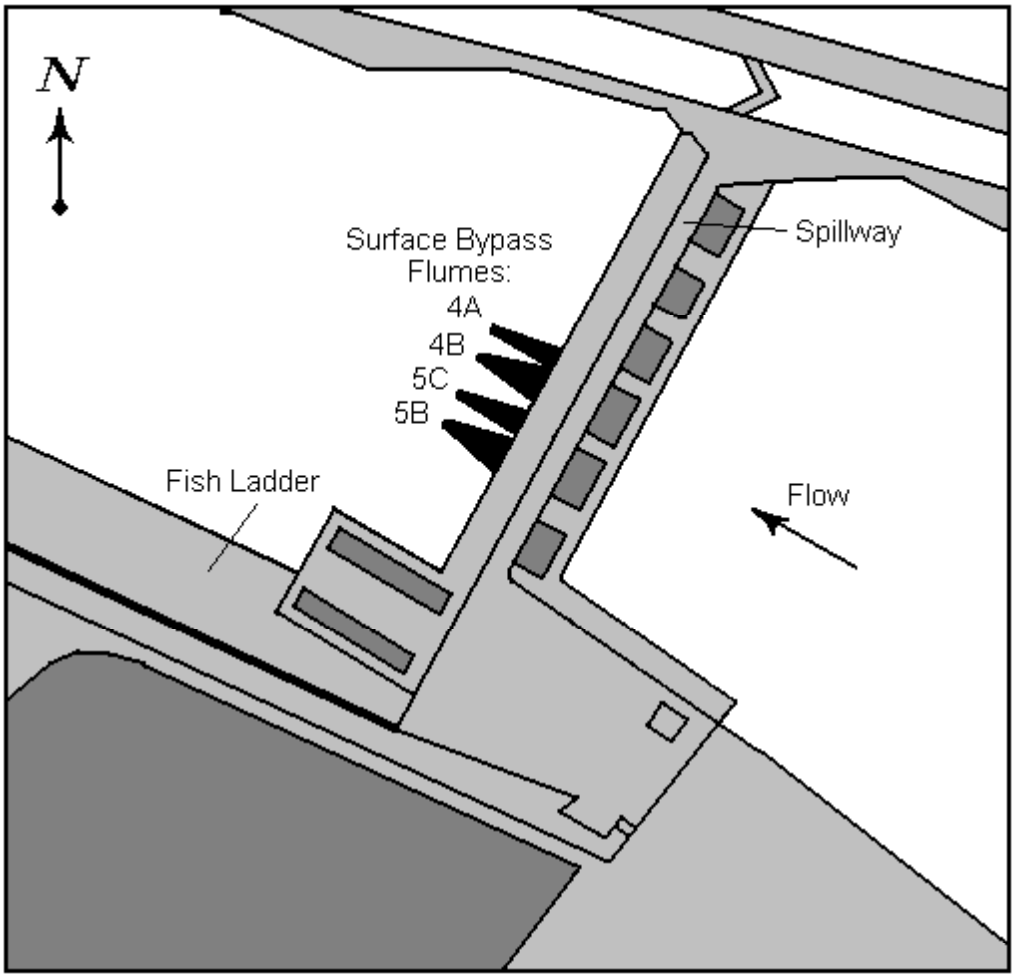


Figure 23. Plan view of the spillway showing location of the smolt passage flumes. Flume Number and Flow Volumes are as Follows -- 4a - 50 cfs (a.ka. no. 1), 4b - 130 cfs (no. 2) , 5c – 95 cfs (no. 3), and 5b 130 cfs (no. 4).



port system. This system includes two 14 feet high by 8.5 feet wide, 900 feet long, oblong conduit running longitudinally along each side of the lock (east-to-west on the north and south walls of the lock). Water is taken into these conduits via two 14 feet x 16 feet culvert intakes located immediately upstream of the eastern most miter gates. Water conveyed through each conduit is discharged into the lock chamber through lateral (outlet) culverts. There are 22 outlet culverts per side of the chamber, each 2 feet by 4 feet, with an additional 4 lateral, 6 feet by 2 feet. Barnacles cover over 80% of all conduit surfaces, increasing in area along the conduit from 1) top to bottom and 2) east to west (going towards saltwater). Three Stoney gate valves control fill in each conduit, six total, which are located so that either lock chamber can be operated independently. These valves are number 1 through 3 going east to west, respectively. In November of each

year, the large lock is dewatered for annual maintenance and debris removal. Maximum use of the chamber occurs between May and October.

Salmon smolts become entrained (pulled) into the culvert intakes during the fill cycle and injured as they are passed through the conduit system (WDFW 1996; USACE 1999). Since 1997, and again in 1999, the filling period of the large lock has been progressively extended in an attempt to reduce the smolt entrainment and injury rates. Slow fill procedures are now a standard operating procedure for the large lock but are at the maximum extent of slowing fill due to limitations in the valve system (USACE 1999). To provide further flexibility in reducing fill, all six original valves are planned for replacement in 2002 with a hydraulic, variable speed system. To further reduce entrainment, strobe lights were installed around the intake perimeter in November of 1999. These lights have not been in operation as yet due to equipment problems with the flashheads. The USACE is currently considered rejecting the system; contingency plans have not been fully developed as yet.

One option to add further protection if the strobe lights are rejected would include further reducing the fill rate of the lock chamber. The current fill rate (a.k.a. as intermediate fill) began in 1999, at 10 minutes, is 100% longer than the standard fill rate (SOP) or first slow fill procedure begun in 1997, 5 minutes. In 2003, after the new valves are installed, the fill rate could be further extended anywhere from another 5 to 10 minutes, 15 to 20 minutes total time.

Saltwater Drain. The saltwater return system consists of the saltwater drain and fish attraction (auxiliary water supply) diffusion pipe (Figure 22). The fish attraction diffusion pipe was added to the saltwater drain in 1976. The saltwater drain segment that is downstream of the diffusion pipe became known as the “old” saltwater drain. The inlet for the saltwater return system is a 48 feet wide by 4 feet high opening at the bottom of the Ship Canal (47-51 feet depth) at the east end of the large lock south wall. During rehabilitation of the intake in the late 1970s, a trash rack was originally placed at the entrance (intake) of the drain to minimize debris and prevent fish from entering the drain and fish ladder system, but since has been removed (about 1980) because of continual clogging problems. After entering the inlet, saltwater return flow is conveyed westward back toward Puget Sound through a 5 feet by 6 feet concrete, closed conduit to a point just east of the dam structure. Here a “Y” joint splits the flow with part of it proceeding west through the old saltwater drain and exiting via a gated spillway between the south wall of the small lock and spillway gate number 1. Between 1980 and 1994 a fish exclusion screen was attached to the outlet (downstream) of the old saltwater drain to prevent adult salmon from entering the drain at high tide. The screen was removed in 1994 when salmon smolts were found impinged on the upstream side of the screen. Since 1994, the drain has been operated to minimize use at higher tides to reduce adult entry in the drain.

The saltwater drain has a discharge capacity of about 300 cfs. Normally, 160 cfs is discharged inside the lower part of the fish ladder and the rest is released through a separate portal, the “old” saltwater drain. During the low flow period, the 160 cfs going

to the fish ladder is used, but the 140 cfs that is released through the old drain is shut off at night or during high tides. The daily average discharge is then approximately 230 cfs after the end of June. This volume (230 cfs) represents about 67% of all water used (330-350 cfs total) during the low flow season.

Fish Ladder. The present fish ladder, located on the south side of the spillway, was completed in 1976 and is designed to operate within fish passage criteria at Lake Washington elevations of 18.5 to 22 feet (USACE datum), and Puget Sound tidal elevations of –0.5 feet to 12 feet (MLLW datum). The fish ladder is 8 feet wide, with 3 adjustable weirs at the fish exit, 18 fixed weirs with submerged orifices, 1 adjustable and 1 fixed slot in the entrance, and 6 bottom diffusers to provide transportation and attraction water (auxiliary water supply). The ladder is designed to operate with about 23 cfs ladder flow (freshwater from the forebay) and a maximum of 160 cfs attraction supplied from the saltwater drain (183 cfs total flow). During low flow conditions from July through October the fish ladder uses over 50-60% of the total water budget (330-350 cfs) for the Locks. Prior to rehabilitation of the current ladder less than 10% of the water budget was used for adult fish passage.

Smolt Passage Flumes. Prior to 1995, little or no water was spilled over the dam during most days in June and July. In 1995, at the request of the WDFW and NMFS, the Locks built and installed a low-flow smolt bypass (smolt slide or smolt passage flume), the smolt slide that used 20-25% the water volume (80-100 cfs) of a 1.0 foot gate opening (400-450 cfs). This flume was installed each year by mid-April and operated for as long as water was available during 1995-1999. In 2000, the prototype flume was replaced with four smolt passage flumes capable of passing a total of 405 cfs or nearly equivalent to a 1-foot gate opening.

Each year, two to four flumes will be installed in spillway bays 4 and 5 (Figure 23) during early to mid April. These flumes were designed and built as part of the Lake Washington Ship Canal Section 1135 Smolt Passage Project in conjunction with fish passage engineers and biologists from the WDFW and NMFS. The flumes were built to design criteria supplied by both agencies. Two flumes are of equal size and discharge, 6 feet width and 130 cfs, the other two flumes are incrementally smaller at 4-feet, 95 cfs, and 2-feet, 50 cfs. The flumes are numbered by spillway bay (4 or 5) and by size (a, b, or c) with the following combination going north to south 4a (50 cfs), 4b (130 cfs), 5c (95 cfs), and 5b (130 cfs) (see Figure 23). Each flume can be open or closed independently, thus giving a large range of available flow combinations from 50, 95, 130, 180, 225, 260, 285, 310, 355 and 405 cfs. Further, during reduced flow, flumes can be turned on for selected time periods, such as day vs. night or for selected peak daytime migration periods.

Water Quantity/Water Use/Water Quality and Circulation

The following section provides details on water quantity/use at the Locks and altered water circulation patterns. This discussion is considered necessary for the Locks sub-area as the Locks is the water control point for the basin for freshwater releases out and

saltwater intrusion into the Ship Canal. Water quantity use through various outlets has direct implications on effective juvenile and possibly adult fish passage, for providing or not providing functional value to the estuary areas below the Locks, and for saltwater intrusion into the Locks.

The Locks is the control point in managing the elevations of Lakes Washington and Union. Active storage space in the two lakes is limited to the upper two feet, 20-22 feet, with a maximum volume of 46,424 ac-ft. The historic reliability of maintaining the lake elevation is 70%. The lowest elevation ever reached is 18.8 feet in 1958. As elevations fall below 20.0, potential damages to infrastructure increase at an increasing rate beginning at or near 19.5 feet. Each 0.1 feet elevation below 20.0 feet provides an additional 2,500 ac-ft of water storage. The Lake Washington General Investigation (GI) Study is investigating the feasibility of changing the reliability of the current minimum lake elevation (20 feet).

Maintenance of the lake elevations is dependent on two items: 1) the inflow from tributaries located upstream and within the two lake basins; and 2) water use at the Locks. The Cedar River provides approximately 50% (663 cfs) of the mean annual flow into Lake Washington. The drainage area for the Cedar River at Renton is 184 square miles, which is about 30% of the watershed area at the Ship Canal. Through its water storage and supply activities on the Cedar River, the City of Seattle provides considerable influence over the stream flows in lower 35 miles. The Masonry Dam, above Cedar Falls captures run-off from approximately 43 % of the Cedar River Basin and at Landsburg Dam, RM 21.8, the city diverts between 25-30% of the total annual river flow for municipal water. The Sammamish River is the largest tributary to Lake Washington based on drainage area (240 square miles), which is approximately 40% of the Lake Washington watershed. The Sammamish River provides approximately 25% (or 307 cfs) of the mean flow (USACE 1999). The remainder of Lake Washington inflow comes from a variety of small creeks, mainly on the north and east shores. Until 1967, METRO effluent discharge provided about 30 cfs inflow into the Lake at Renton. Water conservation use at the Locks is one of two primary project purposes of the Lake Washington GI Study.

All freshwater leaves the Lake Washington system through the Locks. Figure 22 shows a plan view of the significant outlet features. Planned water use at the Locks during low flow periods (May to October) and prior to addition of smolt passage flumes (pre-flume, see below) was 420 cfs before June 30 and 330-350 cfs from July 1 to September 31: currently, spill is <u>not</u> a programmed water use with a guaranteed reliability of use during low flow conditions. Both locks together pass a daily average of 100 cfs before July 1 and from 80-100 cfs during summer months. Together, the Locks use about 25% of the planned water budget. The fill of the chambers is accomplished with the filling culverts inside of each lock wall. The two large lock culverts combined can pass a maximum of 5,000 cfs (1500-2500 cfs/conduit) for a few minutes when the lock is being filled. This large variation from the daily average discharge has implications during the smolt migration period. Downstream migrating fish tend to travel in the direction of flow. During periods with spill, the process of filling a lock chamber with high discharges,

even for a short period, may attract many fish that would otherwise swim to and over the spillway. Prior to 2000, in periods without spill, entrainment into the conduits may have been the primary means for passing juvenile salmonids through the project.

Returning saltwater to Puget Sound is the greatest water use at the Locks. The saltwater drain has a discharge capacity of about 300 cfs. Normally, 160 cfs is discharged inside the lower part of the fish ladder and the rest is released through a separate portal, the "old" saltwater drain. During the low flow period, the 160 cfs going to the fish ladder is used, but the 140 cfs that is released through the "old drain" is shut off at night or during high tides. The daily average discharge is then approximately 230 cfs after the end of June. During the low flow season, May-October, the drain uses approximately 67% of all planned water use at the Locks.

The fish ladder passes a constant 23 cfs (freshwater) and is augmented by the 160 cfs auxiliary water supply (brackish water) from the fish ladder. After July 1, combining the total volume of water used, the fish ladder passes from 50-60% of all planned water use at the Locks.

Spill, either through spillway gates or smolt passage flumes is not a programmed water use as the volume of water available for spill is highly unpredictable depending on the year and season. The Locks has a historic leakage volume that varies between 0 to 30 cfs: between 1987-1992 leakage was reduced to less than 3 cfs. Since May of 1995, the prototype smolt passage flume has been used periodically during summer months. Prior to installation of the flume, most years there was no water spilled during June and July. In 2000, the prototype was replaced with four new low flow flumes.

The frequency of available spill volume for the flumes is illustrated in Figure 24 where 1) 10% of the time there is no available spill after the first week of June; 2) 30% of the time spill ends by the third week of June; 3) 50% of time about 100 cfs is available during July; and 4) 30% of the time 250 cfs is available and 10% of the time 400 cfs is available in July. If smolt passage flumes were programmed for use in July at the current full capacity of the flumes, running all 4 would use 110% more water than the planned pre-flume water budget (350 cfs) for the Locks. In 2000, three of the four flumes were operated continuously from May 16 to June 29 (330-355 cfs; volume varies depending on lake elevation) and from June 30-July 14 one flume (about 95 cfs) was operated for varying periods of time.

The amount of available water for spill varies tremendously during different smolt migration seasons. Figure 30 shows the generalized migration timing for salmon smolts migrating through the project. Coho and sockeye salmon migrate during late spring while chinook salmon start later and migrate up to 5 weeks later. The available volume of water for spill is typically less than 100 cfs when the peak migration and estuarine rearing period of juvenile chinook salmon occurs (mid June to early July; see below). To illustrate the reduction in available water from late spring to early summer, -- during 2000 from May 16 to June 29, spill passed through the smolt passage flumes and spillway

gates used from 48-80% of all available water, while from June 30-July 14, 4-30% of all water was used to run one flume.

In contrast to the laminar flow input of freshwater into a natural estuary, freshwater enters the saltwater below the Locks either over the spillway, through the fish ladder, or in a series of pulses during lock operation: brackish water enters from the saltwater drain. The fish ladder provides a continuous low flow of brackish water throughout the year below the Locks. During summer months, the amount of freshwater flowing over the spillway is limited by reservoir storage capacity and available inflow and normally a freshwater lens is not maintained. Similarly, saltwater enters the freshwater above the locks in pulses during the operation of the Locks. The extent to which saltwater travels up the Ship Canal and into Lake Union is primarily controlled by outflow at the Locks and the frequency of lock operations. With each eastbound locking ("up-lockage"), denser salt water migrates into the Ship Canal. The saltwater barrier and drain partly prevents saltwater intrusion from moving upstream. However, during the summer period when the boat traffic is heavy, the saltwater drain cannot keep up with the amount of saltwater entering the freshwater system, and a salt wedge intrudes into Lake Union and up to the Montlake Cut (USACE 1999). The Ship Canal is strongly stratified, with salt up to ~ 6 practical salinity units restricted to near-bottom (Simenstad et al. 1999).

Although exchange of water above and below the Locks does occur, the Locks physically separate the freshwater and saltwater system and freeze the location of the high salinity gradient (low salinity above the Locks, high below). The exchange of freshwater and saltwater occurs predominantly in pulses resulting in unusual circulation patterns within the estuarine portion of the Ship Canal, which is unlike typical estuaries that have uniform flow. In Shilshole Bay, salinity structure is highly stratified, with a freshwater lens, which is typically less than 1-2 meters in depth, and limited to areas immediately west of the Locks (Simenstad et al. 1999). Salinity immediately below the Locks is approximately 10-29 parts per thousand (ppt), depending on the volume of freshwater spill. A surface lens of relatively low salinity water may occur in the area immediately downstream from the Locks, however most of the water has a relatively high salinity. During periods of low freshwater flow, the salinity gradient becomes more severe and, as mentioned previously, no freshwater lens is formed.

When performing an east bound lockages or uplocks (from Puget Sound into Lake Washington) salt water enters the Ship Canal. It is has been a long standing concern that if enough salt water were allowed to enter Lake Washington it would create density stratification and possibly affect the ecosystem within the Lake (USACE 1999). It is for this reason the Washington Department of Ecology (DOE) has imposed a special condition that salinity shall not exceed one ppt at any point or depth along a line that transects the canal at the University Bridge. Saltwater at full salinity is 30-40 ppt, reduced salinity is 18-30 ppt, low salinity is < 18 ppt, and freshwater is < 0.5 ppt with water between 0.5 to 30 ppt called brackish.

An unusual component of uplockings, is the periodic introduction of cold, saline, dense salt water into otherwise freshwater Ship Canal (subsequent return through the saltwater

intake and drain system). As discussed above, this introduction has always been considered a degradation of the system, intrusion into a freshwater system, and results in the greatest water use at the Locks to control this degradation. A rethinking of this standard concept has occurred in the past two years as focus has shifted to investigations of basin change impacting the migration of chinook salmon. One unprecedented finding of initial investigations, is the identification that probably all adult chinook salmon in Lake Washington watershed use this small area (about 2 surface acres) for periods of days to 1-½ months (Fresh et al. 1999; 2000; HTI 2000). In mid-summer, this area is the only stratified part of the Ship Canal, with lower temperatures, and higher dissolved oxygen (DO) content (below 8 m) than all areas in the Ship Canal/Lake Union System for up to 6 miles upstream. It is now coined the "cool water refuge" and is increasingly considered a critical habitat feature for minimizing stress and possible mortality of adult chinook salmon restricted to using this area by high temperatures and low DO levels upstream (see below, Factors of Decline, Temperature).

The Locks are the sole source of salt entering the Ship Canal (via eastbound lockages through the small and large locks). The large lock requires about 25 times more lake water (86,000 m^3) than the small lock to fill and allows about 25 times more salt water to enter the Ship Canal during each lockage. Compared to the large locks the amount of salt entering the system via the small locks is insignificant. The Lake Washington GI Study is investigating changes in lock operation as a means of conserving water use to provide more flow for juvenile fish passage. Conversely, the GI study is considering increasing use of the large lock at night to maintain water quality in the "cool water refuge". a minimum number of lockings must be performed on a regular basis to refresh the area or the saltwater return system "degrades" conditions by returning the coldest, highest DO water to Puget Sound. To reiterate, saltwater return to Puget Sound is the greatest water use at the Locks, about 67% of all passed flow. Modeling of saltwater intrusion with resultant changes in saltwater management is another key component of the GI study.

The USACE conducted a one month study of water quality conditions immediately upstream of the large lock, in the holding area for adult chinook salmon, the cool water refuge. Following is a discussion of the more important points (VanRijn 2001).

Lock operations have an effect on dissolved oxygen (DO), temperature and salinity at depths less than 7 m both just above the Locks and for several hundred meters upstream). The effects upstream are less pronounced. Each time an uplocking is performed it provides a pulse of cold water with higher DO, lower temperature, and higher salinity (relative to water above 7 m). There is little or no change in environmental conditions due to Locks operations in the upper 6 meters (true for DO, temperature, and salinity). There is a transition layer around 6-8 m with some effect for very short periods. The two periods include 1) high salinity, (saltwater barrier down and increased lockages) this transition area becomes more like the bottom saltwater layer; and 2) low salinity (old drain on and few lockings). This transition area becomes more like the top freshwater layer in response to little saltwater input from few lockings and removal of existing saltwater because of increased discharge through the old drain. Further from the lock the water becomes more homogenous with less effect from the Locks: the only observed effects occur at deeper depths due to the density of the saline water.

Over the entire study period (VanRijn 2001), July 25-August 25, DO at lower depths fluctuated more upstream than at the large lock. The average rate at which DO declined was equal at both locations (0.9 mg/l per hour). Upstream, the quantity of new water is less than at the large locks. With less new water the DO levels upstream tend to reach lower levels during periods of infrequent lockages than at the large locks. The minimum DO at the large locks was 5.2 mg/l and at the upstream sensor was 3.6 mg/l. The average rate of change per lockage was 0.9 mg/l increase at the large lock and 0.7 mg/l upstream. Dissolved Oxygen levels decrease faster upstream during low salinity input. The lowest DO levels (3.6 mg/l) were found during periods of few lockings.

There is a greater fluctuation in water temperatures at the Locks than at points several hundred meters upstream (VanRijn 2001). This is the opposite of D.O. The overall effect of lockings on temperature is that there is a -1.2^0 C drop in temperature following a locking at 14 m at mid-channel; -0.6^0 C at 13.9 m at Locks; -0.4^0 C at 11.5 m; -0.2^0 C change at 8.1 m; no change at 5.2 m. The water column warms at a decreasing rate with decreasing depth increasing 0.2^0 C per hour at 13.9 and 11.5 m and 0.1^0 C per hour at 8.1 m with a return to ambient conditions within 2-3 hours. At a point upstream, a locking drops the temperature at mid-channel by –0.9° C with a return to ambient conditions within 4.5 hours or 0.2° C warming/hour.

The USACE actively monitors and controls the amount of salt water entering the Ship Canal and ensures that the DOE water quality standard is not violated. In 1992 the USACE installed 17 sensors located at 5 different sites from the Locks to the University of Washington Bridge. In the early spring each year these sensors are installed and report salinity, conductivity, and temperature every hour. The sensors are removed each fall. These sensors are closely monitored and adjustments to lock operations are made to control the salt entering the system.

Currently, there are three ways at which the USACE controls the rate at which the salt propagates upstream during an eastbound lockage. Saltwater Barrier - The saltwater barrier was constructed in 1966. It is an 18-foot tall wall that extends across the large lock chamber between gates 1 and 2. The barrier is hinged and can be lowered to allow the passage of deep draft vessels (>14 feet) as they enter or exit the large lock chamber. When the barrier is up it significantly reduces the amount of saltwater that enters the Ship Canal. The barrier is in operation all year. Saltwater Drain - The saltwater drain is the most efficient method for controlling the saltwater from entering the Ship Canal; although it is the greatest water use in summer, 67%. To reduce use of the drain and to find more water for fish passage, the Lake Washington GI is investigating structural improvements to the drain.

Flow - Increasing flow through the Locks is another method of controlling the saltwater. Any flow through the Locks creates a counter force that pushes the salt back toward the Locks. During the high winter flows there is enough force to prevent the movement of salt water into the Ship Canal. As flows drop off in the spring the force from fresh water flow is reduced and the saltwater drain is required to control the saltwater. Spill over the

smolt passage flumes also creates a fresh water force that reduces the rate at which the saltwater enters the Ship Canal but it is not enough to prevent salt from moving up the Ship Canal. Currently there is not enough water to continually provide a fresh water force to control the saltwater through the summer. The use of the saltwater drain is required from early summer to the start of the rainy season. The Lake Washington GI is investigating using flumes as a saltwater control. To do this, a salinity waiver will be necessary to "test" the "flow" method.

Mini-Flushing - A fourth method of control is called mini-flushing. This process ran fresh water through the lock chamber before opening the gates. This would "flush out" the saltwater from the lock chamber before the gates opened allowing the vessel to enter the Ship Canal. Even though this method was extremely effective it was discontinued in 1994 due to the adverse impacts to salmon smolts.

The USACE has two models that provide additional information for the management of water and the control of saltwater. A saltwater intrusion model was developed in 1997. This model simulates the movement of the saltwater under various management processes. The USACE is currently looking to update this model. A new reservoir regulation model was developed for Lake Washington in 2000. This model takes current Lake conditions and historic data from 1947 to 1992 to model future reservoir conditions under various operating procedures.

Because both fish passage and saltwater control requires water, the USACE is constantly monitoring salt movement and adjusting Lock operations to maximize the amount of water available for fish passage. The drier the year the more complex it is to balance the saltwater control and fish passage needs. Over the years, the USACE has improved their water monitoring system and evaluated the lock operations to provide accurate salt control and increased fish passage water. The system is currently being used at full capacity with no additional capacity available for summer fish flows unless new water sources or additional efficiencies in existing use can be found. Again the Lake Washington GI study, is investigating both types to provide additional flow for fish passage.

Water quality in the bay below the Locks, and water quality gradients between the Ship Canal (above Locks) and the bay is dependent on the time of year (spring or summer), volume, tidal condition and location of discharge from the Locks. The *greatest divergence or largest gradient* between water quality above and below the Locks occurs during mid-summer, after the known period of chinook migration (see below), when no spill (no freshwater export) is passed over the spillway. Near-surface water (4 m) quality data collected from late July to late August (2000) shows an average difference from above and to below the Locks of 1) 8.3 C warmer temperature (21.3 C above vs. 13.0 C below); 2) 1.0 mg/l higher dissolved oxygen (8.0 mg/l vs. 7.0 mg/l); and 3) and 28.2 ppt lower salinity (0.3 ppt vs. 28.5 ppt) (USACE, unpublished data).

The *least divergence or smallest gradient* occurs (during high flow years) in late spring or early summer (June), at the peak of chinook migration, when high volumes of fresh water

(maximum export) are spilled over the spillway and surface water temperatures have not reached a maximum. Water quality profile data collected below the Locks by C. Simenstad and W. Couch of the University of Washington in 1999, and by D. Houck of King County/Metro in 2000, under high spill conditions from flume(s) or spillway gates of 300-400 cfs, indicated that there was a low-salinity lens (< 20 ppt in concentration) in roughly the upper 1 to 3 meters of the water surface. The lens at high volumes (250-400 cfs) may extend beyond the railroad bridge -- depending on the level of discharge at the Locks and tide.

Tidal conditions can influence the depth and the integrity of the freshwater lens with high tides resulting in a much deeper, less saline fresh water lens than at low to moderate tides. Salinity readings were taken by King County Metro (D. Houck, unpublished data) during a high (10 feet) and moderate tides (4.8 to 8 feet) in June 2000 when 3 of the 4 flumes were operating (350 cfs). The depth and salinity of the freshwater lens (two strata -- < 20 ppt and 20.1-25 ppt) varied considerably with the tide. At high tide the lens was the deepest and least saline with minimum values as low as 9 ppt and readings < 20 ppt found to a depth to 4.9 m and depths to 10.8 m for readings from 20-23 ppt. At moderate to lower tides, the lens was negligible with a minimum value of 16.7 ppt with lens width at < 20 ppt averaging less than 1 m (varying from 0.02 to 2.2 m) while values less than 25 ppt were only found to 3.1 m deep. Temperature levels were slightly different -- at high tide, maximum temperatures reached 15.0 C while at low to moderate tide the maximum was 13.0 C.

In mid-June, under conditions of near maximum spill and at high tide, the water quality difference between the forebay above the Locks and the tailrace is at a minimum. The average values of temperature and salinity below the dam are 1) 2.5° C cooler (15.5° C above vs. 13° C below) and 2) 15 ppt higher (0.0 above vs. 15 ppt below) to a depth of 4 m. This contrasts with the maximum difference of 8.3° C cooler and 28 ppt higher in mid-summer after the known period of chinook migration.

Under low spill conditions, 100 cfs, little functional change in salinity levels is detectable at a distance of 75 m from the Locks and a depth of 4 m. A 5 day spill test in mid-August 2000, resulted in statistically significant lower levels of salinity at the end of the tailrace ($P<0.001$) but average levels were barely different -- 28.2 ppt with spill and 28.6 ppt without, levels much higher than that used by recently migrating juvenile chinook salmon. There was also higher dissolved oxygen during the spill period, with average D.O. levels at 7.6 mg/l with spill and 7.0 mg/l without (USACE, unpublished data). The frequency of available spill volume to create a freshwater lens is described above and illustrated in Figure 24.

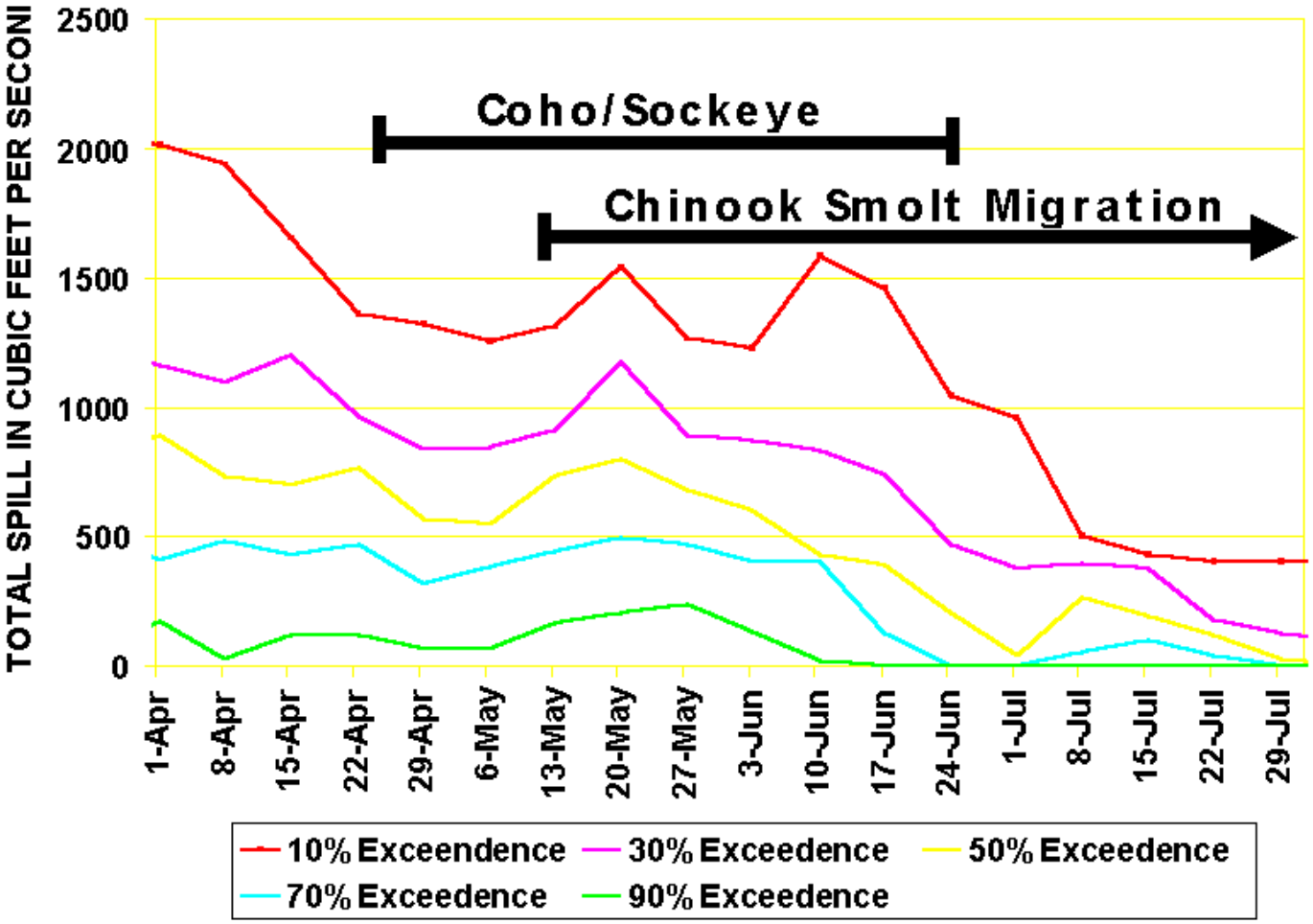
Aquatic Resources

Over 50 freshwater and anadromous fish species are found within the Lake Washington basin. Of these, over 20 are non-native species introduced into the system over the past 140 years (further discussion in Lake Washington sub-area). Specific freshwater fish found within one mile of the Locks include native species -- three-spine stickleback

(*Gasterosteus aculeatus*), peamouth chub (*Mylocheilus caurinus*), and non-native species such as yellow perch (*Perca flavescens*), black crappie (*Pomoxis nigromaculatus*), and smallmouth bass (*Mictropterus dolomieui*). Since the Locks is at the interface of the fresh and water waters of the basin, a variety of estuary and marine species can be found at the project throughout the year.

Marine and estuarine species found just below the project, within the large lock, and above, include starry flounder (*Platichthys stellatus*), wolf eel (*Anarrhichthys ocellatus*), shiner surfperch (C*ymatogaster aggregata*), striped surfperch (*Embiotica lateralis*), pacific herring (*Clupea heringus*), Pacific staghorn sculpin (*Leptocottus armatus),* ratfish (*Hydrolagus colliei*), and surf smelt (*Hypomesus pretiosus*). Anadromous species include native species -- longfin smelt (*Spirinchus thaleichthys*), river lamprey (*Lampetra ayresi*), Pacific lamprey (*L. tridentatus*), bull trout, possibly Dolly Varden (*S. malma*)[1], cutthroat trout, steelhead, coho salmon, sockeye salmon, chinook salmon, occasional chum salmon, pink salmon (juveniles), and non-native species -- Atlantic salmon (*Salmo salar*), and American shad (*Alosa sapidissima*).

Figure 24. Summary hydrograph showing total available spill during low flow season.



Freshwater and anadromous fish may be classified based on temperature preference, with bass residing in the warm water guild, perch in the cool water guild and salmonids in the cold water guild. The temperatures that are centered on each guild are 11.0-14.9^0 C cold water, 21.0-24.9^0 C cool water, and 27.0-30.9^0 C warm water.

In addition, as the marine waters of Puget Sound intrude into the large lock during lockings, a variety of sessile marine animals can be found on the hard surfaces within the large lock chamber (none are found in the small lock, or saltwater return system). Notably, the walls and filling conduits are lined with barnacles – (*Balanus crenatus; B. cariosus*) and blue mussel (*Mytilus edulis*). Barnacle coverage is limited by salinity, with growth (surface area and depth) decreasing from west to east, with virtually no growth above the upper miter doors, and from bottom to top, no growth above high tide line in the chamber and growth to the bottom of the lock entrance (38 feet below lake elevation). Approximately 80% of the large lock filling conduits surface area is covered with barnacles (removed in November 1999, see below). Below the Locks, Dungeness crab (*Cancer magister*) is found in high densities in selected areas of Salmon and Shilshole Bay. Freshwater benthic invertebrates include one or more species of crayfish. These animals have been found in high densities on the bottom of the Ship Canal just upstream of the Locks.

Zebra mussels (*Dreissena polymorpha*) have not found within western Washington to date. Survival of mussels is reduced at salinities >5 ppt. The USFWS maintains a monitoring site at the Locks.

B. Salmonid Utilization

The Cedar - Sammamish Watershed appears to be highly productive, producing nearly the largest salmon smolts (coho, chinook, and sockeye) for their age class of any river basin within Puget Sound (Weitkamp et al. 1995; Meyers et. al. 1998; Burgner 1991; J. Woodey, UW, unpublished data). In addition, the Lake Washington sockeye salmon run is largely introduced, after construction of the Locks, and has increased to such size as to be called the largest sockeye salmon run in the contiguous United States. However, these same reports have indicated that since the mid-1980s, all salmon (chinook, coho, and sockeye) populations and steelhead stocks have been in decline in the Lake Washington system.

Following is a detailed discussion for the chinook salmon.

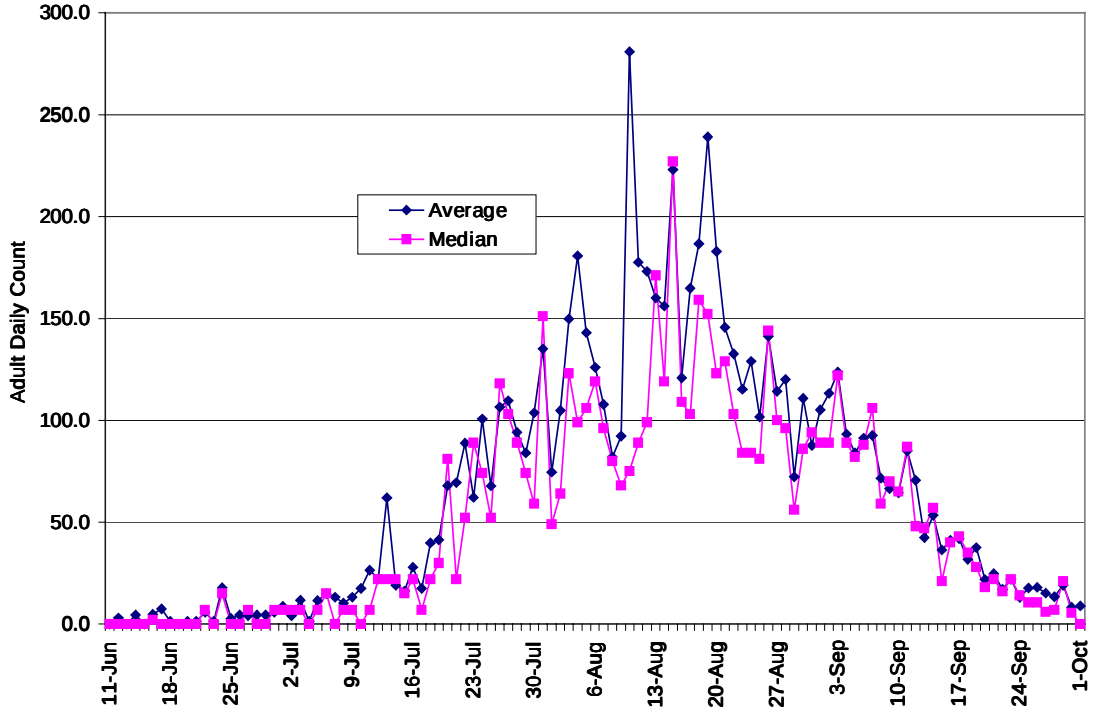
Chinook Salmon

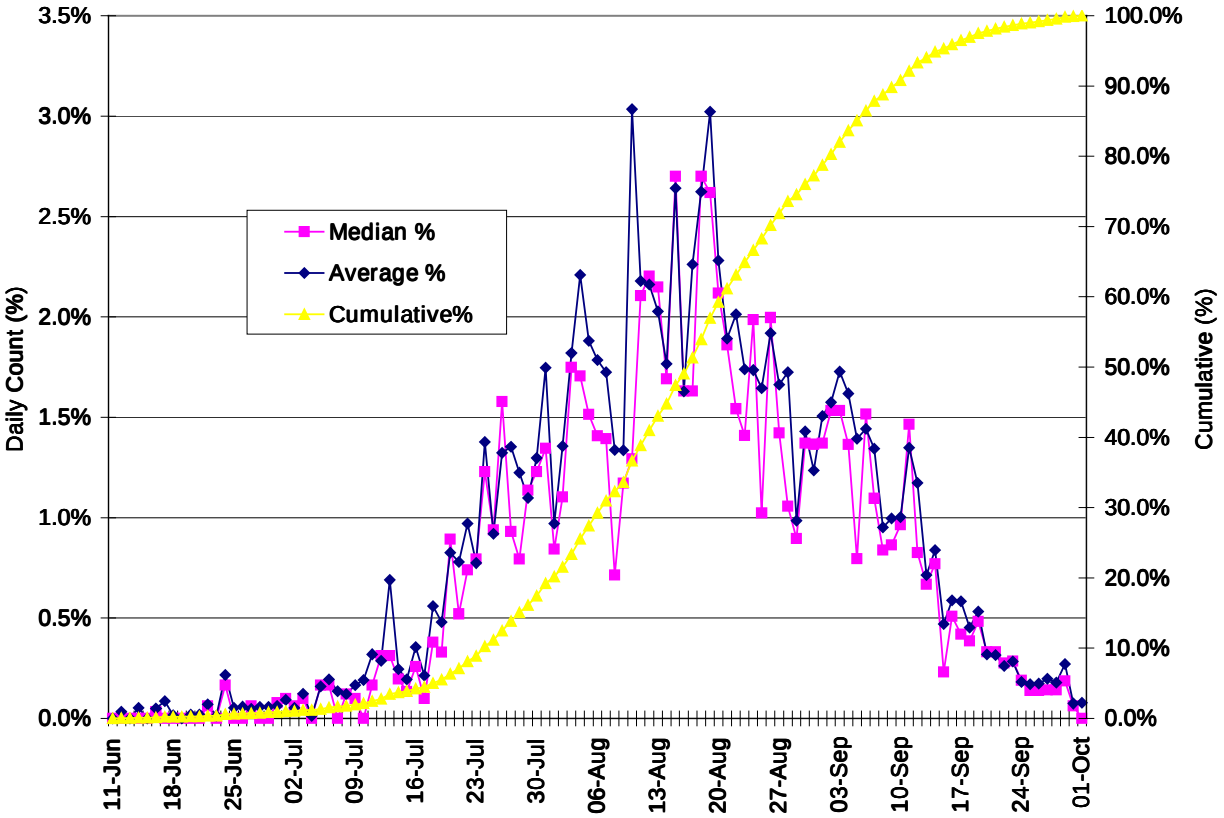
Unlike most other sub-area descriptions, the following level of details on chinook salmon migration timing, fish pathways through the project, and observed fish behavior provided are considered essential in order to provide a good understanding of project effects. The timing of chinook salmon migration through the Locks occurs under the poorest conditions for flow (juvenile migration) and water quality (adult migration).

Adult Migration Timing at the Locks: Adult chinook salmon migrating from ocean rearing grounds entering the Lake Washington drainage from Puget Sound must pass through Shilshole Bay, Salmon, Bay, the Locks, Ship Canal, and Lake Union System prior to reaching Lake Washington. This migration route is considerably different from the migration routes in which Lake Washington chinook evolved prior to the diversion of the Lake Washington drainage from the Duwamish/Green watershed. As adult chinook migrate through the marine waters of Shilshole Bay they encounter the Locks complex and must negotiate passage through one of several possible routes. At the Locks, chinook encounter an abrupt change from cooler, more saline marine water below the Locks to warmer, less saline water above the Locks. Also, chinook encounter water currents below the Locks, but currents are negligible once they pass into the forebay. In contrast to the constraints imposed on chinook movements near the Locks, chinook in a natural estuary would be free to move up and down the channel selecting preferable temperature and salinity.

At the Locks, since 1994, the Muckleshoot Indian Tribe (MIT) and the Washington Dept. of Fish and Wildlife (WDFW) have provided trained observers for daily index counts from June 12 to September 30 (methods available from MIT and WDFW). The end of counting period is arbitrarily selected and probably excludes counts of some number of later migrating adult chinook. Figure 25 shows the median (50%) and average daily fish ladder counts for 1995 through 1999 from June 12 through September 30 or October 2. The date when 50% of the run passed through the fish ladder varies by year but generally falls between August 6 and August 23. By year the median date is – 1995 August 23, 1996 August 22, 1997 August 19, 1998 August 6, and 1999 August 14. Water temperatures in 1998 were the highest recorded temperatures in the Ship Canal for the period of record. This coincides with an earlier period of chinook migration with the median date of passage occurring two 1-2 weeks earlier than in any other year.

Figure 25. Average and median daily counts (top figure) and percentages (bottom figure) for adult chinook salmon (1995 - 1999) passing through the fish ladder and large locks.





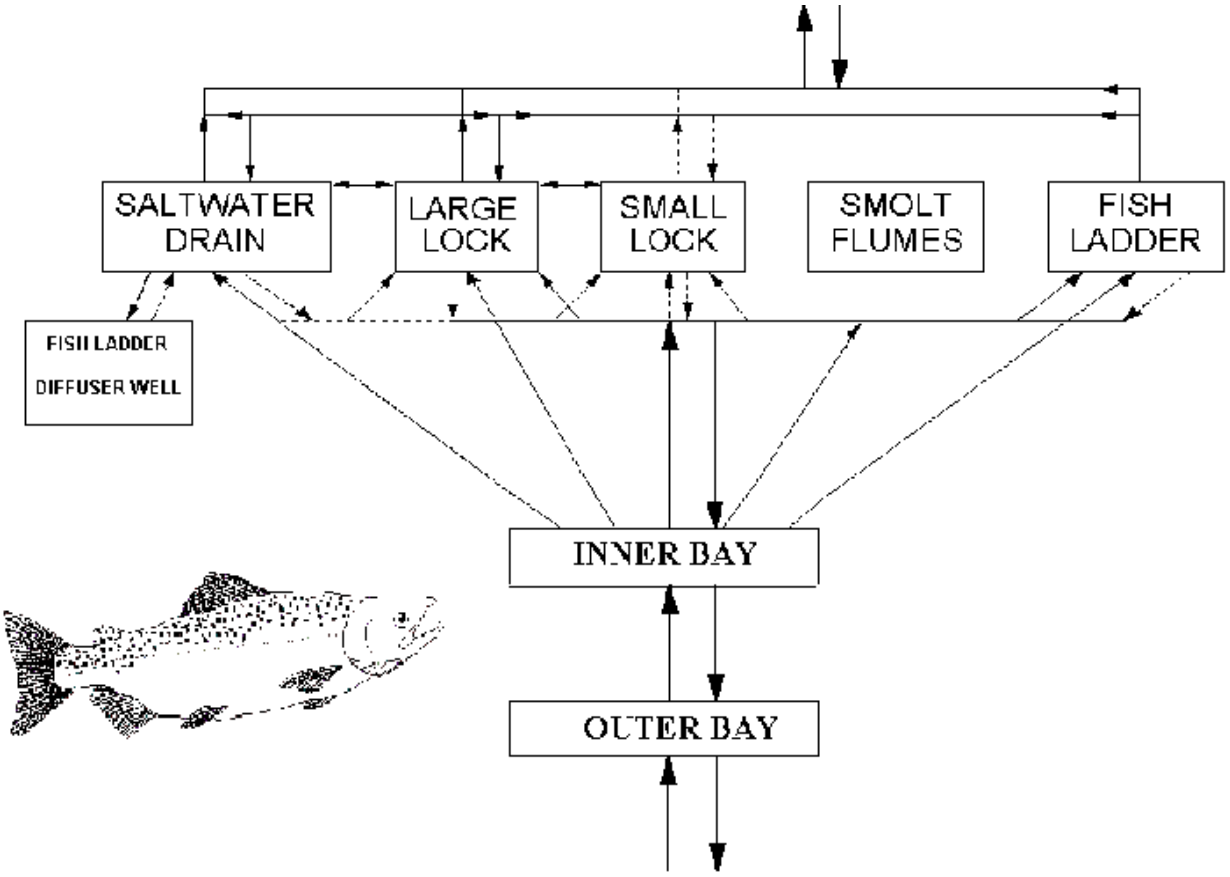
The counts provided in this section do not include the time adult chinook spend residing in the saltwater return area otherwise known as the "cool water refuge" (see below). For example, in 1998 tagged adult chinook salmon spent an average of 19 days residing at the Locks primarily in the cool water refuge area. The average number does not reflect the large variation in individual residence times – range from 1 to 49 days (Fresh et al. 2000). The 1998 data is probably the extreme for residence time, reflecting the highest water temperatures recorded in the Ship Canal to date. Data from 1999 and 2000 indicates that fish migrating during lower water temperatures probably spend less time at the Locks (USACE unpublished data; Fresh et al. 2000; HTI 2000).

Migratory Pathways through the Locks

Prior to rehabilitation of the existing fish ladder, the Washington Department of Fisheries provided evidence that delay and passage problems at the Locks may have reduced the annual runs of sockeye and chinook salmon by up to 20 percent (WDF 1971). Based on resource agency observation, the ladder passed fewer than 10 percent of the adult sockeye and chinook salmon and steelhead fish runs with 90 percent using other routes, primarily the large lock and saltwater drain, to reach the Ship Canal. Beginning in 1970 when the sockeye salmon reached extensive size, the USACE began design efforts to rehabilitate the existing fish ladder and on an interim basis implemented "fish lockages". It was a 6-year process to rehabilitate the ladder from completing the design memorandum (1972), to the City of Seattle acquiring land for expansion of the ladder (1974), to construction and final completion of the ladder in 1976. Since rehabilitation, approximately 80% of all chinook salmon use the ladder (Muckleshoot, WDFW, unpublished data).

Current observed and potential migratory pathways for adult chinook salmon through the project area are shown in Figure 26. As fish first enter Shilshole, and then Salmon Bay, they may elect to enter the project area one or more times before committing to passing through the multiple upstream pathways. Adult salmon and steelhead pass through the Locks complex at one of four potential routes: the fish ladder, large lock, small lock, and the saltwater drain. The goal of the fish ladder is to facilitate efficient migration of salmon through the Locks complex. In 1976, the fish ladder was rehabilitated to attract more fish and to facilitate upstream migration because WDF (1971) suggested that migration delay and other passage problems may have reduced the annual runs of sockeye and chinook by up to 20%. In addition to these improvements, the USACE has implemented some additional improvements and is considering others, based on recommendations from the WDFW (see Factors of Decline, Fish Passage).

Figure 26. Conceptual model of observed (solid line) and possible (dashed line) upstream passage routes for adult salmonids at the Hiram M. Chittenden



Since 1998, King County Metro has funded three consecutive years of study of adult chinook migration through the Lake Washington watershed using acoustic tags. The USACE has cooperated in conducting the study during 1999 and 2000 under the Lake Washington GI Study. To date, the only published results are a draft report for 1998, summary results presented at the Lake Washington Workshop, and a draft report from HTI (Fresh et al. 1999; 2000; HTI 2000).

Automated data loggers at the Locks showed that annually 30-40% of the acoustic tagged adults fell back below the Locks one or more times. Based on results in 1998 and 1999, from 10-14% of these fish fell back below the Locks and did not re-enter the project area. These fish were likely strays from other systems (Fresh et al. 2000). In the Columbia River basin, fish that fallback may re-ascend the fishway, remain below the dam to spawn, or migrate downstream and enter another river (Mendel and Milks 1997): no spawning occurs below the Locks. The rate of fallback over a dam varies with flow and spill, by dam, and by fish species or run timing (Dauble et al. 2000). Based on fish

counts by the Muckleshoot Tribe about 20% of all adult chinook salmon use the large lock. The major fallback route is also presumed to be the large locks.

Average residence times of fish vary depending on whether they fall back one or more times. In 1999, non-fallback fish had an average residence time of 15 days while fallback fish averaged 23.5 days residence. Fallback fish may move back and forth through the locks (presumably the large locks) up to 4 times (Fresh et al. 2000). Reporting by HTI should include more specifics on fallback and re-ascension pathways (HTI 2000).

The Muckleshoot Tribe has indicated that there may a gender and/or size bias in the upstream pathways used by adult chinook salmon (E. Warner, pers. comm.). Based on trapping of adult chinook during three years of acoustic tracking at the Locks, the WDFW and Muckleshoot Tribe believe they have been seeing more males and overall more smaller fish using the fish ladder relative to the total population of fish moving through the project. In August of 2000, the Muckleshoot Tribe sampled adult chinook using the large lock chamber by purse seine. The catch was predominately female chinook salmon. Based on these observations, the initial hypotheses put forth by biologists is that the vertical gates on the fish ladder are either too narrow to pass the largest fish (typically females) and/or the female chinook are not using the fish ladder for other reasons, such as temperature shock.

A standard operating procedure is to spill additional water (when available), either through the gate or a flume, to provide additional attraction to the fish ladder. This is based on the assumption that more freshwater spill will increase fish use of the ladder. Most years spill ceases prior to the migration of adult chinook, an exceptional year occurred in 1999 when spill was provided through September 3 (80 cfs bay 5, 200-400 cfs bay 2). A simple test was used to identify if any obvious change occurred in the proportion of fish using the ladder or the large lock during periods with and without spill. Observer counts were used to compare the number of chinook salmon using the fish ladder during periods with and without spill (3 weeks with and without). During periods with spill, 17% of the fish used the locks and 83% used the ladder, while periods without spill 15% used the locks and 85% used the fish ladder. In this comparison of the counts with and without spill it appears there is little or no difference in the percent of fish using the ladder. This would suggest that spill may not change the pathway selection for chinook salmon (USACE 2000). Spill may serve other benefits for adult chinook, such as drawing Lake Washington fish closer into the Locks, thereby avoiding sea lion

predation and reducing the water quality gradient from below to above the Locks.

Observed Behavior

In 1985, observer counts were conducted at the current fish ladder over a series of weeks in August and September (Grette 1985). Twenty-four counts showed nearly all fish moved during the day with little movement occurring at night. Of the three salmon species observed, sockeye were most prone to migrating at night. Daytime counts suggested a fairly consistent pattern with numbers increasing in the morning and

remaining high until about 1800 hrs. For the three salmon species observed, counts were generally highest in the afternoon. Unofficial counts indicated that approximately 90% of the fish entered the fish ladder viewing window through the lower orifice opening while the remaining 10% used the overflow weir. During tidal cycles, counts were fairly uniform except that counts were generally low during major low tides. Water temperature conditions varied from 20.4 to 22.7° C. No relationship was seen in fish counts against temperature but the author suggested that greater activity would be expected at the lower end of this range.

Another measure of fish passage through the fish ladder is the electrical impedance counter located at the beginning of the fish ladder viewing pool (pool no. 18). This counter was installed by the WDFW in 1986 and has been maintained by the USACE since that time (USACE 2000). Chinook salmon migrating through the fish ladder come in with increasing numbers as light levels increase and tidal height increases (Figures 27 and 28). Fish counter data were used to estimate the diel and tidal migration pattern of chinook salmon using the fish ladder[2]. Figure 27 shows the net (up-down count) average counts for a three-week period, August 10-31, when chinook salmon were the most abundant fish using the fish ladder (60-100% of the daily observer expanded count). At night, less than 1 fish per hour passed through the counter. Fish counts increased regularly following sunrise reaching a peak (5 - 7 fish/15 minutes) during mid-afternoon. Figure 28 shows that counts vary with tidal conditions with more fish coming in at increasing tidal elevations up to tides of 10 feet. The flood tide backwaters the lower end of the fish ladder allowing easy passage over the top of each flooded pool. The increase in counts with increasing tides would imply that salinity levels in the entry pool may not be a concern. Summer salinity levels in the entry pool are typically between 2-9 ppt while Puget Sound is near full strength seawater at 28-29 ppt.

[2] Use of the count data in relationship to entry pool conditions must include an assumption that counted fish took some short period of time 15-60 minutes to enter the ladder and swim upstream to the fish ladder viewing window.

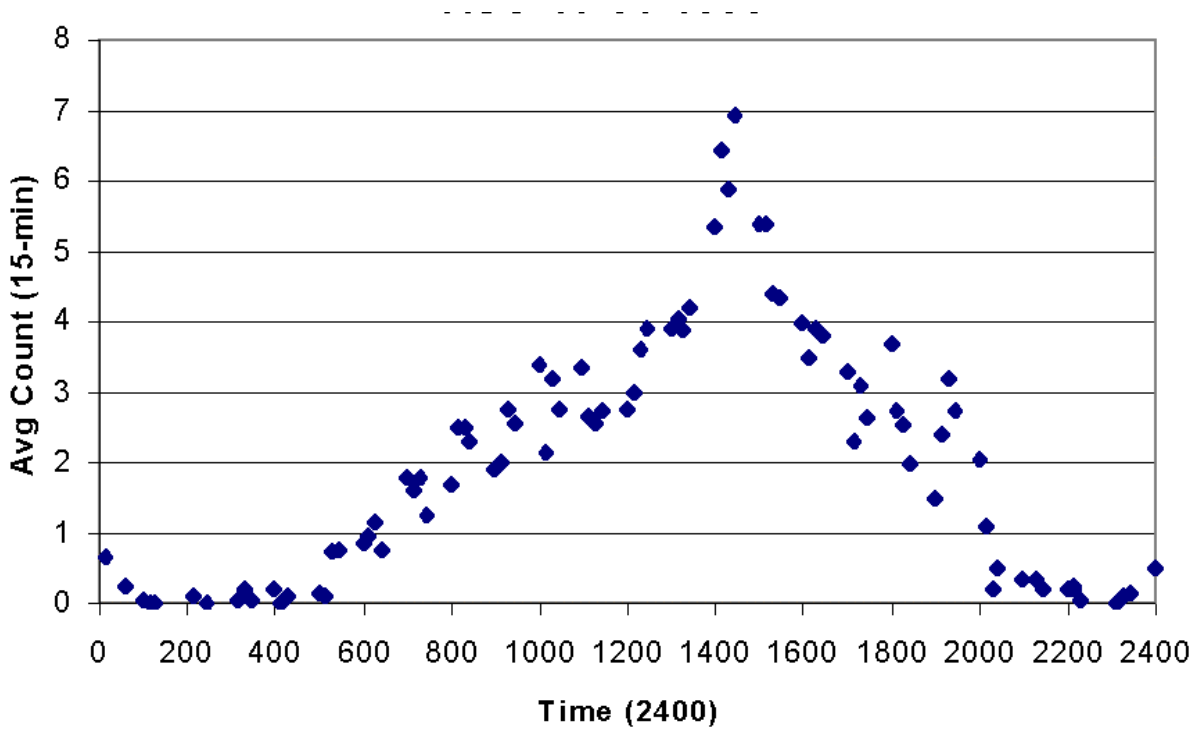
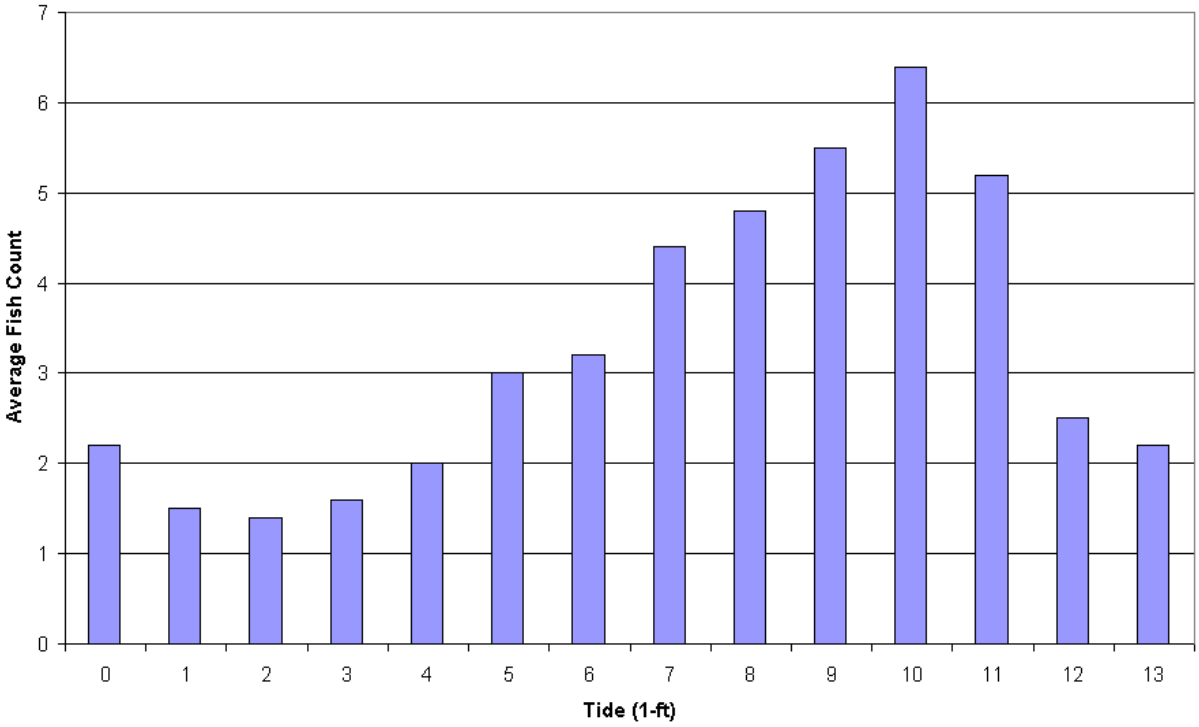


Figure 27. Net average fish tunnel counts (15-minute) after down counts have been subtracted from up counts for August 10-31, 1999.

Figure 28. Average fish tunnel count by tidal elevation for the period August 11 - 31, 1999.



Chinook behavior in a large estuary, the Columbia, has been studied using acoustic tags (Olson and Quinn 1989). In general, fish in the estuary usually moved in the direction of the prevailing tidal current, milling during low current velocity, and reversing their direction of movement with the change in tides. Mean fish depth was 5.5 m in mean water depths of 13.4 m. Temperature and salinity conditions changed dramatically during tracking sessions -- temperatures ranged from 9-23° C and salinity from 8-34 ppt.. Two observed patterns of vertical movement include 1) some fish swam in brackish surface water with large vertical gradients of salinity and temperature with occasional excursion into uniform bottom water; and 2) others demonstrated periods of swimming in the water column and near the bottom. The frequency distribution of temperatures and salinities occupied by fish showed modes between 14-16° C for 5 of 7 fish, and 17-19 ppt for 4 of 7 fish. Chinook spent most of the tracked time either close to the bottom, or within the salinity gradient.

The findings of Olson and Quinn (1989) tend to agree with other estuarine tracking studies of salmon. Fujioka (1970) found that the position of chinook salmon tracked in the Duwamish estuary was dependent on tidal stage, moving further upstream on a high tide compared with a low tide. Other studies have demonstrated that salmon may hold in estuaries for about one month (Wendler 1959; Verhoeven and Davidoff 1962; and Vernon et al. 1964). In the Columbia River estuary, the lack of substantial net upriver

progress of tagged fish support the hypothesis that fall chinook may spend an indeterminate amount of time holding within the estuary prior to upstream movements (Olson and Quinn 1989).

At the Locks, after migrating through the fish ladder, fish immediately move to the deepest part of the channel upstream of the saltwater drain. Researchers noted that chinook that passed upstream into the Ship Canal area were holding for long periods (average 19-20 days) near the saltwater drain in the cool water refuge (Fresh et al. 1999; 2000; HTI 2000). As described previously, this area has the coolest (below the thermocline), most highly oxygenated water for a significant distance upstream of the project.

HTI's initial monitoring results from tracking adult chinook salmon above the Locks showed that tagged fish spent up to 90 percent of observed time in the immediate vicinity of the saltwater drain intake in the cool water refuge (an area only 1-2 acres in size). Secondary areas of importance included the entrance to the small lock, the large lock entrance and areas of the Ship Canal upstream of the Locks. Individual fish would move between areas of the drain intake, lock entrances and the Ship Canal. The time fish spent in the general vicinity of the cool water refuge varied by the migration timing of the tagged fish. Fish entering the ladder in late July and early August had the longest residence times while fish migrating later in the summer had the shortest residence time. By week, fish entering the fish ladder and tagged in 1) late July spent an average of 35 days in the project area; 2) early to mid-August spent 20 days; 3) late August 15 days; 4) early to mid-September 5-10 days. Residence time as a function of arrival time at the Locks was a significant relationship (r^2=0.49). The initial theory, based on observations in 1998, is that residence time is a function of water temperature with fish holding at the Locks until near-surface temperatures drop below 22° C (Fresh et al. 1999).

Fresh et al. (2000) stated that the total time of fish migration from tagging at the Locks to arrival at tributary spawning grounds varies from 45-55 days. In 1998 the average residence time at the Locks was 19 days while in 1999 it was 17 days. Typical times to pass through other major sub-reaches in the basin include 1) 1 day through the Ship Canal; 2) 2-5 days in Lake Washington; 3) 8-15 days in the Slough. Once fish leave the Ship Canal they migrate quickly through the basin and hold at tributary river mouths where they hold below the thermocline.

Fresh et al. (2000) stated that during 1998 and 1999, females took longer to leave the Locks and migrated more slowly to the spawning grounds than males. Between 1998-2000, the longest residence time for any tagged fish at the Locks was 52 days. Once fish leave the Locks, most fish move through the Ship Canal in less than one day, varying from 4 hours to 7.7 days with bigger fish migrating faster than smaller fish. The earliest date fish reach the University of Washington data logger was August 27 in 1998 and July 20 in 1999. The percent of fish leaving the Locks by August 27 was 0% in 1998 and 25% in 1999. In 1998 water temperatures did not decline to below 22° C until the end of August.

Concurrent with HTI tracking of adult chinook at the Locks, the USACE was manipulating lock operations, from July 25 to August 25, to monitor and evaluate the conditions in water quality (temperature, dissolved oxygen, and salinity) within the cool water refuge (VanRijn 2001). Data collected from water column sensors, point-measurements, and from bottom sensors has already been provided to HTI and will be merged with the adult fish tracks to attempt to identify ranges of use for each of the measured water quality conditions. A summary of the monitoring results is described above.

Juvenile Migration and Rearing: Juvenile chinook from the Cedar River enter Lake Washington over an extended period from January through at least mid-July (WDFW unpublished data). There is a bi-modal peak in juvenile chinook salmon abundance during migration from the Cedar River to Lake Washington. A large downstream movement of chinook fry occurs immediately after emergence. The first and largest peak occurs in February and early March when small (40-45 mm), recently emerged fry leave upper river areas presumably seeking rearing areas. The early downstream migration of newly emerged fry is probably a dispersal mechanism that helps distribute fry among downstream rearing habitats (Lister and Genoe 1970). The second smaller peak occurs during May and June when larger juveniles (70-90 mm) migrate downstream beginning the emigration from the lake to the estuary (D. Seiler, WDFW, pers. comm.).

Lister and Walker (1966) observed a bimodal distribution of chinook fry in the Big Qualicum River, British Columbia that nearly parallels that observed in the Cedar River. In the Qualicum River they found that chinook fry migrated either within a short time of their emergence or after six weeks or more of rearing. The early group of fry measured 40-48 mm in length and migrated downstream during late March and April. A later pulse of fry migrated downstream during May and early June and measured 60-90 mm in length. Downstream movement of chinook fry in Northwest rivers may occur between February and July and the timing of peak downstream migration can vary substantially from year to year. The beginning and end of the chinook outmigration season appears to vary less than the timing of the peak of downstream migration (Healey 1991).

The Lake Washington chinook stock is fairly atypical in providing an extended period of lake-rearing, the only other known stocks in Washington with possible lake rearing demographics include Lakes Quinault and Ozette in western Washington and Lakes Osoyoos and Wenatchee in eastern Washington. Outside Washington, the Wood River system in Alaska has a chain lake system that would indicate a significant amount of lake-rearing potential (USACE 1999).

Early migrants that enter Lake Washington are typically small in size and use the near-shore littoral zone as they reach smolt-size (Martz et al. 1996). There is a wide variation in outmigrant size indicating some fish are rearing in the river while others entering the lake are rearing in the lake Mean size of emigrating chinook salmon juveniles caught in the lower Cedar River in 1998 was 40 mm in January and February, 43 mm in March, 61 mm in April, 75 mm in May, and 96 mm in June (from D. Seiler, WDFW, unpublished data). Fresh (2000) compared the maximum length of juvenile chinook caught in the

river vs. fish caught in the lake and showed that lake-reared fish averaged from 10-40 mm larger than river reared fish. This comparison indicates lake reared fish may grow larger faster than river reared fish.

Marked Issaquah Creek hatchery chinook have been captured at the south end of Lake Washington (Fresh 2000). Hatchery chinook released from the University of Washington have been observed to move upstream into Lake Washington (K. Fresh, WDFW, pers. comm.).

Juvenile chinook salmon migrating from rearing areas in the Lake Washington drainage to Puget Sound must pass through the Ship Canal, Lake Union System, and the Locks. This migration route is considerably different from the migration routes in which Lake Washington chinook evolved prior to the diversion of the Lake Washington drainage from the Duwamish/Green watershed. As juvenile chinook migrate from the fresh water of Lake Washington, they encounter the Ship Canal and Lake Union system where they may rear for days to months prior to migrating further downstream towards marine waters and the Locks. At the Locks, juvenile chinook encounter an abrupt change from the warm freshwater above the Locks to cool, more saline water below the Locks. Further, chinook 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 chinook movements near the Locks, juvenile chinook in a natural estuary would be free to move up and down the channel selecting preferable temperature and salinity and habitat rearing areas.

Migration Timing at the Locks: One of the most important pieces of information necessary to improve fish passage conditions at the Locks is to accurately define the timing of juvenile chinook salmon passing through the project area. The period of available spill and range of migration periods for sockeye, coho, and chinook are shown in Figure 24.

A number of monitoring efforts provide some background for deducing the migration timing of juvenile chinook salmon through the Locks (Figures 24, 25 and 30). In their status review of west-coast chinook salmon stocks, Myers et al. (1998) listed the general juvenile chinook salmon migration timing through rivers and period of estuarine residence for Puget Sound rivers. As shown in Figure 29 they listed the beginning, peak, and end of migration/estuarine residence by region, drainage, and run-type (spring, summer, and fall). As shown in the figure, there is an overall pattern of earlier migration timing for south Puget Sound summer/fall stocks (March-July for Nisqually) compared to north Puget Sound summer or fall stocks (April-August for Nooksack). The overall pattern of abundance shows a consistent peak timing in June for all stocks with a prolonged peak in June and July for selected fall stocks and one spring chinook stock. As described in Myers et al. (1998) the Lake Washington summer/fall stock is shown to parallel the end of the South Puget Sound migration in July with peak in June. The described timing also somewhat parallels the river migration timing of juvenile chinook salmon leaving the Cedar River (discussed above) but deviates significantly from the estuarine entry timing at the Locks. As shown in Figure 30, the Locks appears unique in

migration timing for Puget Sound, in contrast to the NMFS status review, with the first migrants reaching the Locks in mid-May. Even with historic and current sampling efforts (discussed below) conducted in March, April, and early May, no chinook have been captured in March or April and in only 1 out of 5 years have juvenile chinook been found in the first week of May. The only year of capture in early May, 1998, also coincides with the warmest water year on record.

The implication of this altered migration timing is a modification in the life history types found within the Lake Washington basin, in particular the early migrant phase. The observed peak in juvenile migration into Lake Washington in late February and early March would conceivably be the archetype that migrated historically into the Black River and into the immense intertidal wetlands of the Duwamish Estuary (5,000 acres). An apparent lake rearing type that has opportunistically utilized the nearshore-rearing environment found in along the lakeshore has replaced this early phase.

Smolts may remain in the Locks project area for days to weeks. Larger smolts, such as steelhead or sockeye salmon, may move through the project in hours or days. Smaller smolts, in particular chinook salmon, could remain in the project for weeks at a time, attaining size prior to entering Puget Sound. In natural estuaries, chinook can remain for up to 3 months (Healey 1991). Large numbers (thousands) of juvenile chinook may remain in the large lock chamber, feeding, for several days (M. Mahovolich, Muckleshoot, pers. comm.; Goetz et al. 1999). Given that smolts may remain at the project for extended periods, it is unknown whether smolts could become entrained more than once into the lock conduits. It is known that PIT-tagged chinook may lock up through the small or large locks and be passed a second time through the smolt passage flumes (R2 Resource Consultants 2000).

Figure 29. Timing of juvenile chinook salmon migration from rivers and estuary residence in Puget Sound: grey=present, black=peak. (Source: adapted from Myers et al. 1998).

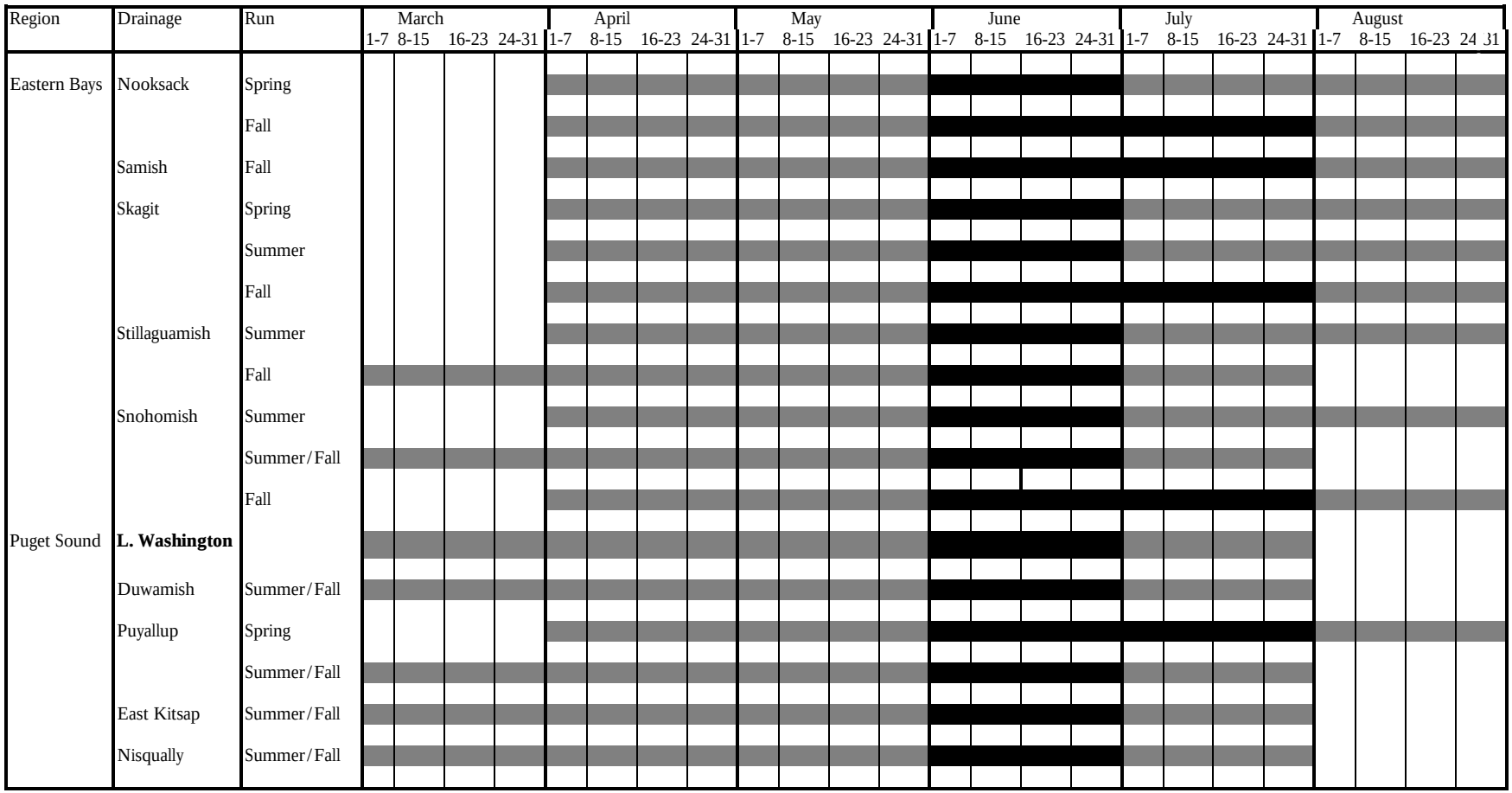
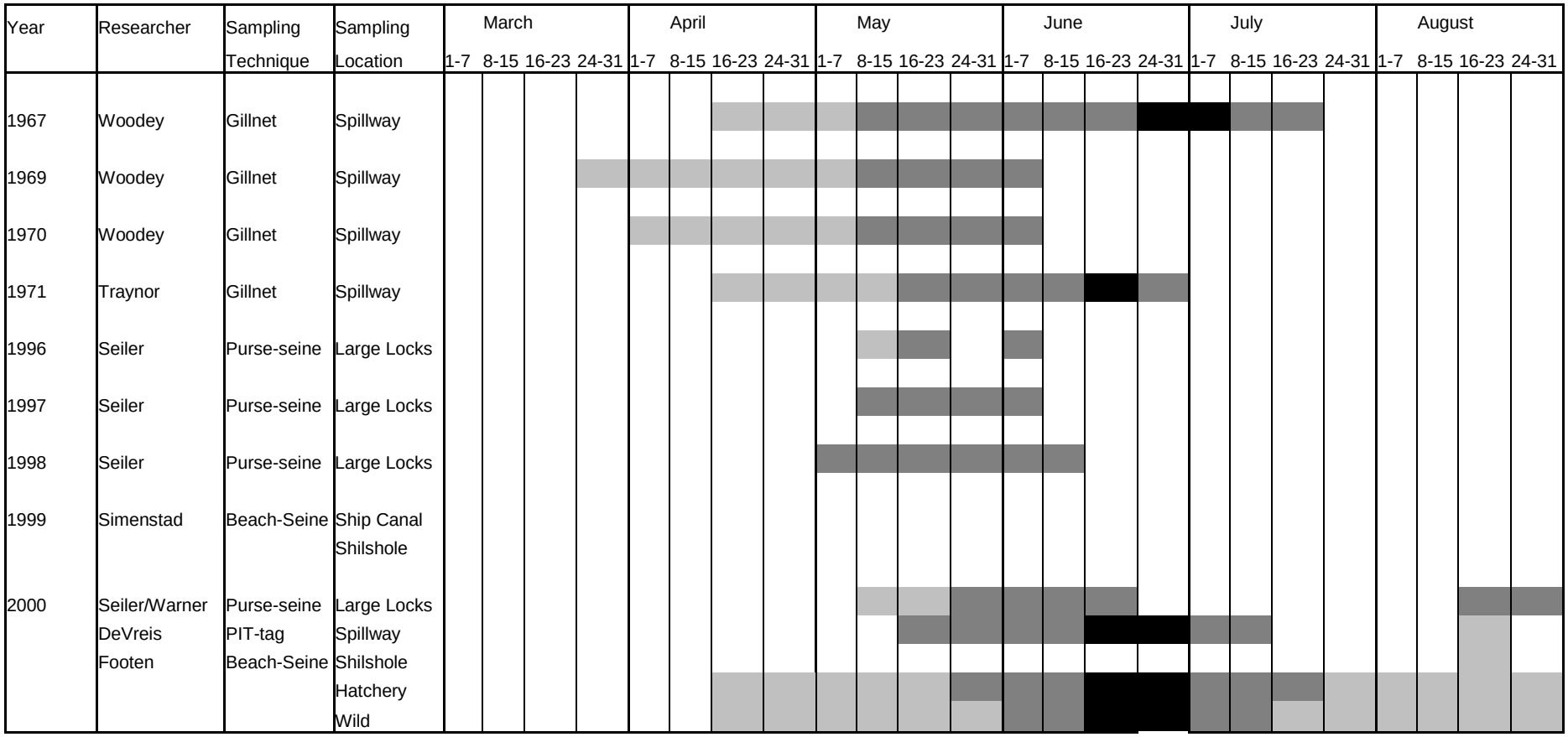


Figure 30. Presence of juvenile chinook salmon at the Hiram M. Chittenden Locks and Shilshoe Bay. light gry= sampled but absent, grey=present, black=peak catch.



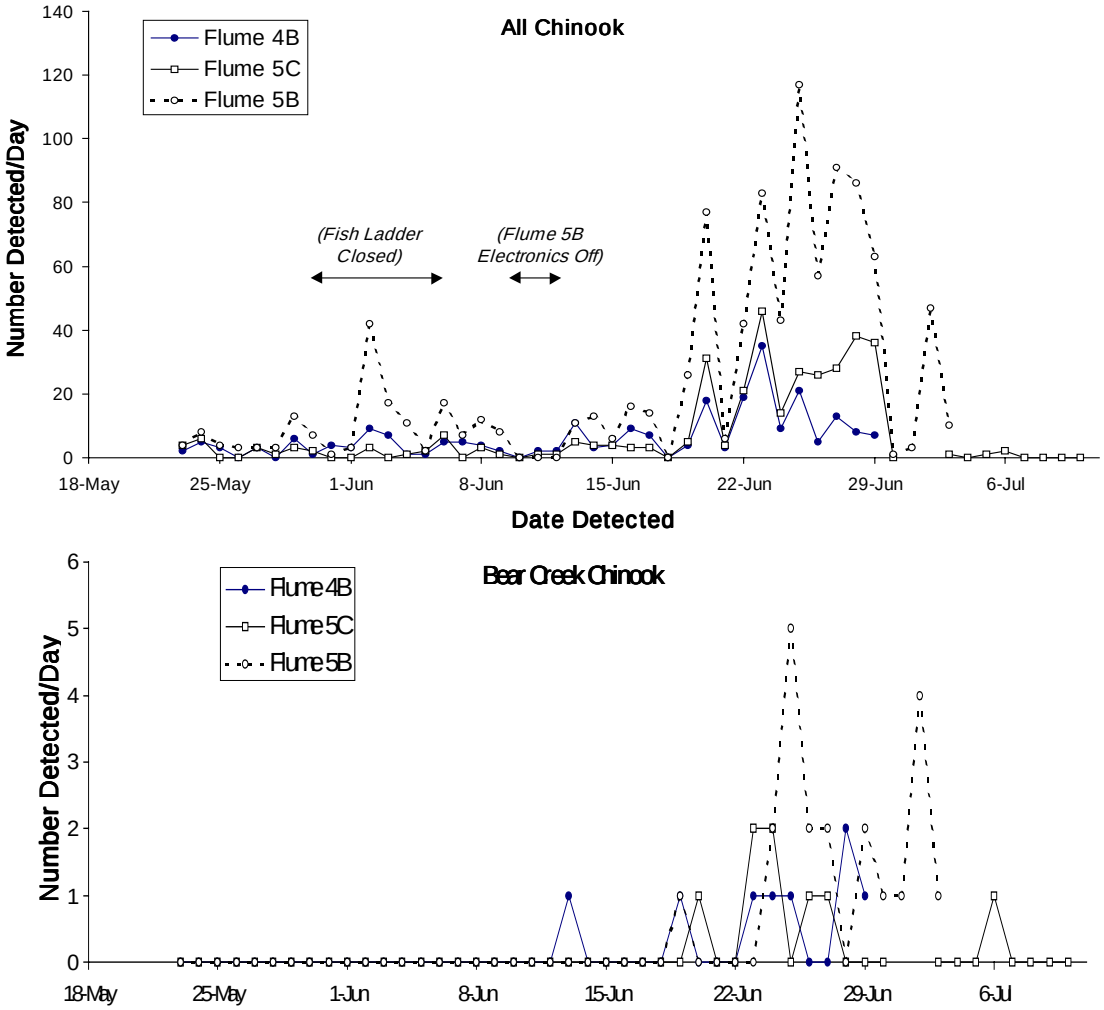
Historic migration timing at the Locks was developed from data collected by the University of Washington during the late 1960's and early 1970's in the forebay of the Locks spillway (Woodey 1967, 1969, 1970; Traynor 1971). This information was used to begin creation of the bar chart of migration timing shown in Figure 30. Based on the average weekly catch, juvenile Chinook salmon migrate later than coho and sockeye salmon with about 5% passing the Locks in May, over 50% passing in June and 40% passing in July. The earliest date of capture was the second week of May with the peak catch in mid to late June. Note that this data set only includes sampling past mid-July during one of the 4 years. The WDFW has conducted purse seining in the large lock chamber during 1996, 1998, and 2000. The first date of capture of juvenile chinook salmon was either the first or second week of May as shown in Figure 31 (D. Seiler, WDFW, unpublished data).

Under current timing, 2000, there was a congruence in determining the peak passage period, second half of June, for wild juvenile chinook salmon at the Locks using two separate monitoring methods. Passive-integrated-transponders (PIT) tags were used to mark 12,000 hatchery and wild juvenile chinook salmon at several points in the Lake Washington Basin (R2 Resource Consultants 2000). These tagged fish were subsequently detected through one to three tunnel readers attached to the end of the smolt passage flumes. The detection times of these fish provide the best information to date on the migration timing of Lake Washington juvenile chinook salmon passing through the Locks. The timing of the hatchery and wild release groups are shown in Figure 31. The peak in wild fish migration timing was during the last half of June. Concurrent with PIT-tag detections, the MIT was conducting beach seine sets below the Locks to capture juvenile salmonids and potential predatory fish (Footen 2000). Wild fish were first caught in early June with a peak during mid to late June.

The PIT-tag data also provided information on the juvenile chinook migration to the Locks (R2 Resource Consultants 2000). Larger chinook caught by purse seine in Lake Union migrated through the Ship Canal and past the Locks sooner than smaller fish tagged at tributaries or reared and released at the University of Washington (Montlake) and Metro (Fremont Cut) fish rearing facilities. Fish released at Montlake and Fremont Cut in late May and early June arrived at the Locks in small, steady numbers, until the last week of June when passage numbers increased substantially. Wild, tributary fish tagged in mid to late May began arriving at the Locks beginning the second week in June with peak passage the last week of June with migration continuing through early July. The arrival date of hatchery and wild chinook at the Locks was generally independent of release date or flow in the Ship Canal, which may indicate a strong behavioral influence related to the time of year and smolt readiness. Most chinook released in the Ship Canal (hatchery) either reared for some period of time in the Canal or migrated at a much slower rate than tributary (wild) fish. Most hatchery fish released and migrating through the Ship Canal travel at less than 0.3 miles per day while tributary fish traveled between 0.5-1.5 miles per day, taking between 20 to 40 days to reach the Locks from various release points.

In contrast to the protracted juvenile chinook migration, sockeye moved more quickly through the Ship Canal. About 90 percent of all tagged sockeye took 3 days or less to travel from the Fremont Bridge to the Locks (2.7 miles). Coho travel time to the Locks from the Fremont Bridge was intermediate to the slow chinook (0.3 miles/day) and fast sockeye (about 1.0 mile/day) migration. About 50 percent of all tagged coho took 3 days or less to travel from the Fremont Bridge to the Locks while 90 percent took 15 days or less (R2 Resource Consultants 2000).

Figure 31. Juvenile chinook salmon migration timing for 1) top figure -- all tagged fish (hatchery and wild); 2) middle and bottom figure -- wild fish as determined by PIT-tag monitoring at the Locks.



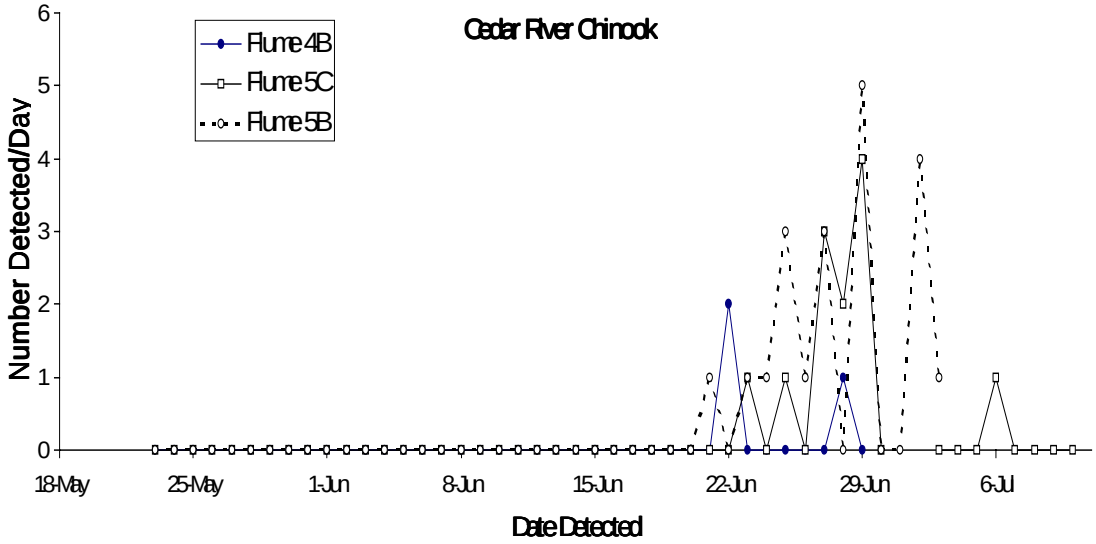


Figure 32. Cedar River juvenile chinook migration timing through the Hiram M. Chittenden Locks

Migration Pathways at the Locks

Observed and potential migratory pathways for juvenile chinook salmon through the project area are shown in Figure 33. There are 12 different routes smolts can pass through at the Locks, we do not know the numbers of fish or survival for 8 of these routes, but assume most fish are going through the main routes. The twelve routes are as follows: 1) fish ladder; 2) spillway gates; 3) four, (new) smolt passage flumes; 4) "old" saltwater drain; 5) saltwater drain through the fish ladder auxiliary water supply; 6) entrainment into small lock culvert intakes above the chamber; 7) volitional migration through the small lock miter gates and down lock as boats; 8) entrainment into the small culverts (2 x 4 side portals) during down lock in the small lock chamber; 9) entrainment into large lock culvert intakes (above the chamber) with discharge into the upper lock chamber; 10) entrainment into large lock culvert intakes with discharge into the full lock or lower lock chamber; 11) entrainment into the small (2 x 4 feet) culverts in the lock chamber during downlock (of the upper or full lock); and 12) volitional migration through the large lock miter gates and down lock as boats.

Table 29 shows the best available information on juvenile fish passage through known and possible routes at the Locks (more details are in Factors of Decline, Fish Passage). Conduit Type includes categories of fish safe, unsafe (without and with potential injury), or uncertain. Fish Passage Likelihood is whether it is a known route, possible, or uncertain. A qualitative ranking of Fish Passage Use is shown for high spill, low spill, and no spill conditions. Monitoring and Injury Assessment are also included with details in the Factors of Decline. Although we have indicated there are up to 12 possible routes that juvenile salmon may take through the Locks, monitoring to date indicates that these fish are likely

to pass through one of three major routes: the spillway (smolt passage flumes, spillway gates), large lock gates, or filling culverts. Understanding of smolt migratory behavior through the project is based on four years of monitoring of smolt passage at the locks and information from other water control projects in the Pacific Northwest (WDFW, MIT, USACE and other).

Figure 33. Conceptual model of observed (solid line) and possible (dashed line downstream passage routes for juvenile salmon at the Hiram M. Chittenden Locks**.**

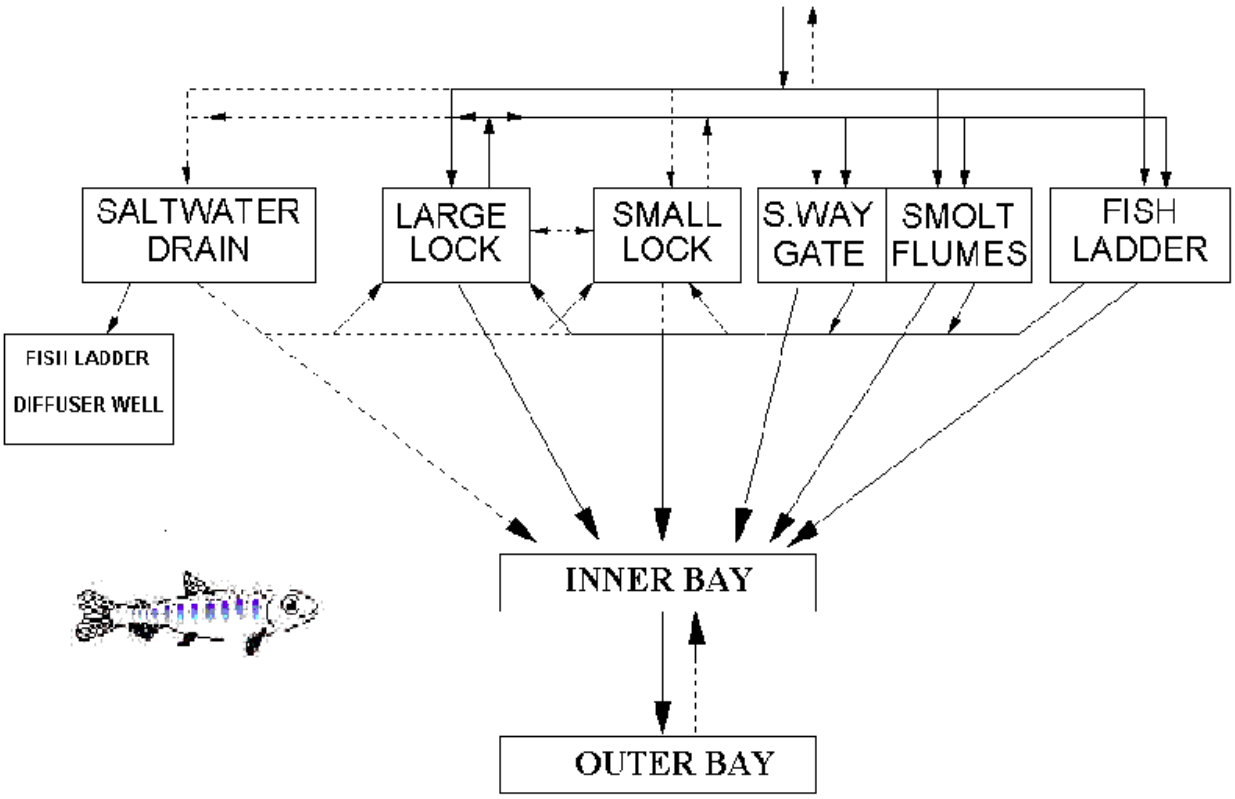


Table 29. Summary of juvenile salmonid passage by conduit route

Pathway	Conduit Fish-Type	Fish Passage Likelihood	High Spill	Low Spill	Without	Monitored	Injury Assessment
Spillway							
	Safe	Known	Low to None	Low	Low to Mod.	Yes	No
Smolt Passage Flume	Safe	Known	High	Moderate	None	Yes	No
Spillway Gate	Safe	Known	High	Moderate	None	Yes	No
SW Drain Intake							
Diffuser Well Outlet	Uncertain	Known	None	Low	Uncertain	Yes	No
Old Drain Outlet	Safe	Known	None	Low	Uncertain	Yes	No
Small Lock							
Culvert Entrainment Uplock	Uncertain	Uncertain	None	Uncertain	Low	Yes	No
C. Entrainment Downlock	Uncertain	Uncertain	None	Uncertain	Low	Yes	No
Volitional and Downlock	Safe	Uncertain	None	Uncertain	Low	No	No
Large Lock							
Uplocking							
C. Entrainment U. Chamber	Unsafe	Known	Low	Mod. To High	High	Yes	Yes
C. Entrainment F. or L. Chamber	Unsafe	Known	Low	Mod. To High	High	Yes	Yes
Downlocking							
C. Entrainment L. Chamber	Unsafe	Uncertain	Uncertain	Uncertain	Uncertain	No	No
Volitional and Downlock	Safe	Known	Uncertain	Uncertain	Uncertain	No	No

In addition to the 12 different routes smolt may pass through, data from the PIT-tag pilot study has shown that juvenile chinook salmon pass can pass through the flumes more than once: 32 of 1990 detected fish passed through twice or about 1.5% (R2 Resource Consultants 2000). This recycling of fish would require that juvenile chinook migrate upstream through the project. The only known routes for which juvenile chinook could pass is during an up lock of either the large lock or the small lock. If juvenile fish can pass upstream above the project, to pass downstream they could elect to use, or become involuntarily entrained, into one of the 12 potential routes a second time.

The migration of juvenile chinook salmon from the Locks into Shilshole Bay occurs from mid-May to the end of July with the peak from mid-June through early July (Figures 31 and 32) corresponding to the period of warming summer temperatures and decreasing flow releases from the Locks[3]. As chinook pass through any of the outlets at the Locks, they are discharged from the freshwater Ship Canal to the marine waters of Salmon and Shilshole Bay. In general, chinook salmon encounter an abrupt change in temperature and salinity as they pass from the warm (~15-21° C), less saline waters (0-0.3 ppt) upstream of the Locks to the cool (12-16° C), saline (10-29.7 ppt) waters of Shilshole Bay.

[3] The MIT reported that juvenile chinook were caught in the large lock chamber in mid August during purse seining for adult chinook salmon. Numbers and source of fish (wild or hatchery) have not been provided to the Corps (E. Warner, MIT, pers. comm. 2000).

As chinook swim away from the locks towards Shilshole Bay, they probably occupy less saline, warmer surface waters (depths~2-4 m or less) in the inner bay) during the first few days, moving over time to the outer Bay where temperature is less and salinity is relatively great (Simenstad et al. 1999; R2 Resource Consultants 2000).

Little information is currently available regarding the baseline characteristics of freshwater, nutrients, and food exported from the Lake Washington/Lake Union Basin from all outlets at the Locks: although pilot water quality measurements of spill have been taken, and duration of freshwater spill is given in Figure 24, summary hydrograph of available water for spill. Following is a summary of preliminary results and recommendations from a pilot study conducted by the University of Washington and Battelle Labs in the Salmon and Shilshole Bay estuary during summer 1999 (Simenstad et al. 1999).

Simenstad et al. (1999) noted that there was a prolonged occurrence and abundance of juvenile chinook in inner Shilshole Bay through September indicating that the bay is a possible "attraction," if not "rearing," area for juvenile salmon. During this time, the size class of fish in the inner bay did not change, with smaller fish remaining throughout the study period, suggesting constant recruitment and flux. There was also some evidence for poor feeding success, or behavioral disruption of feeding, in juvenile chinook immediately below Locks. Surveys of benthic and planktonic salmon prey organisms showed that regardless of size, chinook salmon in inner Shilshole Bay (RR bridge to Locks) ingested mostly *Daphnia* (up to 90% of total biomass) (freshwater cladocerans), while fish from outer Bay fed on gammarid amphipods, other crustaceans and fish. Larger chinook juveniles in the outer Bay fed primarily on fish and polychaete worms; smaller fish consumed mainly amphipods and other benthic/epibenthic crustaceans.

Recent studies of acoustic-tagged juvenile chinook salmon in the Columbia River estuary (Schreck et al. 2000) may provide the most appropriate information on individual chinook salmon behavior upon entry into an estuary and tend to support observations from Shilshole Bay. Acoustic-tracking results indicate that at least 40% of monitored fish remained in freshwater as long as possible. A sample of fish was tracked with depth tags -- all indicated migration depths of less than 4 meters. Further analysis showed the tracked fish were most likely at the surface where freshwater was located. Other observations were that larger fish migrated faster and presumably moved through the estuary faster and thus avoided predation (see Factors of Decline Predation below). Movement of the acoustic-tagged chinook in lower Columbia River estuary was influenced by the tide, with individuals moving downstream on the ebb tide and holding or moving upstream on the flood tide (Schreck et al. 2000). Saltwater preference testing, has suggested that more smolted chinook are more likely to enter saltwater, while less smolted fish may avoid saltwater and remain in freshwater (Seals and Schreck, unpublished data cited in Schreck et al. 2000; Schreck et al. 2000).

Other field studies of juvenile chinook salmon estuary rearing support and contrast with the acoustic tag data (showing general use of the freshwater lens) from the Columbia River. Observations from two large rivers, the Sacramento and Fraser Rivers have shown fry and

fingerlings using estuary areas with low salinity (Kjelson et al. 1982; and Levy and Northcote 1981; 1982). In moderate size rivers, Cowichan, Nanaimo, Courtenany and Campbell, fry and fingerlings have been observed in higher salinity areas, 15-20 ppt or more (Healey 1980(b); 1982(b); Levings et al. 1986). MacDonald et al. (1987) described differences in habitat use between hatchery and wild chinook in the Campbell River. Larger hatchery chinook were in deeper, frequently more saline water (up to 30 ppt) than smaller wild chinook. Wild chinook were frequently observed in the upper freshwater layer, rearing in average salinities of 4 ppt (vs. 8 ppt for hatchery) and temperatures of 13° C. Surprisingly, wild chinook also tended to rear in areas of higher velocity (mean=0.8 feet per sec (fps)) than hatchery chinook (0.4 fps). At low tide, the wild chinook were found at the outer edge of the estuary in areas of low velocity.

In 2000, the MIT conducted pilot studies of predation of juvenile chinook salmon below the Locks (Footen 2000). During the study, although the freshwater lens probably extended only a few hundred meters beyond the Locks, the catch per unit effort for smolts in the inter-tidal zone dropped dramatically as the smolt passage flumes were closed suggesting either that: 1) the main chinook migration period had ended; or 2) smolts may have become delayed or entrapped above the Locks following closure of the flumes. In related monitoring of PIT-tagged chinook, there was a large fraction of the PIT tagged fish that was caught in saltwater within a few days of detection in the smolt flumes, suggesting a rapid osmotic transition had occurred. The PIT tag data suggest that the captured downstream migrants spent relatively little time in the lower salinity lens below the Locks before making the transition to higher salinity water. Those smolts not ready to transition to more saline water may swim back upstream through the locks as suggested by the recycling data (fish detected twice in the flumes) (R2 Resource Consultants 2000). What remains unknown, however, is: 1) whether fish that are ready to make the transition are susceptible to avian or other forms of predation during that short period while they are confined to the relatively small freshwater area below the Locks; and 2) how necessary is the freshwater lens to less developed smolts for additional time and space to complete the smoltification process.

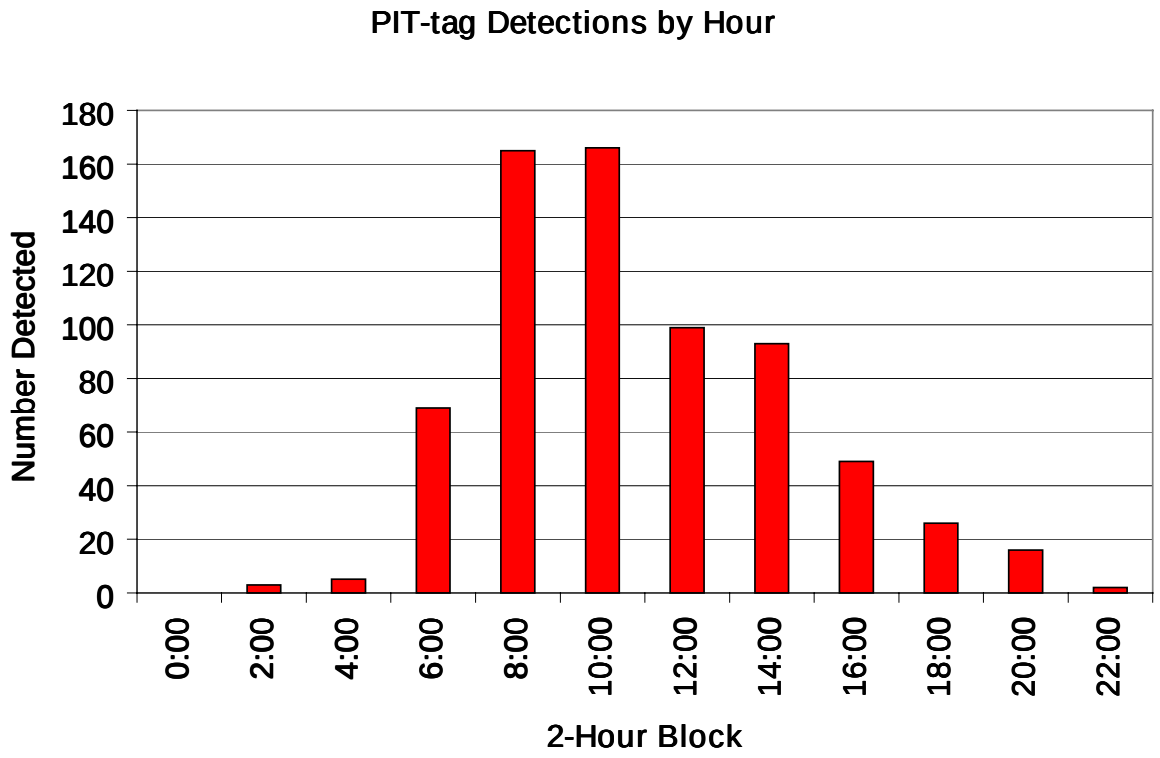


Figure 34. Diel timing of PIT - tagged juvenile chinook salmon using 3 flumes during June 20-28, 2000

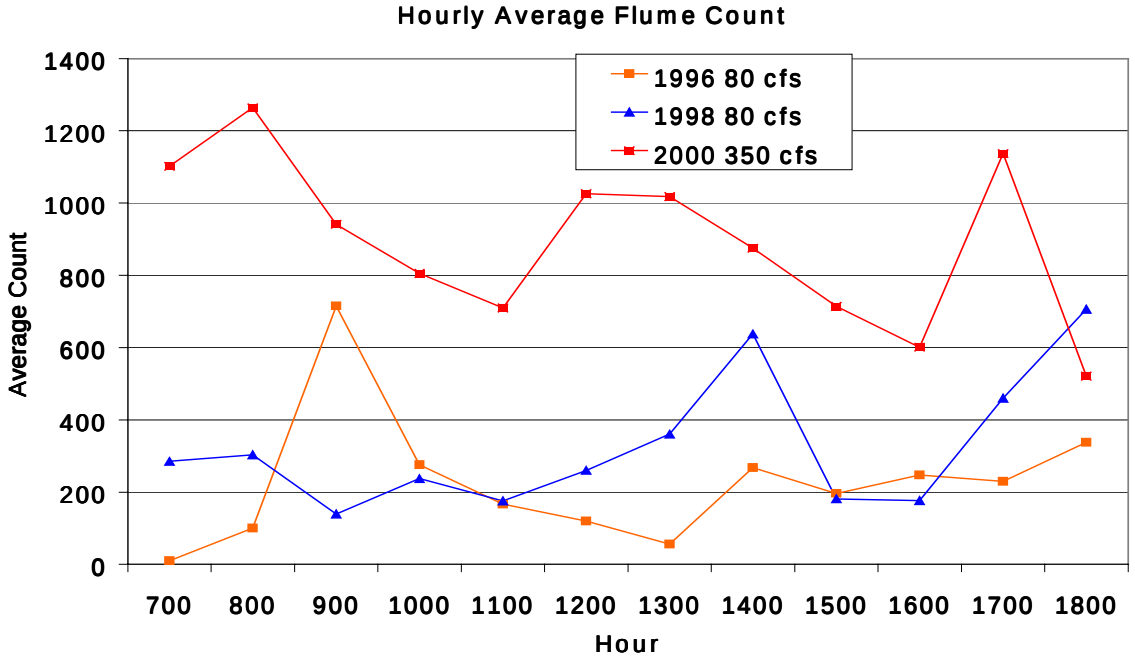


Figure 35. Comparison of the hourly smolt flume counts for 1 flume, 1996 and 1998, and for 3 flumes, 2000.

C. Habitat Factors of Decline

FISH ACCESS AND PASSAGE BARRIERS

Fish Passage Facilities: Anadromous (migratory) salmon and steelhead that pass through the Locks and Ship Canal must complete this migration twice, once as juveniles during downstream migration to salt water (Puget Sound) and again as adults during upstream migration to spawning areas. At the Locks, there is a large degree of uncertainty in knowing how past actions in the basin have contributed to the decline in productivity of anadromous fish stocks. However, monitoring at the Locks and analysis of coded-wire-tag data completed by the WDFW and USACE has indicated that operation of the Locks can and have significantly affected year-to-year differences in salmon and steelhead smolt-to-adult survival (USACE 1999; D. Seiler, WDFW, unpublished data). This awareness was gained through an interactive, iterative process between resource agency biologists and USACE staff using long-term indicators of system health, and specified measurements of existing project operations and controlled or paired evaluations.

As previously stated, the Locks were built with adult fish passage facilities, a freshwater log-weir fish ladder and included a series of six spillway bays to pass excess inflow. The log weir fishway was replaced in 1976 with a concrete fish ladder. The new fish ladder included an auxiliary saltwater water supply system. However, the original construction of the Locks nor rehabilitation later did not include specific features to pass downstream migrating juveniles (smolts) salmon and steelhead. In 2000, the Lake Washington Ship Canal Section 1135 project was completed, which added 4 low flow flumes, slow fill of the large lock, and barnacle removal within the large lock conduits. Strobe lights were included in the project, but the purchased system has not met operational criteria and will likely be returned to the manufacturer.

Adult Fish Passage Facilities: An important question is the extent to which the Locks complex delays upstream migration of salmon from Shilshole Bay to the forebay of the Locks. Migration delay may lead to increased energy expenditure, stress, reduced reproductive success, susceptibility to disease, and altered spawning timing, if the delay represents a significant portion of time prior to spawning. The rehabilitated fish ladder was designed to reduce migration delay and facilitate upstream migration, based on the best available information at that time (USACE 2000). Observations of chinook migrating through the fish ladder in relation to diel period and tidal stage indicate a pattern that is generally typical of upstream salmon migration. Nearly all chinook in the ladder migrate during daylight (0700-2200 hrs) with peak migration in mid-afternoon (USACE 2000). The greatest downstream movement of adults occurs during the night, apparently the effect of reduced swimming activity at night (Ruggerone et al. 1990) and downstream moving currents. Tidal stage also affects upstream movement of chinook, as is typical of movement in natural estuaries. Movement during 1999 increased steadily from 1.4 fish per hour at a 2 foot tide to a maximum of 6.4 fish per hour at 10 feet tide, then fish movement declined rapidly with tides up to 13 feet (2.2 fish per hour). Reduced movement at the extremely high tide levels probably reflects lower attraction of fish to the entry pool due to low water velocities (i.e., the lower ladder is flooded). In contrast, movement at the highest

water velocities, as indicated by the lowest tide stage monitored (0 feet), were slightly greater than those at slightly slower velocities (tide level: 1-4 feet). Thus, high velocities associated with tide levels as low as 0 feet do not appear to inhibit migration.

In addition to the improvements from rehabilitating the fish ladder in 1976, the USACE has implemented some additional improvements and is considering others, based on recommendations from the WDFW (Table 30).

Table 30. Status of recent fishway operation and design alternatives.

Status	Operational Considerations
completed	Refine entrance gate of ladder and attraction water control to optimize head differential and gate geometry.
completed (steelhead)	Continue specific review of the effects on passage efficiency of using the saltwater drain to supply ladder attraction water.
underway	Fully evaluate the risks of adult entry to the drain. If necessary, evaluate operational and structural modifications.
Will initiate evaluation next year under LW GI study	Add means to observe and remove fish that enter saltwater return system and fishway auxiliary water system, alternatively evaluate need and means to exclude adult entry at the saltwater return intake.
	Design Considerations
considering the alternative	Evaluate installation of controllable gate at the north (auxiliary) entrance. Analyze effect on flow and head control, alternatively, consider closure of the gate utilizing only the main entrance
considering	Replace west entrance vertical wing gates with horizontal telescoping weir including an orifice opening.
considering	Determine feasibility of modifying the ladder water supply system to allow specific tests of water source (freshwater vs saltwater) on passage efficiency.
underway	Conduct comprehensive evaluation of passage through the entire project area.
requires feasibility study	Evaluate installation of a second fishway.
controlled by predator removal	Evaluate feasibility of creating a refuge/sea lion barrier near the fish ladder entrance.
considering	Evaluate need and design of a fishway entrance lighting.
completed	Review and evaluate fishway entrance flow.

Time spent by chinook salmon below the Locks prior to upstream migration has not been studied. However, Tabor et al. (1994) tagged and tracked 9 adult steelhead below the Locks using ultrasonic telemetry equipment. Only two fish migrated through the Locks (six fish migrated back to Puget Sound and one died). These fish spent 4.7 to 8 hours below the Locks before entering the fish ladder. These data do not indicate an unusual delay of steelhead below the ladder, but only two fish were observed. As noted previously, it is not unusual for adult salmon to spend up to 1 month holding in estuary areas prior to initiating upstream migration.

Salinity in the ladder entry pool has been identified as a potential factor affecting attraction of fish to the ladder. Salinity is influenced by operation of the saltwater drain, which transports 160 cfs from the bottom of the forebay to the lower half of the fish ladder, and by tide stage (high salinity at high tide). The moderately saline water from the saltwater drain mixes with 18.6-23 cfs of surface freshwater in the ladder. Although effects of

salinity on chinook migration in the ladder have not been conducted, Tabor et al. (1994) suggested that the low salinities observed in the entry pool of the ladder during their study (< 3 ppt) did not appear to inhibit migration of steelhead. In contrast, other researchers suggested salinities greater than 9-10 ppt in the entry pool may slow steelhead passage (Infometrix 1994, Pfeifer 1994). Frequency of salinity at or above 9 ppt was 14.4% during July through September 1999 (USACE 2000). Maintaining cues, such as freshwater, for homing chinook is an important function of the fish ladder.

A small number of fish may currently pass through the saltwater drain, but recent improvements in the drain operation procedures are believed to minimize use of this route. During 1980 to 1994, a screen to exclude adults covered the outlet of the saltwater drain, but the screen was removed in 1994 after WDFW observed smolts impinged on the upstream surface of the screen. Video monitoring of the diffuser well portion of the saltwater drain system (i.e., part of the fish ladder design) showed up to 11 chinook and 1 sockeye trapped in the well. This observation led to changes in the standard operating procedure of the saltwater drain in 1998 to minimize attraction of chinook to the drain outlet. Fish attraction is reduced by closing the drain during summer tides exceeding 7 feet and by operating the drain primarily at night when fewer adults migrate.

Adult salmon may enter the intake of the saltwater drain in the forebay of the Locks. The intake was initially screened, but accumulation of debris required that the screen be removed. Salmon entering the drain should be able to swim out of the six-foot diameter pipe since velocities are not high (5.6 ft/s). Numbers of chinook entering the intake and time spent there is currently under investigation by hydroacoustic and video monitoring as well as by tracking movements of adults in the forebay (Biosonics 2000; HTI 2000).

Juvenile Fish Passage: To reach Puget Sound, smolts in this portion of the Cedar - Sammamish Watershed must migrate through the Locks. In most years more than 2.5 million smolts will migrate through the Locks. There are over 12 different routes smolts can pass through at the Locks (Figure 33 and Table 29).

Major issues for juvenile migration through the Locks include evaluation of recent changes and future concerns that have as yet not been addressed. Major issues are as follows:

- Mortality and injury of juvenile salmon passing through the Locks requires improved conditions. Fish passage improvements were completed in 2000 with full implementation expected by 2001 or 2002 through structural and operation changes including experimental technology. Strobe lights were originally included in project rehabilitation, the lights may be removed. One replacement for strobe lights could include further lengthening the fill time of the large lock, following replacement of the Stoney gate valves in 2002.
- Have fish passage modifications actually improved fish passage survival -- by reducing entrainment through non-fish passage routes and increasing passage over preferred routes. Monitoring and evaluation has occurred in 1996, 1997, 1998, 2000, and will again in 2001.

- There is not enough water in most years to run smolt passage flumes. As explained above and shown in Figure 24, in most years there is little available water for spill after mid to late June. Without action, future conditions are expected to further reduce available water (see Altered Hydrology below).

A number of factors relating to fish health and development (smoltification) have been shown to influence the behavior of juvenile salmonids, and by extension, direct or indirect survival. For example, injury (descaling, bruising) of smolts can increase the delayed mortality of smolts (Bouck and Smith 1976) while injury and stress can reduce the quality of outmigrants in terms of predator avoidance (Mesa 1994; Schreck et al. 1997); preparedness for saltwater entry (i.e., smoltification; McInerney 1964; Schreck 1982; 1992), and disease resistance ability (Schreck 1996; Maule and Vanderkooi 1999; Maule et al. 1989); which also negatively affects predator avoidance and smoltification (Schreck 1982; Schreck et al 1985; Mesa et al. 1998). Since 1994, monitoring and evaluation coupled with smolt passage improvements have been used to improve the survival of juvenile salmon migrating through the Locks. The following effects discussion covers fish passage through various routes at the Locks.

Smolt Passage Flumes: Fish passage monitoring of the new flumes corroborated pre-baseline information on diel timing observed for the prototype flume. PIT-tag monitoring showed a predominate diurnal migration timing for juvenile chinook (Figure 34). In counting all smolt species, observer counts did not show a clear pattern for peak abundance for any daytime period. Mean hourly counts were 3-5 times greater in 2000 at 335-350 cfs vs. 80 cfs in 1997, 1998 (Figures 34 and 35). There was a pattern of increased fish counts for flumes closest to the fish ladder (50% through closest flume) although there was a decreasing proportion of fish using this flume throughout the season (Figure 35). This overall pattern of greater use of the flume nearest the fish ladder was corroborated by the PIT-tag tunnel counts (R2 Resource Consultants 2000; Johnson et. al 2001).

During the primary chinook migration period, mid to late June, from 2,000 to 15,000 juvenile salmonids were counted passing over the 3 flumes while from June 30-July 14 with one flume operating, less than 500 fish were counted per day (Johnson et al. 2001). The proportion of fish exiting the flumes vs. entrainment through the large lock culvert intakes is described in the Large Lock section below.

In 2001, the WDFW will evaluate a prototype rigid net-pen to capture unmarked smolts passed through one flume. Captured smolts exiting the flumes will be evaluated for injuries and identified for species composition. If the pilot monitoring is successful, a larger more expansive net-pen may be constructed to capture smolts exiting from more than one flume. Capture and evaluation of smolts exiting the flumes could become the basis for a new WDFW program to estimate smolt production for all salmon stocks in the Lake Washington Basin including chinook (D. Seiler, WDFW, pers. comm.).

The primary concern remaining with the smolt passage flumes is the obvious lack of available water for spill during the later part of June and July when most juvenile chinook salmon are migrating through or rearing below the Locks. When spill isn't available,

chinook and other smolts are forced to select other routes (fish friendly or not) to exit the Locks. By this late time in the migration season, juveniles are likely highly motivated to migrate from physiological cues or due to the increasingly poor water quality conditions in the Ship Canal – increased water temperatures (discussed in Water Quality section below).

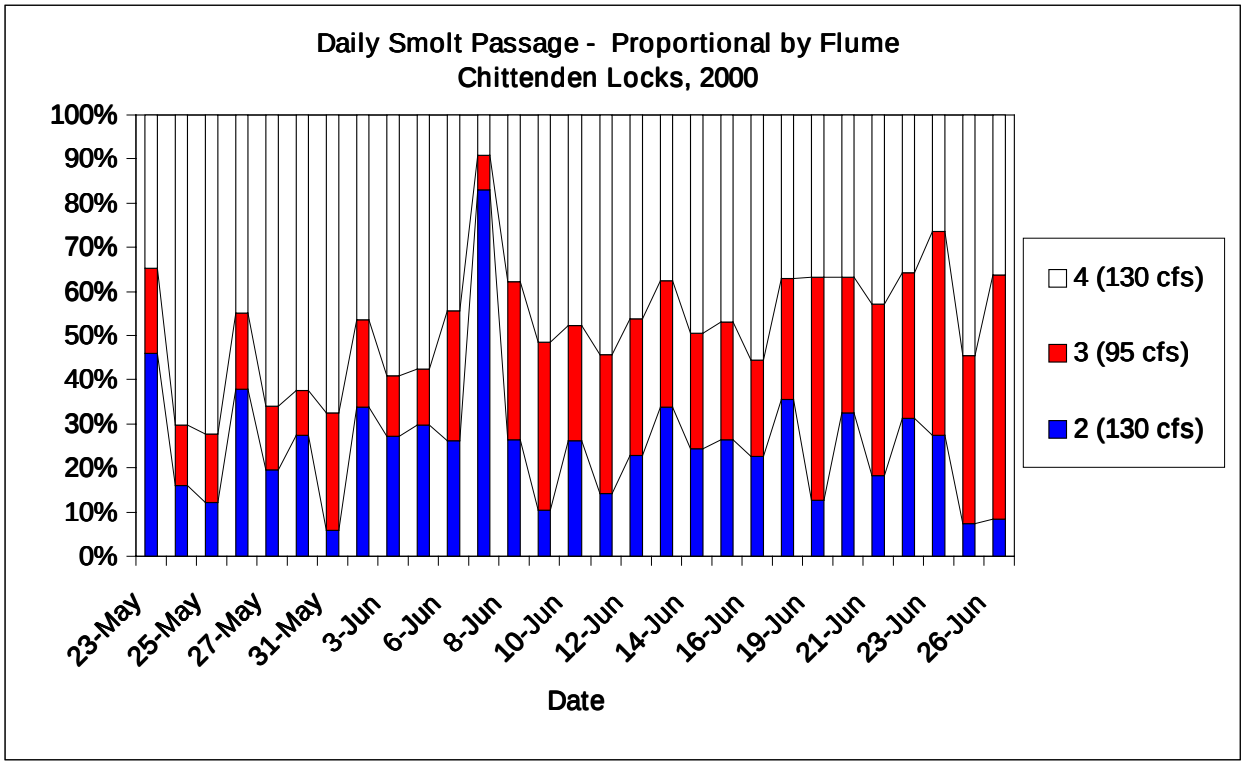


Figure 36. Proportion of fish using 3 different flumes over a 6 week period in 2000: flume 4 (5b) is closest to the fish ladder; flume 2 (4b) is furthest from the ladder.

The detection of PIT-tagged juvenile chinook after passage through the Locks confirmed and contradicted some preliminary hypotheses. It was thought that some juvenile chinook were passed through the Locks more than once. Of 1990 detected PIT-tagged chinook, 32 passed through the flumes twice indicating that juvenile chinook were passed back up into the Ship Canal through either the large or small locks before passing through the flumes again. The time from the first to the second flume detection (recycling time) decreased from the beginning of the experiment (maximum 40 days) to the end of the experiment (minimum 5 days). It was also thought that smaller fish were more likely to rear for longer periods at the Locks increasing the probability they would be passed through the project more than once. There was no relation between the recycling time and fish size at the time of tagging. 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.

Spillway Gates: By late spring, the flow volume into the Ship Canal is usually reduced such that the spillway gates cannot be opened wide enough most days to safely pass smolts. Further, late spring and early summer inflow (May-July) to the Ship Canal appears to have been reduced since the late 1970s as a result of natural climate variability (Houck 2000) and (probably) due to reduced baseflows from continuing development within the basin (Horner and May 1998). Reduced inflow requires conservation of water to maintain elevations of Lakes Washington and Union 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. Prior to 1995, little or no water was spilled over the dam during most days in June and July. In 1995, the Locks built and installed a low-flow smolt bypass, the smolt slide that uses 20-25% the water volume (80-100 cfs) of a 1.0 foot gate opening (400-450 cfs). In 2000, the prototype flume was replaced with the four smolt passage flumes (see above) capable of passing a total of 400 cfs or nearly equivalent to a 1-foot gate opening.

Even with the addition of the four smolt flumes, there are still periods of time in late spring when additional water must be spilled (an infrequent occurrence during the main chinook migration) to maintain the maximum pool elevation. As part of the Lake Washington GI study, Biosonics (2000) monitored fish passage through spillway bay number 2 from April 24 to late June. There were two distinct monitoring periods, prior to flume operation from April 24-May 12, and during flume operation with selected days between May 18 and June 23. Study objectives were to determine 1) the minimum gate opening (0.5 feet or 1.0 foot) that passes the greatest number of fish and 2) document the numbers and behavior (time of passage) of additional fish passed during spill with and without flumes in operation.

The minimum opening for the spillway gates is 0.5 feet or 200 cfs (at 20.0 feet) to 230 cfs (22.0 feet). This opening is used for two purposes, regulating the lake elevation during periods of slight excess inflow, and for providing additional adult fish attraction during the adult steelhead migration. At other water control projects in the Pacific Northwest, the minimum gate opening recommended for passing juvenile salmon is 1.0 foot (Williams et al. 1996). The WDFW and NMFS have never prescribed a standard operating procedure for minimum gate opening(s) for excess spill during the smolt migration season. The first monitoring objective for Biosonics (2000) was to determine if there is a statistical difference in the number of fish passing through a 0.5 feet or 1.0 foot gate opening: results are expected by April 200. The results from the study would be used to evaluate developing a SOP for efficiently passing spill using the minimum opening that passes that most fish.

The second objective (behavior and numbers of fish) for spillway monitoring provided some interesting results. The diel passage of fish (smolts) was distinctly diurnal, with passage commencing about one hour before dawn (0400), peaking between 0800-1600, and ending about 1-hr before dusk (2000). Even during periods of flume operation, from 100 up to 12,000 juvenile salmon were passed through bay 2 during spill in late May and late June. In mid-June, during the peak of chinook migration, from 200 (6 hrs open at night) to 1200 (24 hrs open) fish were passed per day through bay 2 while 2,000-15,000 smolts were

passed over the flumes (Biosonics 2000). The diel pattern of fish movement through the spillway gate corresponds to observed movement patterns over the flumes (see above) and provides clear guidance on when excess spill should be released to provide additional passage opportunities for juvenile salmon.

One possible data gap remains, does a 0.5 feet opening result in additional injury to fish than a 1.0 foot opening? This does not appear to be a concern for fish survival. Spillway gates are typically mentioned as the preferred means to pass juvenile salmonids through water control structures (Williams et al. 1996). There are no indications that the characteristics of the spillway gates at the Locks should be a concern. The gate opening is at a low head, 8.0-9.0 feet, and the average maximum velocity through the 0.5 feet opening is between 12 to 15 fps, well below velocities reported as causing injuries to fish. The spillway crest does not have an overly rough surface nor are there structures protruding from the crest or tailrace that could result in mechanical injury or mortality (R2 Resource Consultants 1998; and see large lock discussion).

Fish Ladder: The fish ladder passes a small number of migrating juvenile salmon. In 1994, prior to 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 (Dave Seiler, WDFW, unpublished data. 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. Study plans for 2001 include observer counts concurrent to smolt flume counts for a selected number of days. Counts will be used to help define estimated numbers of smolts using monitored pathways.

Saltwater Drain: Historical fish protection measures have included screening the intake and the outlet so adult salmon would not enter the culvert. During rehabilitation of the fish ladder in 1976-1977, a fiberglass mesh screen was installed across the entrance of the saltwater drain (SW) 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. 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 first concern over juvenile fish use of the drain occurred in 1994 when the WDFW found sockeye salmon smolts impinged on the upstream side of an adult exclusion screen at the drain outlet. The screen was removed in June of 1994. Since that time, the depth and inaccessibility of the intake have limited monitoring of the intake. In 1995 the WDFW tried a short-term monitoring experiment with installation of an incline plane trap at the outlet to the old saltwater drain. The trap was installed when the drain was in off. When the drain was turned on 140 cfs was passed over the flume. Flow was supercritical and it was very hard to observe if fish were passed through over the screen. A few fish were observed going over the screen before the support structure collapsed. A small number of juvenile fish may still pass through the saltwater drain, but recent improvements in smolt

passage facilities are believed to minimize use of this route during periods of available spill.

As part of the Lake Washington GI study, Biosonics (2000) monitored fish use and entrainment into the saltwater drain intake from April 24 through September 30 using split-beam hydroacoustics and an underwater video camera. Monitoring during the smolt migration season included a period of high spill, April 24 to June 29 when 200 to 400 cfs was continuously spilled, a low spill period, 95 cfs from June 30 to July 13, and no spill after July 17. Preliminary results of their acoustic analysis showed no entrainment of any fish into the intake through the end of May. In June and July 120 fish targets, 68 and 52 per month respectively, were counted by acoustic tracking. Of the targets counted in June, 48 of the 68 targets were counted during the afternoon and evening of June 29, when 2 of the 3 fish flumes were closed. This coincides with the primary migration period of juvenile chinook salmon. This coincidence suggests that juvenile chinook salmon may have been the primary targets observed on June 29. The 52 targets observed in July were counted over 9 days and followed no apparent pattern in regards to flume or Locks operations. Entrainment of juvenile fish may be more of a concern during drought years when little spill is available after early June.

The majority of entrained fish were observed in August and September. Initial review of the video data (providing verification of species) suggests that the majority of entrained fish were surf perch (*Cymatogaster aggregata*) with very few entrained smolts.

If a smolt is entrained into the SW drain intake there are two possible routes the fish may take 1) through the old drain directly from the intake out to Puget Sound; and 2) through the auxiliary water supply pipe to the diffuser well in the fish ladder. Entrainment into and through either pipe is not considered to be a serious concern as the velocities are low (5-8 fps) and the pipes are straight and smooth (no barnacles, no sharp turns). Discharge out the old drain outlet over the spillway crest is unlikely to result in any injuries or mortalities. Discharge into the fish ladder diffuser well may be a problem as there is no direct outlet to Puget Sound from the well. Smolts might pass from the well through fiberglass screens (3 x 3 inch opening) at the base of 5 pools where the water up wells or they may remain in the well. During annual dewatering of the fish ladder in late May few smolts have ever been observed.

Although the SW drain cannot be eliminated as a pathway for juvenile salmon under current operating conditions, even during periods of little or no spill, the SW 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 average vs. 33 feet for lock culvert intake, 2) velocities into the intake (0.5-1.0 ft/sec) are much lower than velocities typically encountered and selected by smolts passed through either the flumes or the culvert intakes (3 to 5 ft per sec), and 3) poor water quality conditions (low dissolved oxygen) may exist for sustained periods. This analysis is supported by fish passage research and environmental conditions at the drain intake.

Fish passage studies at dams in western Oregon and Washington have consistently shown that juvenile fish will use shallow depth intakes (15-30 feet) whenever available. They only elect to sound to greater depths when no other outlet is available (Dilley and Wunderlich 1992 and 1993). Greater numbers of fish will also use outlets with entrance velocities that are 3-5 fps such as the smolt flumes and the intakes to the large lock chamber (M. Jundt, NMFS, K. Bates, WDFW, pers. comm.). Water quality conditions at the intake may fall below 5 mg/l for extended periods during low flow conditions (VanRijn 2000). Juvenile chinook salmon have been shown to actively avoid water with concentrations of less than 5 mg/l (Whitmore et al. 1960).

Small Lock: No direct monitoring of juvenile salmon passage has been conducted in the small lock although anecdotal information indicates few fish use this pathway (USACE, unpublished data, D. Seiler, WDFW, pers. comm.). Based on previous observations of smolt use of the small locks and direct monitoring of the large locks, during periods with enough available water to run 3 or more flumes (see below), it is likely that very few if any fish would use the small locks. Even if fish were to use this pathway, during periods with low or no spill, attributes of the small lock suggest few fish would be injured. Unlike the large lock the small lock is not lined with barnacles. Further, conduits in the small lock operate under lower head and lower velocities than the large lock. Juvenile salmonid use of this pathway will be monitored by underwater video camera on a weekly basis in 2001. Also in 2001, the WDFW may conduct a limited number of purse-seine sets in the small lock to verify that fish use and injuries are as low as expected.

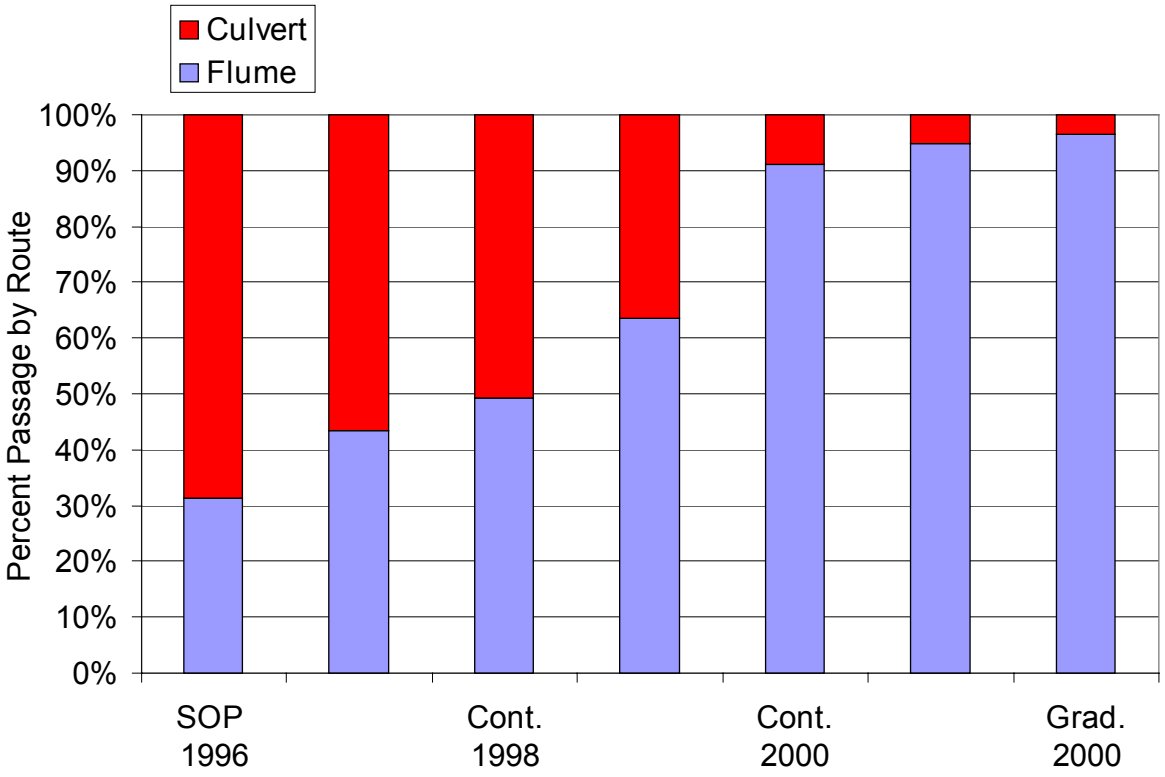
Large Locks: Over time, the large locks has been implicated as the primary source of injury and mortality for smolts passed through the Locks. The primary concerns regarding juvenile salmon use of the large lock are: 1) entrainment into the filling conduits and culverts, and subsequent injury and morality during passage through the conduit system; and 2) predation of injured or disoriented smolts passed through the conduit system. Smolt passage improvements completed in 2000 and 2001 include the objectives: 1) reduce entrainment of juvenile fish; and 2) reduce injury of any remaining entrained fish.

Entrainment Reduction: Smolt entrainment has been monitored by purse seining in the large lock chamber in 1996, 1998, and 2000, and by hydroacoustic monitoring of the culvert intakes in 2000 (WDFW 1996; D. Seiler, WDFW, unpublished data; Johnson et al. 2001).

Entrainment of smolts into the large lock filling culverts has seen a dramatic reduction from 1996 to 2000. In 1996, 540 smolts were entrained during normal fill conditions. In 1998, from 211 to 360 smolts were entrained during slowest to fastest slow fill procedures (see previous discussion). These entrainment rates were with one flume (80 cfs) in place. With the addition of 4 new flumes (3 flumes operating most of the migration season) the entrainment rate in 2000 was reduced to 45-120 fish per fill. The average entrainment was 93 fish per fill or an average 83% reduction in the entrainment rate from 1996 to 2000 (WDFW 1996; D. Seiler, WDFW, unpublished data).

Another way of showing a redirection of smolts away from entrainment to passage over the flumes is to compare the proportion of fish passed over the flumes vs. entrained in the large lock filling culverts[4]. Figure 34 shows the change in proportional passage from 1996, to 1998, to 2000. There has been an increase in the proportion of fish using the flume(s) from 30% in 1996 (normal fill), to 50% in 1998 (continuous fill), to an average 95% in 2000 (intermediate fill).

Figure 37. Change in proportion of fish passing through one of two major outlet(s) at the Locks over time – 1) entrained through the filling culverts of the large lock chamber; and 2) passing over 1 flumes (80 cfs, 1996 and 1998) or 3 flumes (350 cfs, 2000). Categories for each bar list the fill type used (SOP=standard fill; Intermediate is a moderately slow fill; continuous is the fastest "slow fill"; and graduated is the slowest "slow fill").



The proportional passage of 95% was measured during purse-seine periods between May 9 and June 22 when 250-400 cfs was being spilled during any one monitoring period (or 48-80% of all water used at the Locks). Alternatively, culvert entrainment was reduced from 70% in 1996 to 5% in 2000. The 2000 measure of fish passage efficiency has been corroborated by another entrainment monitoring method, split-beam hydroacoustics.

[4] The term "proportional passage" or "proportion of fish" used here is considered equivalent to the terms "fish collection efficiency" or "fish guidance efficiency" used to described the percentage of fish passage through juvenile bypass systems on the Columbia River.

Waterways Experiment Station (WES), independent of the purse-seining monitored the entrainment of fish into each large lock culvert intake with separate split-beam systems over a longer time frame (Johnson et al. 2001). WES then developed separate measures of proportional passage and came up with nearly the exact same percentage of fish being entrained (2% vs. 5%) as did purse-seining or 98% (vs. 95%) using the flumes (Figure 38).

A dramatic change occurred in the proportional passage following closure of two of three smolt flumes on June 29. While the percent of fish using 3 flumes was 98%, the percent of fish using 1 flume dropped to as low as 20% (80% into the culverts) in the days immediately following the closure. After several days the percentage increased to as high as 80% until the final flume was closed in mid-July (Johnson et al. 2001).

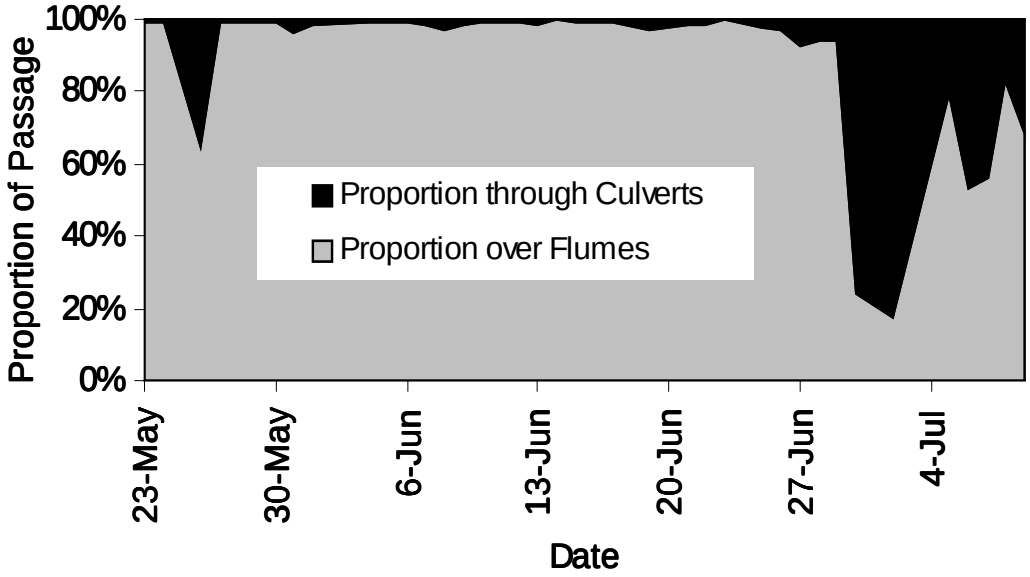


Figure 38. Relative daily proportions of flume and large lock culvert passage estimates.

The estimates of proportional passage are based on smolt entrainment into the upper lock chamber. The upper chamber is the primary chamber used to pass vessel traffic during late spring and summer months. However, some number of lockings are performed using the full lock chamber, usually to pass gravel barges, large ships, and to accommodate heavy recreational traffic on weekends. Hydroacoustic monitoring showed approximately 40% more smolts were entrained during full lockings than half-lockings, average of 41 vs. 29 fish, respectively. Fish passage through the filling culverts over time shows that the highest concentration of passage occurred from the latter part of June through early July (chinook migration period) and from mid July to early August. An estimated total of 14,018 fish were entrained through the study period of 19 May to 7 August (Johnson et al 2001).

In contrast to the diurnal passage over the spillway (flumes and gate) hourly entrainment estimates for both upper and full chambers during intermediate fill types show that the majority of fish passage occurred during nighttime hours. This trend was most apparent

with full chamber fill events as daylight entrainment remained relatively constant. Full chamber entrainment peaked during 0200 and 2200 hours. Upper chamber hourly entrainment was considerably more erratic, with peaks at 0100 and 0500 hours, and lowest hourly entrainment occurring at 2000 hours (Johnson et al 2001).

The 2000 results must be conditioned given that water for flume passage is not available in all years and is severely limited in most years in late June and July (see Figure 24). Sustained entrainment reduction during low flow conditions may be possible if additional behavioral guidance measures are used, such as fill rates slower than those already tested, and/or if new strobe light equipment is available.

Even though there is a reduction in our measured entrainment rate, there is still no available information on whether smolts are migrating into the large lock chamber through other pathways (volitional through the gates) or may be re-entrained during downlock. PIT-tag results show that fish are passed upstream, most likely through the large lock.

Injury Reduction: A second objective related to the large locks, was to reduce the injury rate of any smolts still entrained into the culvert intakes and deposited in the upper half of the lock chamber. In November of 1999, all of the conduits of the large lock chamber were cleaned to bare concrete by a high pressure wash. Since 1996, as part of estimating smolt entrainment in the conduits in the upper lock chamber, the WDFW has evaluated captured smolts for injuries (heavily descaled, 10% or more descaling on one side the body; lightly descaled, 10% or less). In 1998, monitoring included injury evaluation prior to barnacle removal with all slow fill types. These results were compared with monitoring in 2000 after barnacles were removed. In 2000, as shown in Figure 39, there was a 75% reduction in heavy descaling of fish captured in the large lock chamber. Prior to barnacle removal (1998), from 10-15% (13% on average) of smolts were heavily descaled when entrained and passed through the filling conduits in the upper half of the large lock chamber. After barnacle removal (fall 1999) 1-5% (3% on average) of all smolts were heavily descaled when entrained (D. Seiler, WDFW, unpublished data).

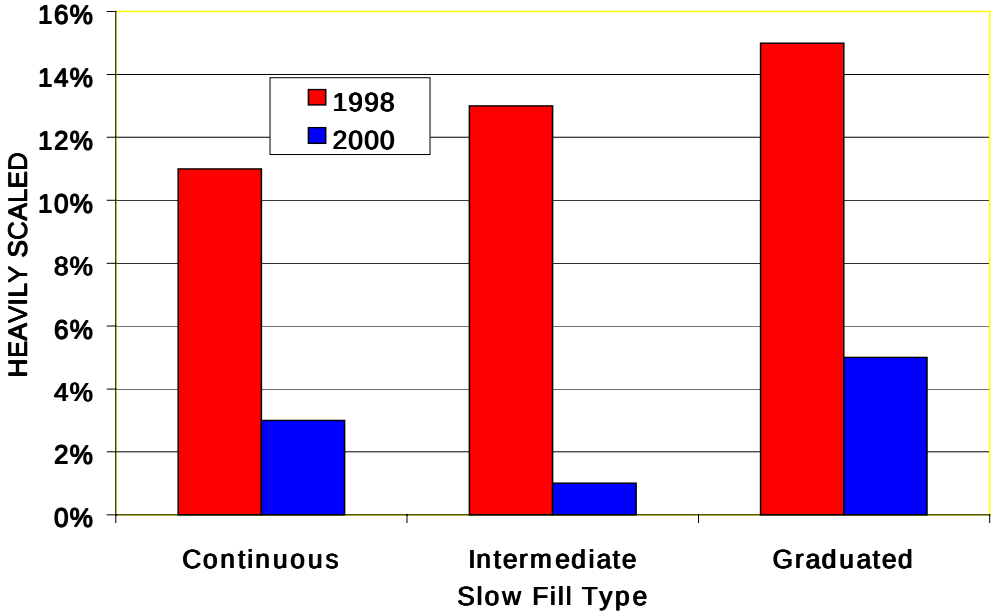


Figure 39. Comparison of heavy (> 10%) descaling of fish captured in the large lock before (1998) and following (2000) barnacle removal.

While the reduction in injury rate for fish captured in the upper chamber is substantial, there is a data gap regarding fish injured after entrainment and being deposited in the lower lock chamber either during a "down lock" or during filling of the full lock. We know more fish are entrained during a full locking but we have no measure of entrainment during a down locking (both result in depositing juvenile salmon in the lower chamber). Pre-baseline injury values in the lower lock are up to 3 times greater (35%) than those reported in the upper lock chamber (10-15%). Barnacle regrowth is slightly higher in the lower chamber than the upper chamber, whether barnacle removal could lead to a lower reduction in injury rates for the lower chamber is uncertain.

With the entrainment and injury reduction in the upper chamber in 2000, a hypothetical calculation of improved survival can be provided for the period May 16-June 29. Using 1996 figures, if 70% of the smolts were entrained in the culverts with 13% heavy descaling (low estimate) and if all smolts are considered mortalities, than 9.1% of every 100 smolts would be killed. Using 2000 data, if 3% of smolts are entrained with 3% heavy descaling (high estimate) and if all heavily descaled smolts are considered mortalities, then 0.9% of every 100 smolts would be killed a 90% percent reduction. Please note that this calculation is not true for the entire chinook salmon migration as the flumes were only operated at 350 cfs until June 29 and then were shut off due to low lake elevation.

R2 Resource Consultants summarized research on sources of mechanical injury to fish (R2 1998). They noted the primary sources of mechanical injury for fish passing water control structures result from: 1) immediate mechanical injury from passing through spillways or conduits from abrasion, strike, and related mechanical mechanisms (rapid deceleration, pressure differentials, striking impacts, shearing effects and turbulence); 2) short term

delayed injuries that occur within 3 minutes after passage; and 3) longer term injury, injuries that occur after fish leave conduit outlets.

Immediate injury from shear zone conditions occurs when fish move from high velocity to lower velocity layers in the water column. This situation could occur when a fish moves from the rapidly moving water of the spillway into the slower waters of a stilling basin or when a fish entrained in the large lock conduits is moved from high velocity waters in conduits to the slower waters of the chamber. Injuries typically occur to juvenile salmon when the submerged high velocity jet exceeds 55 fps (Johnson 1970a, 1970b, 1970c, and 1972). Estimated and measured velocities in the lock conduits do not exceed 25 fps (Fagenberg et al. 1998). Given the lower velocities within the lock conduits, shear zone injuries are not likely to be a main source of mechanical injury.

Immediate injury may also take the form of abrasion when fish contact physical structures such as spillway gates or flip lips or the concrete walls and highly serrated barnacles covering the walls within the lock conduits. As an example, juvenile coho and chinook salmon injuries were measured after passage through a narrow (4 inch) high velocity jet (80 fps) into flip buckets with various roughness levels, using enamel, sand, and gravel. Delayed mortality (12.3%) and the percent of descaled fish (34%) both increased with high roughness when compared to smooth bucket surfaces (1.3% delayed mortality and 0% descaling) (USACE 1997). In the large lock chamber, abrasion may be the primary mechanism of immediate injury for juvenile salmon passed through the lock conduits. The removal of barnacles in 1999 reduced the roughness of the lock conduit surfaces and corresponds to a 75% reduction in heavily injury smolts still entrained within the conduits (from 13% to 3%).

Short term delayed injury includes injuries that occur after fish have passed through a water conduit (i.e. spillway or lock conduit) but prior to leaving the outlet area. This type of injury is thought to be more likely as the area affected by turbulence increases, a function of discharge as well as the energy dissipation characteristics of the conduit outlet. There is no available information on short term delayed injury and its relative impact on fish passed through the spillway gates or conduits of the large lock chamber. The largest problem in evaluating this type of injury is isolating it from other types of injury, such as that occurring during passage through the conduits (R2 1998). However, good survival conditions may be provided as long as highly turbulent conditions are controlled (USACE 1996). If this condition can be assumed true for other outlets, then short term delayed injury conditions within the large lock chamber have been reduced since implementation of slow fill procedures in 1999. The current method of slow fill is meant to increase the fill rate (with subsequent reduced entrainment) and to avoid any turbulence at the water surface in the lock chamber. The initial objective of eliminating turbulence was to eliminate seagull predation of up welled smolts but the subsequent effect may have also resulted in reduced short term delayed injuries.

Longer term delayed injuries occur after fish leave the conduit outlet but which can be attributed to physical impacts and modifications in behavior occurring from exposure to conditions in the spillway, stilling basin, tailrace or conduit outlet. Examples of this type

of injury include abrasion and descaling of fish during spillway or conduit passage which later result in disease and mortality, disorientation of juvenile fish during migration, and changes in behavior which may increase susceptibility to predation.

Smolts entrained in the large lock conduits start in freshwater and are deposited in saltwater. Injury criteria for the Columbia River basin presumes that smolts that are descaled by 16% or more (on one side of the body) are considered delayed mortalities (as reported in Dilley and Wunderlich 1992). Further, a study by Bouck and Smith (1979) showed a 75% mortality rate for descaled coho smolts immersed in saltwater. The authors also reported that heavier descaling (25%) resulted in a 90% mortality rate after 10 days. The authors speculated that scale loss may even have an even greater effect on the smolts than mortality alone can indicate. They note that Lorz and McPherson (1976) reported that sublethal levels of copper stress can cause coho salmon smolts to lose their inclination to migrate seaward, hence to become residuals in the stream. If descaling has a similar effect on seaward migration of coho or chinook, this could be have been a very significant problem for fish exiting through the Locks prior up to 1999. With the subsequent improvements in fish passage in 2000, during years with sufficient spill, longer term delayed injuries have probably been significantly reduced.

Juvenile Salmonid Migration: Given that flows are a major variable controlling the migratory behavior of juvenile salmon and steelhead, reduced flow volumes in the Cedar River and Lake Washington watersheds from water withdrawals, development and operation of the Ship Canal/Lake Union may result in an as yet un-measured limitation on the current and future production of Lake Washington salmon and steelhead adults. Successful passage of juvenile migrant salmon and steelhead through this system depends on the ability of fish to pass safely through all areas within their natural outmigration period (Walters et al. 1978). If fish require additional time to exit the system beyond their normal outmigration period their survival can be reduced. Some species of salmon and steelhead can be expected to residualize if held too long beyond their emigration period, others have been found to re-smoltify up to certain limits beyond their emigration window (Zaugg 1981). In some rivers and reservoir systems, an increase in migration time can provide additional opportunities for predators to prey on juvenile fish (Williams et al. 1996).

There are five potential areas in the Cedar - Sammamish Watershed that could increase travel time and could lead to delaying smolts beyond their normal emigration period. These areas are: 1) Migration through the rivers and/or tributaries; 2) migration through the lakes; 3) migration through the Ship Canal; 4) delays in finding an outlet at the Locks; and 5) entrapment by lack of a suitable outlet at the Locks.

The migration of juvenile salmonids through lakes has not been extensively studied and the migration of ocean type juvenile chinook salmon through lakes is relatively rare (City of Seattle, 1999b). While there have been a number of studies on the migration of juvenile river type chinook salmon through reservoirs on the Colombia River system (Bishop and Morgan, 1996) the flushing time of these reservoirs and the life cycle of river type chinook

is much different from the ocean type chinook in Lake Washington. Therefore the comparison may not be applicable.

Prior to the diversion of the Cedar River from the Duwamish system into the Ship Canal, the flushing rate for water in Lake Washington was about 4.6 years (Chrzastowski 1983). After the diversion of the Cedar River, the flushing time was reduced to about 2.3 years (Chrzastowski 1983). Although the ocean type chinook occupying the Cedar River have a different life cycle, this is still a relatively long flushing time when compared to the flushing time of each of the mainstem Colombia River reservoirs downstream of Grand Coulee Dam, which is between one and three days (R. Klinge, fisheries biologist, Douglas County P.U.D., personal communication).

In a review of the factors limiting the natural production of chinook salmon, Bishop and Morgan (1996) list decreased water flow through reservoirs as increasing the travel time of juvenile migrants with concurrent increases in predation from longer exposure to predatory fish. This was in reference to survival through Columbia and Snake River reservoirs. In a study conducted on a USACE operated reservoir (Howard Hanson Dam on the Green River) the USFWS provided evidence that the travel time of coho and steelhead was most closely associated with inflow into the reservoir and was not based on the size the reservoir. The maximum travel time of fish was correlated with the fewest number of smolts successfully migrating through the reservoir (Aitken et al. 1996). Higher flow volumes were also found to decrease yearling chinook and steelhead travel times in the Willamette and Snake Rivers (Raymond 1979; Smith et al. 1993; Schreck et al. 1994). There is only one year of available information on smolt travel time through the Ship Canal and the Locks (R2 Resource Consultants 2000). The results from the study provide no clear basis to say if travel time to the Locks is or is not related to flow changes through Ship Canal. However, the USACE is planning additional studies to determine smolt travel time trough this area as part of the Lake Washington Ship Canal GI Study.

Longer migration times can result in smolts being exposed to higher water temperatures than they would normally migrate through: historical migration timing of smolts through the Locks appears to be later in the spring or early summer than that of other systems. Laboratory evidence suggests that water temperatures in excess of 20° C for about 20 days, or delaying migration beyond the end of June, may cause steelhead smolts to revert to parr (Chapman et al. 1994; Adams et al. 1975). Even in a cool year such as 1999, the temperature of Lake Washington and Lake Union can reach 20° C by mid-June (D. Houck, King County, pers. comm.). High water temperatures, besides affecting the metabolism of predatory fish, the metabolism of juvenile fish and smolt physiology can also affect their choice of migration route. The smolt passage flumes have a surface outlet, drawing water from the upper 6 feet of the water column. Increased water temperatures in the Ship Canal in June and July may adversely affect the migration route selected by smolts at the Locks; with smolts selecting deeper depths as surface water temperatures increase beyond their temperature threshold. The effect of warmer surface waters selectively reducing the number of smolts using the smolt slide has not been studied as yet.

There are other potential impacts to young salmon and steelhead during periods of reduced streamflow. These impacts can include: 1) reduced flows available for operation of fish passage facilities at the Locks; and 2) further impairment of the freshwater transition zone in the estuary below the Locks. Research conducted by the USACE (1999) showed that with historic inflows (between 1984-1994), there is little water available to spill through spillway gates or through smolt slides. In dry years only 50 cfs is available from early June to mid-July, less than 30 cfs is available to the end of July; in a median year 50 cfs is available beginning in mid-June; and in wet years 50 cfs is available after the end of June. Over 90 percent of the chinook salmon smolts migrating through the Locks are expected to be present between June and July. Under the Lake Washington GI Study, the USACE is studying ways of conserving water at the Locks including changing saltwater management, reducing blockages, or changing the structures at the Locks. Any conserved water would be made available for fish passage, however, given the large uncertainty regarding smolt migration through the Locks, it is uncertain whether the means to conserve water may not result in a new effect that further impairs the migration of juvenile salmonids.

ALTERED HYDROLOGY/FLOWS

A second issue of concern (within the overall WRIA review) was altered hydrology and if this habitat factor of decline was exacerbated during low flow conditions caused by human impacts. Some of the human causes of lowered base flow conditions include excess withdrawal of hydrologically linked groundwater or surface water, improper flow regulation by dams or locks, increased impervious surfaces, reduced wetland areas, and isolated floodplains. What is unique about the Locks sub-area is that any reduction in base flows upstream of the Locks can result in a variety of direct and indirect effects to every anadromous salmonid migrating through or rearing above and below the project. These effects may be multiplicative for some species (chinook salmon in particular), occurring as juveniles migrate to the Locks, reach and rear near the Locks, pass through the Locks, rear below the Locks, and when they return as adults as they pass through the Locks, and when they hold in areas influenced by current patterns created by the Locks ("cool water refuge").

Lower flow conditions results in a variety of habitat impacts (from conserving water at the Locks), increased environmental gradients above and below the project affecting adult and juvenile migrants, decreased current speed through the Ship Canal allowing saltwater intrusion to move further upstream, increased temperatures and lower dissolved oxygen levels in the cool water refuge (the holding area for most or all Lake Washington adult chinook), early closure of the smolt passage flumes increasing injury and mortality for later migrating smolts and reducing estuarine rearing habitat for juvenile chinook, reduced export of food and nutrients to the estuary, and increased risk of dropping the lake elevation below 20 feet.

What is the best way to use existing available water for fish passage? As described above, and shown in Figure 24, there is not enough water in most years to run the smolt passage flumes during the entire smolt migration season: during most years there is little available water for spill after mid to late June. Without action, future conditions are expected to

further reduce available water – decreased spring/summer precipitation, further urbanization reducing small stream baseflow, and expected increased diversions from the Cedar River. The USACE is evaluating non-structural (further conservation at the Locks (decreased lockings), decreasing use of the SW drain using flumes for saltwater management; reducing the reliability of maintaining the 20.0 feet minimum lake elevation) and structural alternatives (such as improving efficiency of the SW drain) to find more water under the Lake Washington Ecosystem Restoration General Investigation (GI) Study. The USACE in conjunction with local sponsors, agencies, and selected technical experts is developing a conceptual model on fish passage and functional use of the estuary. Information still needs to be collected on juvenile chinook migratory behavior throughout system from L. Washington through the Ship Canal and Shilshole Bay.

AVAILABLE NEARSHORE HABITAT

The Salmon/Shilshole Bay complex may provide important rearing habitat for central and south Puget Sound juvenile chinook salmon migrating along the marine nearshore. Warner and Fritz (1995) concluded that juvenile chinook salmon from the Green River spend less time rearing, and migrate at a smaller size from the urban Duwamish Waterway than in other non-urban estuaries. In 1999 researchers from the University of Washington in cooperation with King County and Battelle Laboratories scientists conducted a pilot study below the Locks that showed the primary prey source of juvenile chinook salmon rearing in the inner bay was the freshwater shrimp *Daphnia spp*. (J. Cordell, pers. comm.). This freshwater food source is atypical relative to normal conditions in virtually every other year, 1999 was the first year in several decades where enough water was available to spill through the end of August.

Footen (2000) assessed juvenile chinook salmon habitat use below the Locks as part of a pilot study on marine predators. Primary findings include: 1) apparently, chinook smolt habitat use was density dependent. When densities were high smolts were found in large numbers over sandy substrate; 2) during periods of low density, early and late in the study, greater numbers of smolts were found over cobble substrate; and 3) when the spill ceased, catch per unit effort decreased dramatically suggesting that either the migration was near complete or smolts were delayed or entrapped above the Locks.

Since the construction of the Locks and navigation channel in the historic estuary of Salmon Bay and with the development of the West Point Sewage Plant and Shilshole Bay Marina there limited intertidal or shallow, nearshore habitat in either Salmon or Shilshole Bay. Most of the shoreline is composed of either bulkheads, riprap or bordered by the natural steep bluffs of Magnolia Hill. Up to 87% of the eastern shore of the Puget Sound nearshore from Shilshole Bay to the King County boundary is bulkheaded or rip- rapped.

INCREASED PREDATION/COMPETITION

In the Lake Washington watershed, Warner and Fresh (1999) identified 23 non-native fish species (see Table 31 in the Lake Washington Chapter). This is possibly the largest number of non-native species in any major freshwater body in the Pacific Northwest.

Many of these non-native fish species have been identified as predators and/or competitors of naturally produced salmonid species. Many of these species are found in the developed nearshore habitats (both fresh and marine), near docks and piers, as well as along the shores of the lakes and the Ship Canal (Warner and Fresh 1999). Recent monitoring in the Ship Canal has shown that smallmouth and largemouth bass may consume a large number of emigrating coho and chinook salmon smolts (B. Footen, MIT, and R. Tabor, USFWS, pers. comm.).

Predation Above and Below the Locks: Predation on salmon is often greatest at bottleneck areas where fish aggregate. Within the project area, juvenile chinook salmon may be vulnerable to predation as they migrate from Lake Washington through the Ship Canal and Lake Union system (above the Locks), as they pass through the primary outlets at the Locks aggregating below the spillway and locks, and as they rear in the estuary.

The major source of mortality from predation on juvenile chinook salmon may come during migration through the Ship Canal and Lake Union system. Fish predation on juvenile chinook salmon occurs throughout the Lake Union system up to Salmon Bay just east of the Locks. The primary predators are non-native fish, smallmouth and largemouth bass. Pikeminnow appear to be an important predator but little data is available on their population size. There are an estimated 3400 smallmouth and 2500 largemouth bass in the Lake Union system. The smallest number of smallmouth is at the west end of the Ship Canal in Salmon Bay (approximately 3% of total) while the highest number is at the east end at Portage Bay (approximately 60%): few if any freshwater fish predators have been captured within the immediate vicinity of the Locks. Smallmouth bass consumed almost twice as many smolts per fish compared to largemouth bass (500 vs. 280, respectively) with chinook salmon making up 50% of identified smolts. Consumption of smolts occurred primarily from mid-May to the end of July, bracketing the documented migration period of Lake Washington juvenile chinook salmon. Salmon smolts represented 50-70% of the diet of smallmouth bass during this time period (Tabor et al. 2000).

The incidence of freshwater predation in Ship Canal may be increasing due to increasing water temperatures. There has been a long-term trend of increasing water temperatures in the Lake Union system which may result in increased energy demands and higher predation rates from native and non-native predators on later migrating smolts (chinook) (Schindler 2000).

The incidence of freshwater predation on later migrating smolts has also been linked to the delay of juveniles during their migration through the Columbia River reservoir and dam system (Williams et al. 1996). In a review of factors limiting the production of chinook salmon, Bishop and Morgan (1996) list decreased water flow through reservoirs as increasing the travel time of juvenile migrants with concurrent increases in predation from longer exposure to predatory fish. The Ship Canal/Lake Union system functions more like a reservoir than a true lake due to the low water retention time: 12, 7, and 17 days for annual, winter, and summer conditions (Houck 2001). Water conservation measures at the Locks normally begin in June (as inflow to the lake declines) to ensure maintenance of the lake elevations with a concurrent reduction in the total flow through the Ship Canal and an

increase in the water retention time. PIT-tag studies in 2000 provided the first documentation of juvenile chinook travel time in the Lake Washington system. The arrival date of hatchery and wild chinook at the Locks was generally independent of release date or flow in the Ship Canal, which may indicate a strong behavioral influence related to the time of year and smolt readiness (R2 Resource Consultants 2000). Studies have not yet been conducted analyzing what factors may or may affect chinook travel time (or residence time) through the Ship Canal.

The primary known avian and mammalian predators on juvenile chinook salmon are sea gulls, harbor seals and California sea lions. Sea gull predation in the lock chamber has virtually been eliminated since implementation of the slow fill procedures in 1999. Prior to 1999, up to 1 of every 8 smolts entrained in the large lock conduits were eaten by sea gulls (WDFW 1996). Since implementation of slow fill procedures in 1999, sea gull predation in the large lock has not been observed. In 2000, anecdotal information has indicated there were only isolated periods when sea 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 day(s).

In the Columbia River estuary, from 10-30% of all radio-tagged juvenile chinook were eaten by birds (Schreck et al. 1996; 1997). A link between fish smoltification and bird predation may exist: those fish eaten were typically less developed (less smolted) than fish not eaten. This link needs to be more firmly established through further sampling. If it does exist, the likely conclusion from this is that these fish were avoiding entry into saltwater by remaining at the surface of the water column, thus making them more susceptible to avian predators (Schreck and Stahl 2000). Avian predation in Salmon and Shilshole Bays, outside of seagulls, has not been previously identified as a possible factor in the mortality of juvenile chinook salmon and does not appear to be an issue for smolts passed through the Locks. However, avian predation outside of the estuary, further into Puget Sound, cannot be ruled out.

Numbers of harbor seals (*Phoca vitulina*) and California sea lions (*Zalophus californianus*) in Puget Sound have increased significantly in recent decades. Between 1985 and 1995, significant numbers of adult steelhead (up to 60%) were consumed by sea lions. In 1996, NMFS authorized removal of several “nuisance” sea lions and subsequent 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 10-15 kHz, a frequency range that appears to exclude most animals from the project area (Fox et al. 1996). Sea lions have not been observed preying on juvenile salmonids near the Locks since 1999.

Harbor seals are present in Puget Sound year-round and are more abundant than sea lions. They commonly attack salmon in some areas, 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. Numbers of juvenile chinook taken by harbor seals is believed to be a very small percentage of the run. Harbor seals have been documented to prey upon higher

numbers of migrating smolts at other west coast estuaries, such as Puntledge River, British Columbia. AHD's have recently been tested as an experimental means to reduce seal predation on smolts and were found to be the most effective, non-lethal means of protecting juvenile salmonids in the lower Puntledge River. The second most effective means was turning off bridge lights at the primary feeding location in the lower river (Yurk and Trites 2001).

Below the Locks, in west Salmon Bay (inner bay) and Shilshole Bay (outer bay), a pilot study was conducted by the MIT in spring/summer 2000 investigating the level of juvenile chinook salmon predation by marine and anadromous fish (Footen 2000). The most abundant predators in the inner bay were sea-run cutthroat trout and staghorn sculpin and in the outer bay were staghorn sculpin and resident chinook or blackmouth. Another important predator was native char (presumably bull trout), with seven native char were caught in the inner bay. Cutthroat, char and sculpin consumed thirty-one juvenile salmon. Chinook made up 12% of the cutthroat trout diet, 34% were other smolts, mostly chum. The char diet consisted of 27% chinook and 12% other salmonids. Fifty percent of the sculpin diet was chinook, although this may be biased by one sample. In review of these results, the initial estimates of the abundance and prey consumption do not suggest that fish predation below the Locks may be a significant source of mortality.

NATURAL SEDIMENT TRANSPORT

Longshore transport of fine sediments (sand-sized) into and through the Shilshole Bay estuary has been disrupted. Most bluffs on Queen Anne, Magnolia, and West Point have been isolated from the erosive force of Puget Sound. If slides do occur, only a small amount of the fine sediments (sand) reach Puget Sound. Up to 87% of the eastern shore of the Puget Sound nearshore from Shilshole Bay to the King County boundary is bulkheaded or rip- rapped.

Sedimentation rates for the lower Ship Canal are relatively stable due to the large degree of development in this area, effectively stabilizing sediment input. This stability is evidenced by the fact that dredging has not been required to maintain the lower Ship Canal at the authorized 30 feet depth. Sediment quality has been degraded by historical and ongoing contamination from surrounding industrial, commercial, and private activities.

This new outlet for the Cedar - Sammamish Watershed cuts through the heart of a highly urbanized watershed. Less than 5 percent of the Ship Canal and Lake Union shoreline has natural vegetation with most of the shoreline bulkheaded (with steep banks) or modified with docks and piers (USACE 1999).

SEDIMENT QUALITY

There are a number of contaminant sites along the Ship Canal including most of the north shore of Lake Union at Gasworks Parks up to Salmon Bay (discussed further in the Lake Union Sub-area).

Sediment bioassays conducted in conjunction with chemical analyses in Salmon Bay showed a high incidence of toxicity (Serder et al 2000). Four sediment bioassays (i.e. *Hyalella azteca* mortality, *Chironomus tentans* mortality and growth, and Microtox) were performed on 20 samples from Salmon Bay. Of the twenty sites, five showed toxicity on all four bioassays, five sites showed toxicity on three of the four bioassays, six sites showed two of four, two sites had only one bioassay showing toxicity, and two stations showed no toxicity. Contaminant distribution in Salmon Bay was characterized by "hot-spots" (highly localized) interspersed among a field of more moderate concentrations. These hot spots generally occurred in nearshore areas with cleaner sediments found toward the main channel. Based on a comparison of the sediment chemistry data to the Draft Freshwater Sediment Quality Values, (FSQVs), organic compounds are suspected as the cause of the observed toxicity. Areas not sampled including points near the Locks.

Chemical concentrations of the Lake Union - Salmon Bay sediments are as high as any found in Washington State. The ecological effects of these high concentrations are unclear. Certain highly localized sites in Salmon Bay (mainly nearshore) have shown toxicity to freshwater organisms in laboratory bioassays. Lake Union appears on the 1998 Washington Department of Ecology's 303d list for excursions beyond acceptable limits for dieldrin and sediment bioassays.

The issue of impacts of contaminated sediments on rearing and migrating salmonid smolts in the Lake Union and Salmon Bay areas still needs further study. Recent studies conducted by researchers from NMFS have shown that juvenile chinook salmon migrating through other nearby urban estuaries (Duwamish) have high concentrations of toxic chemicals. These materials can suppress the immune system of affected animals making them more susceptible to fish pathogens, disease and ultimately mortality (Arkoosh et al 1998a and 1998b). Chinook feeding habits in freshwater have not been studied as yet in the Lake Union and Locks sub-areas.

WATER QUALITY PROBLEMS – TEMPERATURE

The Washington Dept of Ecology (DOE) recently completed a literature review (Hicks 2000) to develop new water temperature criteria for waters of the State of Washington. Hicks (2000) in summarizing studies investigating acute mortality and thermal blockages, noted temperatures of 21-22^0 C, are identified as directly lethal to chinook salmon while temperatures from 20-21^0 C create conditions where for migration barriers for juvenile and adult salmon.

Over the past 25 years the annual duration of maximum, near-surface (5 m depth) water temperatures (exceeding 20^0 C) in the Lake Union System from the Locks eastward has been increasing an average of 2 days per year (USACE, unpublished data). As shown in Figure 40, this increase is significant (r^2=0.63, P<0.001) and expected to continue for the next half-century as ambient air temperature are predicted to increase 3^0 C (PRISM Climate Workshop, September 2000). Using an extrapolation of the 25-year data set to 2040 shows a five-fold increase in the duration of days exceeding 20^0 C, from 30 days in 1974, to 80 days in 1998 and predicted 160 days by 2040. While absolute peak

temperature has not significantly increased, the onset and duration of warm water conditions appears to be increasing. The primary factor associated with these increases appears to be air temperature (Wetherbee 2000).

The volumetric (area and depth) extent of the temperature barrier cannot be underestimated. Surface water temperatures exceeding 20^0 C are found throughout the Lake Washington system, currently being reached by June and extending until late September. The depth of these high temperatures reaches the very bottom of the Ship Canal and Lake Union system. Figure 41 shows monthly temperature readings at the Fremont Cut at 1 and 9 m depths. At this location and throughout Lake Union, there is no thermocline, with bottom temperatures near equivalent to surface temperatures. Effects of low dissolved oxygen are discussed in a following section.

Higher predation rates (discussed above), creation of a thermal water barrier, and direct mortality of chinook salmon are suspected to be a consequence of these warmer waters (discussed above). A bioenergetics model has predicted increased predation rates (D. Schindler 2001, pers comm. to D. Houck). The movement of adult chinook during 1998 appeared to be delayed when no chinook were noted moving into Lake Washington from the Locks until water temperatures dropped below 22.0^0 C (Fresh et al. 2000). The problems related to water temperature apparently will become even more pronounced with the recent trend of increasingly longer, warmer summers.

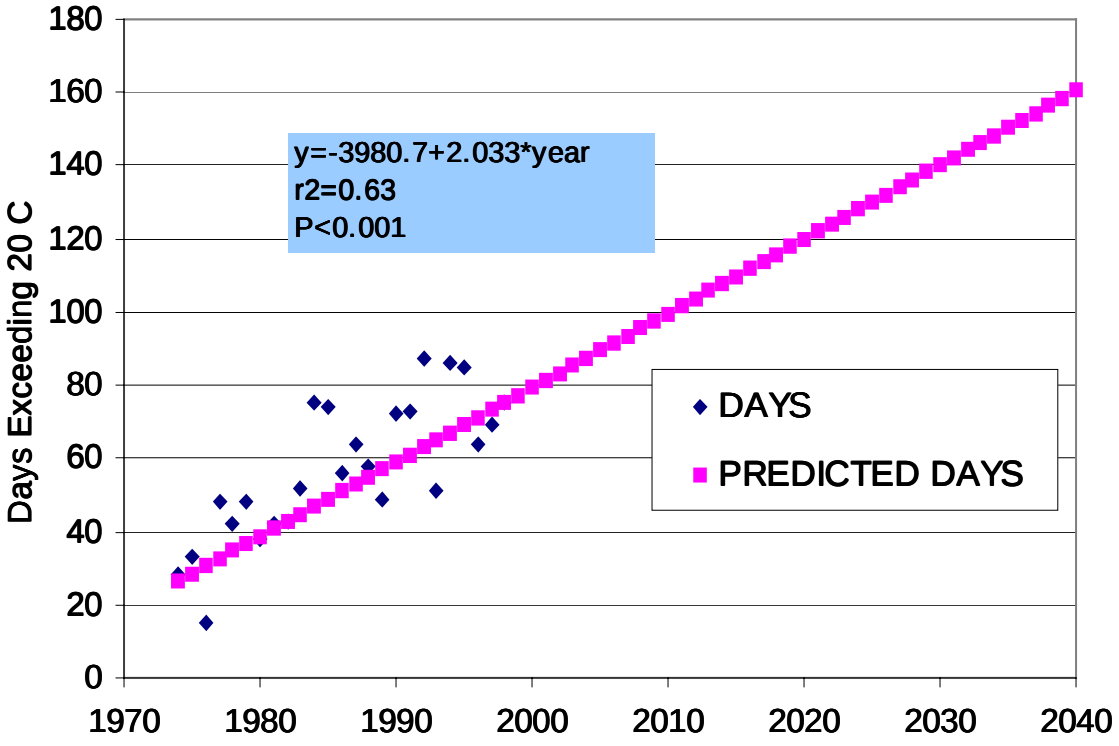


Figure 40. Observed and predicted (linear) number of days near-surface (5 meters) water temperature exceeds 20° C within the Lake Union system.

Adult Chinook Salmon: The influence of high water temperatures on chinook salmon at the Locks can be discussed in order of effect: 1) exposure to acute lethal temperature (passage through the fish ladder); 2) chronic constant exposure to near lethal temperatures and delayed mortality (thermal barrier resulting in residence times of 5-50 days, close aggregation to hundreds to thousands of nearby adults); 3) chronic constant exposure and decreased fecundity (same condition); and 4) chronic constant exposure with unidentified changes in migration timing, behavior.

The adult chinook salmon migration occurs during the most severe temperatures conditions at the Locks and in the Ship Canal. Approximately 80% of all chinook salmon migrate through the fish ladder with the peak of migration normally early to mid August (Figures 24, 30, 31, and 32). During passage through the fish ladder, they move through maximum temperatures of 20-22^0 C in the upper 11 pools (freshwater). These fish also migrate through a maximum temperature gradient of up 8-9^0 C, leaving the bay at 13-14^0 C, moving through the lower 11 pools at 15.5-18^0 C (auxiliary water from saltwater drain), and exiting at the 20-22^0 C range. In 2000, surface water temperatures in the fish ladder exceeded 20^0 C from July 11 to August 31 and 21^0 C from July 21 to August 18. A review of data from 1983 - 1998 at the 2 to 5 meters depth immediately upstream of the large locks showed water temperature exceeded 22.0^0 C in 1984, 1985, 1990,1992, and 1994 through 1998. This steep of a water temperature gradient is exceptional, and not found in most areas were anadromous fish migrate. Fish passing through this water temperature gradient become stressed with unknown effects on their behavior and survival.

Concurrent to the conditions in the fish ladder, researchers noted that chinook that passed upstream into the Ship Canal area were holding for long periods (average 19-20 days) near the saltwater drain in the cool water refuge (immediately upstream of the large locks) (Fresh et al. 1999; 2000; HTI 2000). During August, all fish are typically below 6-7 m depths. This area had the coolest (below the thermocline), most highly oxygenated water for a significant distance upstream of the project. Water quality in the upper 6-8 m are not influenced by Lock operations while water temperature, salinity, and dissolved oxygen levels below this level are affected by the number of lockings and operation of the saltwater drain. A single uplock can reduce water temperatures by 1^0 C and increase DO levels by 0.9 mg/l (VanRijn 2001). In 1998, further upstream, near the Montlake Cut, King County noted the highest temperatures ever recorded in the Ship Canal (25° C) (D. Houck, pers. comm.). NMFS considers water temperatures higher than 17.8° C (64° F) to be "Not Properly Functioning" for migrating adult salmon.

Much of the following discussion is taken directly from the WDOE literature review of temperature effects on salmon (Hicks 2000).

Hicks (2000) in summarizing studies investigating acute mortality, stated that temperatures of 21-22^0 C, particularly at lower prior acclimation temperatures, are identified as directly lethal to chinook salmon (Brett, 1956; Brett et al., 1982; Coutant, 1970; Beacham and Withler, 1991; Becker, 1973; Orsi, 1971; as cited in CDWR, 1988). It also appears from

the available evidence that adults may be more sensitive than the juveniles, which are most typically tested (Becker, 1973). Further, Hicks (2000) stated that as adult fish have been suggested to have lower lethal thresholds than juvenile fish, and that migrating salmon are coming from the cooler waters of the ocean, the use of juvenile fish studies for developing lethal temperature criteria is not recommended. He presented 22-23^0 C as a reasonable representation of the LT50 with a recommended safety factor 2 degrees lower thereby providing a recommended maximum criteria of 20-21^0 C to prevent acute lethality.

Daily maximum temperatures rising above 21° C are widely cited as causing barriers to migrating chinook salmon (Stabler, 1981; Bumgarner et al., 1997; Hallock et al., 1970; Thompson, 1945, as cited in Snyder and Blahm, 1971; Don Raliff, 1977, as cited in Stabler, 1981; Fish and Hanavan, 1948, and Major and Mighell, 1967, as cited in USEPA, 1971). Hallock et al. (1970) suggested that maximum temperatures of 18.9° C in association with low dissolved oxygen levels (5 ppm or mg/l) created a partial block of migrating chinook salmon. However, some authors note chinook not showing avoidance for temperatures as high as 24.4° C (Gray, 1990; Dunham, 1968; as cited in CDWR, 1988). Thompson (1945; as cited in Snyder and Blahm, 1971) suggested that it was the difference in temperatures that stopped chinook from migrating from the Columbia to the Snake River. Differences were 17.2 to 21.7° C and 22.2 to 26.1° C when blockages occurred, with migration resuming when the difference approached 1.6° C. Similarly Gray (1990) suggested that incremental increases of 9-11° C formed a barrier to migration. Sauter and Maule (1997) reported cessation of feeding as well as thermoregulatory behavior in subyearling fall chinook held between 18-20° C, with exposure to 20° C for several hours inducing heat shock proteins (Sauter et al., in review, and M. Hargis, personal comm.; as cited in Sauter and Maule, 1997). In a field study by Frissel, Nawa, and Liss (1992), it was found that maximum water temperatures in a coastal river system in Oregon were linked to the presence or absence of various species of salmonids. While it was noted that cutthroat were absent and coho salmon rare or absent in segments exceeding 21° C, chinook dropped out completely only at 23° C; although, their presence in such waters was associated with positioning in small cool pockets in otherwise warm reaches. Some authors have suggested criteria for the protection of migrating chinook salmon. Bell (1973; as cited by Everest et al., 1985) suggested that temperatures should be within the range of 13.9-20° C for summer chinook, and 10.6-19.4° C for summer/fall chinook. Based on the technical literature, it is recommended that to prevent a serious risk of causing blockage of migrating chinook salmon daily maximum temperatures should not exceed 20-21° C (Hicks 2000).

Several researchers have examined the effects of holding mature adult chinook prior to spawning at warm temperatures. It has been found that temperature can effect both the health of the spawners and their potential reproductive success prior to the act of spawning. One of the ways in which temperature affects the health of spawners is by increasing the risk of mortality from warm water diseases (Schreck et al., 1994; Bumgarner et al., 1997; and ODFW, 1992) prior to spawning. Another way that warm water affects the success of spawners is through its effect on the health of the unfertilized eggs as well as maturation timing of adult salmon. Holding mature adults at warm temperatures has been found to result in the reduced survival of eggs (Hinze, 1959; as cited in CDWR, 1988). Rice (1960) found that holding broodstock at temperatures above 15.6^0 C reduced survival of eggs to

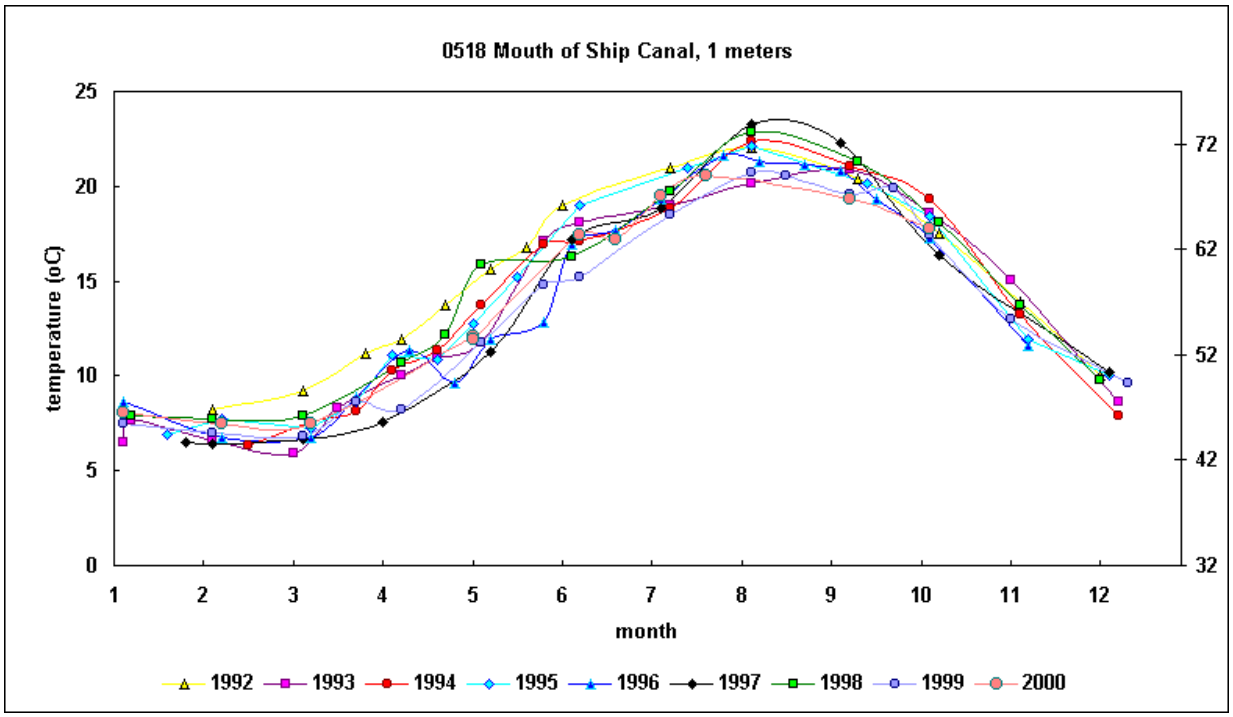
the eyed stage by 12.7% as compared to holding broodstock at 8.3-15.6^0 C. Adult immigrants held at temperatures greater than 15.6 ^{0} C were also found to produce eggs that are less viable in a study by Hinze, Culver, and Rice (1956; as cited in CDWR, 1988). The greatest survival was from adults taken at temperatures in the range of 11.7-12.2^0 C. Berman and Quinn (1989) cite a personal communication with the manager of the Kalama State Fish Hatchery as finding egg mortalities of 50% or more from adults held in river waters fluctuating from 14.4-19.4^0 C. The current supervisor of the Kalama Falls Hatchery, Ron Castaneda, notes that they still attribute some increased losses to holding temperature around 15.6-17.8^0 C; although, they have not had conditions of mortality as high as 50% (Hicks 2000).

Sockeye Salmon Adult Migration: Adult sockeye salmon are the second most affected species and life stage (after adult chinook salmon) exposed to high summer water temperatures.

The following discussion also comes from the WDOE (Hicks 2000). Migration exerts a tremendous strain on salmon. At a constant 16.2^0 C, depletion of fat reserves and reproductive organ abnormalities were noted by Bouk (1977), and Gilhousen (1990) found that high prespawning mortalities were associated with adult sockeye salmon migrating through waters having daily maximum temperatures between 17.5-19^0 C. Temperatures above 15.5^0 C (as an apparent daily average value) were also noted by Gilhousen (1990) as being linked to higher prespawning mortality from columnaris disease in adult Fraser River sockeye salmon.

Welch et al. (1995) found that the upper thermal limit to the off-shore occurrence of sockeye salmon was 8.9^0 C, and 8.9^0 C was found to be the maximum holding temperature in lakes by migrating adults (Wydoski and Whitney, 1979). Quinn and Adams, 1996; as cited in Quinn, Hodgson, and Peven, 1997) note that in the Columbia River, based on passage data at Ice Harbor Dam, migration usually ceases at temperatures above 21^0 C. Fish and Hanava, (1948; as cited by USEPA, 1971) found that during an extremely warm year (1941) sockeye were observed congregating in small previously unused cold tributary creeks when the temperature in the Columbia rose to 21.7- 23.9^0 C. Major and Mighell (1966) noted that entry of sockeye from the Columbia River into the Okanogan River, was blocked when rising or stable daily average temperatures were above 21.1^0 C, but that migration would resume if temperatures were falling. Hatch et al. (1992) found that when water temperatures reached daily average temperatures of 22.8^0 C, all migration of sockeye salmon ceased, that the bulk of the migration occurred below 22.2^0 C, and that surges of migration occurred when

Figure 41. Monthly water temperature at the Fremont Cut at 1 meter (top) and 9 meters (bottom) (data from King County METRO).



temperatures fell to below 21.1° C. Hicks (2000) concluded that based on the research reviewed above, daily maximum temperature above 22-23° C should be considered to have a high potential of causing blockages to migrating adult sockeye salmon. Measures that could provide decreased water temperatures in localized areas within the vicinity of the Locks include:

- Increased spill near the fish ladder. This would increase water temperatures and decrease salinity in the bay reducing the temperature and salinity gradient above and below the Locks.
- Increased "up-lockings" of the Locks during summer thereby refreshing the cool water refuge with decreased temperature, increased DO, and increased salinity. In particular, maintain a minimum number of lockings at night. Without a regular refreshing of the cool water area, the colder denser, saltwater is removed by the saltwater drain. An initial estimate is that a minimum of 1 locking every 4 hours is necessary to maintain DO levels at or above 6 mg/l.
- Increased use of the saltwater drain may actually increase the temperature and decrease the DO at a faster rate. The Lake Washington GI study will be conducting further modeling and evaluation of lock operations on water quality in the cool water refuge area.

Juvenile Chinook Salmon: Most of the following discussion comes from the Washington Dept of Ecology (Hicks 2000). Temperature effects to juvenile chinook can be considered by: 1) acute lethal effects; 2) reduced growth; and 3) changes in smolt readiness. Also, as discussed previously, longer migration time through Lake Washington and the Ship Canal/Lake Union reservoir and higher water temperatures may result in increased predation by warm water fish.

The lethal temperature for juvenile chinook salmon is likely higher than that for adult chinook. The laboratory data considered independently would suggest constant exposure to temperatures of 21-22^0 C carries a risk of causing direct lethality to migrating chinook salmon. With thorough acclimation, however, consistent exposure to temperatures of at 23-24^0 C would be necessary to produce a real risk of direct mortality to juvenile chinook salmon (Hicks 2000).

In examining temperatures optimal for juvenile chinook salmon rearing and migration, it is important to note that disease, predation, and smoltification concerns are all issues that need to be considered in addition to growth rates. Additionally, in considering growth rates, it is important to distinguish between studies conducted under constant and cyclic temperature regimes, and to recognize that the feeding rates used in testing will affect the results of the test. As food becomes scarce, the temperature that provides for optimal growth declines. As food becomes more plentiful fish can grow larger in warmer waters (Hicks 2000).

In constant temperature experiments conducted at high feeding rates, maximum growth tends to be associated with temperatures in the range of 18.3-19^0 C (Brett et al., 1982; Banks, Fowler, and Elliott, 1971, as cited in CDWR). A rearing temperature of 15.6^0 C was found to produce insignificantly less growth as compared to 18.3^0 C and temperatures above 19^0 C were associated with reduced feeding and growth, and increased problems with disease. Brett et al. (1982) estimated that under natural ration levels the optimum of 19^0 C would be reduced to 14.8^0 C and no growth would be possible at 21.4^0 C. Seymour (1956) studied three Washington and one California stock of chinook salmon and concluded that the general optimum temperature for growth and survival of chinook fingerlings was 14.4^0 C. In studying growth in a natural stream, Bisson and Davis (1976; as cited in ODFW, 1992) reported that juvenile chinook grew faster in a stream where temperatures peaked at 16^0 C compared with a stream where temperatures peaked at 20^0 C. Neilson and Green (1985) interestingly found that in comparing fluctuating to constant test conditions, that growth was enhanced through naturally cyclic temperature regimes, suggesting that food utilization in fluctuating environments may be higher.

There is a great amount of variability in the research and recommendations for chinook rearing temperatures. Optimal temperature regimes generally encapsulate the range of 7-17^0 C, but efforts to provide specific optimum temperature recommendations to natural feeding regimes tend to narrow the range to 12.2-14.8^0 C. Recommendations in this range remain connected to studies conducted at constant temperatures, and some minor adjustment to account for fluctuating natural environments seems warranted. While the concern for disease and smoltification capabilities may warrant further reduction, the

WDOE temperature review recommends that to provide for optimal growth conditions that the 7-day average of the daily maximum temperatures not exceed 14.2-16.8^0 C during the peak of summer (Hicks 2000).

Longer smolt migration times through reservoirs (or lakes) can result in smolts being exposed to higher water temperatures than they would normally migrate through. Historical migration timing of juvenile chinook through the Ship Canal and Locks appears to be later in the spring and summer than that of any other Puget Sound basin with peak timing occurring between mid June to early July. In some salmon species, chinook and steelhead for example, delayed migration timing or exposure to water temperatures > 20° C may result in smolts reverting to back to freshwater form (residualizing)(Adams et al. 1975; Chapman et al. 1994). Although anecdotal information suggests residualism of juvenile chinook salmon is higher than commonly found in other river basins (E. Warner, MIT, pers. comm.), the incidence and cause of natural-reared juvenile chinook salmon residualism in the Lake Washington basin has not been investigated. The reporting of overwintering juvenile chinook in Lake Washington is not a recent occurrence (Haw and Buckley 1962). Quinn et al (2000) reviewed trends in adult chinook salmon life history based on adults returning to the University of Washington fish hatchery. They found an increasing trend in the returning numbers of young adults, mini-jacks or 1-year old adults (a possible indicator of residualism), but attributed the likely cause of the trend to hatchery practices rather than environmental conditions.

Temperature is known to affect the ability of smolts to transition to and grow in a saline environment. The physiological preparation of juvenile fish for life at seas is commonly referred to as smoltification. Perhaps the greatest concerns at this stage are that fish will not be able to fully adapt to saline water, and that delays in adaptation will cause extensive losses in the estuarine areas. The literature on the effects of temperature on smoltification of juvenile chinook salmon is not as extensive as for coho salmon and steelhead trout, and direct lethality due to inadequate smoltification is not well established for chinook (Hicks 2000). However, Sauter and Maule (1997) reported cessation of feeding as well as thermoregulatory behavior in subyearling fall chinook held between 18-20^0 C. Exposure to water temperatures of 20^0 C for several hours induced heat shock proteins (Sauter et al., in review, and M. Hargis, personal comm.; as cited in Sauter and Maule, 1997). Zaug and McLain (1976) found decreased (Na+K)-ATPase activity (a measure of sea water adaptability) at 12^0 C as compared to 8^0 C, and Clarke and Shelbourn (1985) found that optimum regulation of plasma sodium concentrations occurred with transfer of fish from 13.8^0 C fresh water to 10.2^0 C sea water. They also noted that severe descaling in their freshwater holding tanks occurred in groups of smolts reared at 16 or 17^0 C, as well as with groups transferred from 8-12^0 C freshwater to 14^0 C seawater. While the research on impairment to smoltification is rather scant, what has been reviewed suggests that temperatures should be generally maintained below 12-13^0 C during out-migration of chinook smolts (Hicks 2000).

FRESHWATER/SALTWATER INTERCHANGE

The physical separation of freshwater in Lake Washington from the marine waters of Puget Sound and rerouting of the Lake Washington outlet have resulted in possibly one of the most modified estuaries on the West Coast of North America. To our knowledge, Lake Union is one of only two freshwater lakes on the west coast of North America that are artificially influenced by saltwater intrusion without a natural tidal flushing. The other lake is Lake Merritt in San Francisco, California where the Lake Merritt Channel connects it to San Francisco Bay.

The artificial estuary below the Locks is lacking most of the functions of a natural estuary. The numerous water outlets at the Locks further diminishes the natural functioning of the small estuary below the Locks, with little or no freshwater lens during the late spring and summer low flow season. Studies from other estuarine areas support the concept that some life history types of juvenile chinook salmon are dependent on low salinity conditions for a period of time prior to movement to marine waters (see above). Juvenile salmon (smolts) normally require a period of time to acclimate to marine waters, at the Locks, smolts are directly passed into the marine waters of Puget Sound. In addition, the rerouting of the lake outlet removed the source of over 5,000 acres of intertidal wetlands in the historic Duwamish Estuary to which the Cedar River chinook salmon population was adapted. Estuarine habitats are important during outmigration of juvenile fish, particularly for smaller emigrants such as chum and ocean type chinook salmon fry. Lastly, construction of the Locks also resulted in inundation of 1300 acres of intertidal and sub tidal habitats in the historic Salmon Bay estuary. This water now has not tidal action nor any modified, shallow water habitat.

Description of the existing freshwater lens and water quality gradients are described above. The least divergence in the gradients occurs during periods with high volumes of freshwater spill.

Can the functional value of the “neoestuary” be improved? Monitoring information with hydrologic modeling could be used to shape future water releases (create a more concentrated river plume). Conceptual values include -- concentrating freshwater releases through flumes which concurrently improves fish passage opportunities, increases size of the freshwater lens, reduces salinity and temperature gradients, and exports food (Daphnia) and nutrients. Pilot-work monitoring by University of Washington/Battelle occurred in 1999 (Simenstad et al. 1999) with further study planned for 2001. Additional sources and means to conserve water whereby freshwater releases could be increased is being evaluated under the Lake Washington GI study.

Saltwater Intrusion and Dissolved Oxygen

The water quality of the estuarine portion of the Locks and Ship Canal project area is controlled largely by conditions in Puget Sound and the associated tidal circulation. Dissolved oxygen characteristics are influenced primarily by oceanographic influences, such as upwelling and large-scale circulation patterns. The saltwater–freshwater mixing is

constrained by the Locks, which effectively removes tidal influences above the Locks. Unlike typical estuarine environments, the Locks create a static mixing zone. Although some saltwater does intrude upstream of the Locks, during periods of low flow (summer months), mixing is limited and a large salinity gradient is present across the Locks.

During the summer period of heavy boating activity at the Locks, the saltwater drain cannot keep up with the amount of salt water entering the freshwater system, and a salt water wedge intrudes into Lake Union and up to the Montlake Cut. The Washington DOE has imposed a special condition that salinity shall not exceed one part per thousand at any point or depth along a line that transects the canal at the University Bridge.

Saltwater intrusion and stratification can lead to low levels of dissolved oxygen in the saltwater drain upstream of the locks and, at times, in Lake Union, although anoxic conditions in Lake Union are considered a historic characteristic (monomictic lake). The anoxic conditions may have deleterious effects on sessile benthic organisms. Several modifications have been made to the Locks to reduce saltwater intrusion above the Locks, including the saltwater barrier and saltwater drain.

Low DO conditions (below 5 mg/l) during late summer are found from just upstream of the cool water refuge at the Locks, through Fremont Cut, the entire Lake Union system, and through the Montlake Cut (USACE and King County, unpublished data). Low temperatures and higher DO (above 6.5 mg/l) are not found until reaching the thermocline in Lake Washington approximately 7 miles upstream. Even if high temperatures at the Locks may be blocking adult chinook migration for some period, low DO levels may persist beyond the period when maximum temperatures begin to fall. Hallock et al. (1970) suggested that maximum temperatures of 18.9° C in association with low dissolved oxygen levels (5 ppm or mg/l) created a partial block of migrating chinook salmon in the Sacramento River. Future monitoring of adult chinook migration behavior should include assessment of DO levels in areas upstream of the Locks.

Measures that could provide increased dissolved oxygen in the vicinity of the Locks are discussed at the end of the temperature section, above. However, if increased uplockings are used, the saltwater wedge would likely become greater in the pseudo-estuarine portion of the Ship Canal and could potentially move into the freshwater area east of the University Bridge at greater quantities than permissible from Ecology. The Lake Washington GI study will include modeling and evaluation of saltwater intrusion into the Ship Canal under various operational scenarios at the Locks.

Stormwater Quality/Quantity

The extensive development surrounding the Ship Canal has continually degraded the stormwater quality and quantity. Combined sewer overflows (CSOs), which are a combination of stormwater and sanitary sewage, discharge into the Ship Canal during severe rain events. Both King County and the City of Seattle have adopted programs to reduce and control CSO discharges.

Key Findings and Identified Habitat Limiting Factors

- The operation of the Locks can and has significantly affected year-to-year differences in salmon and steelhead smolt-to-adult survival;
- There are over 12 different routes smolts can pass through at the Locks;
- Major issues for juvenile migration through the Locks are as follows
  - Mortality and injury of juvenile salmon passing through the Locks requires improved conditions;
  - Have fish passage modifications actually improved fish passage survival -- by reducing entrainment through non-fish passage routes and increasing passage over preferred routes;
  - There is not enough water in most years to run smolt passage flumes;
- Entrainment of smolts into the large lock filling culverts has seen a dramatic reduction from 1996 to 2000;
- In 2000, there was a 75% reduction in heavy descaling of fish captured in the large lock chamber. Prior to barnacle removal (1998), from 10-15% (13% on average) of smolts were heavily descaled when entrained and passed through the filling conduits in the upper half of the large lock chamber. After barnacle removal (fall 1999) 1-5% (3% on average) of all smolts were heavily descaled when entrained;
- With the entrainment and injury reduction in the upper chamber in 2000, a hypothetical calculation of improved survival can be provided for the period May 16-June 29. Using 1996 figures, if 70% of the smolts were entrained in the culverts with 13% heavy descaling (low estimate) and if all smolts are considered mortalities, than 9.1% of every 100 smolts would be killed. Using 2000 data, if 3% of smolts are entrained with 3% heavy descaling (high estimate) and if all heavily descaled smolts are considered mortalities, then 0.9% of every 100 smolts would be killed a 90% percent reduction;
- There limited intertidal or shallow, nearshore habitat in either Salmon or Shilshole Bay. Most of the shoreline is composed of either bulkheads, riprap or bordered by the natural steep bluffs of Magnolia Hill. Up to 87% of the eastern shore of the Puget Sound nearshore from Shilshole Bay to the King County boundary is bulkheaded or rip- rapped.
- Longshore transport of fine sediments (sand-sized) into and through the Shilshole Bay estuary has been disrupted;
- Sediment quality has been degraded by historical and ongoing contamination from surrounding industrial, commercial, and private activities;
- Less than 5 percent of the Ship Canal and Lake Union shoreline has natural vegetation with most of the shoreline bulkheaded or modified with docks and piers;
- Chemical concentrations of the Lake Union - Salmon Bay sediments are as high as any found in Washington State;
- Over the past 25 years the annual duration of maximum, near-surface (5 m depth) water temperatures (exceeding 20^0 C) in the Lake Union System from the Locks eastward has been increasing an average of 2 days per year;
- Surface water temperatures exceeding 20^0 C are found throughout the Lake Washington system, currently being reached by June and extending until late September;

- Higher predation rates (discussed above), creation of a thermal water barrier, and direct mortality of chinook salmon are suspected to be a consequence of these warmer waters;
- The adult chinook salmon migration occurs during the most severe temperatures conditions at the Locks and in the Ship Canal. Adult sockeye salmon are the second most affected species and life exposed to high summer water temperatures;
- The artificial estuary below the Locks is lacking most of the functions of a natural estuary; and
- During the summer period of heavy boating activity at the Locks, the saltwater drain cannot keep up with the amount of salt water entering the freshwater system, and a salt water wedge intrudes into Lake Union and up to the Montlake Cut.

Data Gaps

- Does a 0.5 feet opening in the spillway gates result in additional injury to fish than a 1.0 foot opening;
- While the reduction in injury rate for fish captured in the upper chamber is substantial, there is a data gap regarding fish injured after entrainment and being deposited in the lower lock chamber either during a “down lock” or during filling of the full lock; and
- The issue of impacts of contaminated sediments on rearing and migrating salmonid smolts in the Lake Union and Salmon Bay areas still needs further study.

LAKE UNION and the LAKE WASHINGTON SHIP CANAL

LAKE UNION AND LAKE WASHINGTON SHIP CANAL

PHYSICAL DESCRIPTION

The Lake Union/Lake Washington Ship Canal is defined as the area from (going east to west) Montlake Cut, Portage Bay, Lake Union, Fremont Cut, and the Salmon Bay waterway (see Weitkamp et al 2000). Entering from Lake Washington, the first feature of this system is the Montlake Cut. The Montlake Cut passageway is a channel approximately 100-feet wide with vertical concrete banks (bulkheads). The Montlake Cut opens to Portage Bay, which is naturally linked to Lake Union. Lake Union is approximately 581 surface acres in size with an average depth of 32 feet. The Fremont Cut is a steep rip rap channel that connects the western outflow of Lake Union with the Salmon Bay waterway. The Salmon Bay waterway houses the Fisherman's Terminal (moorage to over 600 commercial fishing vessels) and other commercial development before leading into the Hiram M. Chittenden Locks (Weitkamp et al 2000).

Weitkamp et al (2000) reported that the construction of the Lake Washington Ship Canal (completed in 1916) created a connection between Lake Washington, Lake Union, and Puget Sound where previously there had been none. Lake Union and what is now known as Portage Bay were originally separated from Lake Washington and Union Bay by a natural ridge. Historically, Lake Union was likely a separate drainage basin fed by underground springs and intermittent creeks. By 1885, a narrow canal, which served as a log chute, had been excavated between Lake Washington and Lake Union. As part of construction of the Ship Canal, a minimum 100 foot-wide navigable passage was constructed between the two lakes and between Lake Union and the original Salmon Bay. The lake was incorporated into the Lake Washington watershed in 1916 with the completion of the Montlake Cut as part of an overall plan to promote better flushing of Lake Washington and simultaneously provide a navigable waterway between Lake Washington and Puget Sound. The Hiram M. Chittenden Locks were constructed at the mouth of the Salmon Bay waterway in 1916 (Tomlinson 1977).

Land use within the Lake Union System area is primarily composed of water-dependent commercial and industrial uses, including marinas, commercial shipyards, and dry-docks. Other commercial and residential development also borders the shoreline of Lake Union. Overwater coverage, bulkheads, and shoreline armoring associated with these uses is extensive. As a result, there is relatively little shallow water habitat (natural or altered) along the Lake Union shorelines (Weitkamp et al 2000). Portage Bay, however, has retained shallow water habitat (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).

SALMONID UTILIZATION

Relatively little is known about the natural history and behavioral ecology of salmonids that utilize Lake Union for transportatoin as adults or juveniles or juvenile rearing. However, all of the naturally produced anadromous salmonids, both juveniles and adults,

residing in the Cedar - Sammamish Basin, use Lake Union as a migratory passageway to and from Puget Sound. There is thought to be little if any successful spawning within Lake Union.

HABITAT FACTORS OF DECLINE

Predation

The presence of numerous semi-permanently docked boats, docks, piers and bulkheads has significantly altered the shoreline of Lake Union. One of the concerns regarding these types of structures is their potential to alter the shoreline oriented migratory pattern of juvenile chinook salmon and to increase preferred habitat for predatory fish species, thus increasing potential predation of salmonids by introduced fish species such as smallmouth and largemouth bass. Bass may be attracted to these types of structure during the spring for reproductive purposes (Pflug 1981, Pflug and Pauley 1984).

The results of a salmonid predation study indicate predation on juvenile chinook salmon is highest in June (Tabor 2000). Catch rates of predatory fish (e.g.: bass and northern pikeminnow) were highest in Portage Bay and northern Lake Union, with fewer of these potential predators of salmonids found west of the Fremont Bridge (Tabor 2000). The migration of chinook smolts through Lake Union appears to peak in June (DeVries 2000), while the peak migration for sockeye smolts is mid-to-late May, and for coho smolts from late May through mid-June. Smallmouth bass and northern pikeminnow were determined by Tabor (2000) to be the most significant predators of chinook smolts in Lake Union. The bass population estimate for the Ship Canal was estimated to be a little less than 5900 fish. During the month of June, salmonid smolts comprised approximately 50 percent of the smallmouth bass diet and 45 percent of the northern pikeminnow diet based on gut content analysis. Of the ingested smolts 15 percent could be visually identified and of those identified 52 percent were chinook, 35 percent were coho and 13 percent were sockeye (Tabor 2000). An effort is currently underway, utilizing DNA analysis, to identify the remaining 85 percent of the smolts that could not be identified visually.

Degradation of Riparian Conditions and the Gradation of Nearshore Habitat Conditions around Lake Union

Lake Union's nearshore habitat is highly altered from its historic state. There are only a limited number of short segments (less than 100 feet) of open shoreline along Lake Union with the remainder being armored with bulkheads and docks and overwater structures (Weitkamp et al 2000). A qualitative survey of the shoreline was conducted in the early 1990s (Dillion 1993a). While the nearshore habitat has been greatly altered, the specific impact these conditions have on migrating juvenile and adult salmonids is unknown. The bank armoring and presence of bulkheads and docks along most of this shoreline severely limits the amount of desirable habitat available to rearing and migrating juvenile salmonids. For returning adult chinook, it appears the Lake Union system is primarily a passageway, which is traversed in a few days (Fresh, et al 2000). Work is still underway to assess the effect of limited nearshore habitat on juvenile salmonid smolts.

The riparian shoreline of Lake Union is highly altered from its historic state. The only fragments of Lake Union that retain some natural shoreline characteristics are along the south side of Portage Bay, portions of the Gas Works Park and a few small areas at the south end of Lake Union. Current and future land use practices all but eliminate the possibility of the shoreline to function as a natural shoreline to benefit salmonids. Weitkamp al (2000) investigated 24 separate reaches and found that within the Lake Union/Ship Canal, 96 percent of the shoreline is retained by concrete bulkheads or rip rap. Only two segments had less than 40 percent of the shoreline unretained. Shorelines ranged from 20 to 100 percent retained. Current and future land use practices all but eliminate the possibility of the shoreline to function as a natural shoreline to benefit salmonids.

Water Quality – Increased Temperature

A review of U.S. Army Corps of Engineers, (USACE) temperature data from 1974 - 1998 at the 2 to 5 meter depth near Gas Works Park indicates a linear increase of approximately 2 days per year when water temperature exceeds 20^0 C. Since the early 1970's, water temperatures in excess of 20^0 C have been recorded an average of 31 days per year. This statistic has currently increased to approximately 80 days per year (Weitkamp et al 2000). While absolute peak temperature has not significantly increased, the onset and duration of warm water conditions appears to be increasing. The primary factor associated with these increases appears to be air temperature (Wetherbee 2000).

Higher predation rates, creation of a thermal water barrier, and direct mortality of chinook salmon are suspected to be a consequence of these warmer waters. A bioenergetics model has predicted increased predation rates (D. Schiendler 2001, pers comm to D. Houck). The movement of adult chinook during 1998 appeared to be delayed when no chinook were noted moving into Lake Washington from the locks until water temperatures dropped below 22.0^0 C (Fresh 2000). A review of USACE temperature data from 1983 - 1998 at the 2 to 5 meters depth immediately upstream of the large locks showed water temperature exceeded 22.0^0 C in 1984, 1985, 1990,1992, and 1994 through 1998.

In some years, water temperatures in Lake Union and the Ship Canal may limit the natural production of salmonids in WRIA 8, particularly portions of the chinook and sockeye populations. These adults enter freshwater when the temperatures are at or near their highest values. Water temperature may limit a portion of the juvenile salmonid migration, particularly that portion that migrates in later June and July, when surface water temperatures approach 17.5° C. as found by Hansen (1994).

Probably one of the most significant challenges for both juvenile and adult salmonids is the transition from freshwater to saltwater and saltwater to freshwater respectively. As juvenile salmonids move through the Lock area they face an abrupt transition from freshwater to saltwater. Saltwater immediately below the Locks ranges from 10 to 20 ppt depending on tide and the amount of freshwater spill. Because freshwater is less dense (lighter) than saltwater there may be a "lens" of freshwater, or water of relatively low salinity, in the area immediately downstream of the Locks.

Prior to the rerouting of water in the Cedar – Sammamish Basin, the anadromous salmonids evolved using the Duwamish Estuary as a transition zone. This estuary provided vastly larger areas and habitat types for the physiological transition by juvenile salmonids from freshwater to saltwater. The total impacts to juvenile salmonids of the abrupt freshwater to saltwater transition in Salmon Bay have not thoroughly been investigated and are a data gap. Stormwater runoff during the summer months is likely to have a higher temperature than that of receiving waters. Both Lakes Washington and Union have similar surface water temperatures which implies that the stormwater runoff does not substantially increase these water temperatures.

Water Quality - Other

In general, since the 1960s the water quality in Lake Union has improved, when compared with conditions experienced between 1900 – 1960's. Historic data indicate the lower depths of Lake Union experienced anaerobic conditions year-round due to high saltwater concentrations which prevented mixing (Smith 1927, Collias 1954). This condition most likely was initiated soon after operation of the Chittenden Locks began in 1916 and lasted until 1966 when a saltwater barrier was constructed. Also, during the 1960's, the City of Seattle intercepted most of the direct discharge of raw sewage that had been flowing directly into Lake Union and indirectly from sewage input into Lake Washington that flowed into Lake Union, and the coal gasification plant ceased operation and was turned over to the city for use as a park.

Lake Union still experiences periods of anaerobic conditions that typically begin in June and can last until October. This lack of mixing, along with a significant oxygen sediment demand, can reduce dissolved oxygen levels to less than 1 mg/l. During the summer months (July, August and September) there is also a saline layer along the bottom of Lake Union (Hansen et al 1994). This saline layer is typically 1 mg/l and maintained at that level by Lock operations. The presence of this saline layer and the influence of water temperature are the primary factors influencing a strong stratification of the water column. This stratification inhibits the mixing of the surface and bottom layers during this time period and begins to break up during the fall months. The low DO concentrations present during the summer months would prevent salmonids from using the water column below 10 meters depth.

While some water quality data related to metals and organic compounds are available for Lake Union, much of it is almost 10 years old (Dillion 1993b, Hansen 1993). King County is currently in the process of expanding their routine water quality monitoring in Lake Union to include low levels of metals and organic compounds.

Another indicator of the relative health of the water in Lake Union is the species composition and population of the macroinvertebrate community. Dillon (1993b) determined that the benthic macroinvertebrate communities of Lake Union are typical of the profundal zone (that zone in the water column below light penetration) of deep water mesotrophic lakes. Lake Union has areas typically found in both eutrophic and oligotrophic lakes. As expected, species such as low dissolved oxygen tolerant

chironomids, oligochaete worms and some clam species were found in areas of low dissolved oxygen. Benthic sampling in April showed near normal levels of benthic macroinvertebrate production. Sampling has not been conducted in May, June and July but sampling in September indicated a decline (Weitkamp 2000).

Sediment Quality

Although both the quality of discharges coupled with the implementation of source control programs have improved substantially over the past several decades, historical practices and discharges into Lake Union and the Lake Washington Ship Canal have contributed to the contamination of bottom sediments (Weitkamp et al 2000). Sediment data from Lake Union indicate varying concentrations of organic compounds and metals at various locations (Parametrix 1992, Cubbage 1992, Metro 1993, Herrera and Brown & Caldwell 1994, Hansen et al. 1994). Lake Union sediments are highly contaminated in both metals and organic compounds as a result of both present and past discharges and land use practices in the area. Current sources include storm drains, combined sewer overflows, atmospheric fallout, commercial and recreational boaters, the old coal gasification plant (Gas Works Park), and other industries and businesses around the lake.

Sediment bioassays conducted in conjunction with chemical analyses in Salmon Bay showed a high incidence of toxicity (Serder et al 2000). Four sediment bioassays (i.e. *Hyalella azteca* mortality, *Chironomus tentans* mortality and growth, and Microtox) were performed on 20 samples from Salmon Bay. Of the twenty sites, five showed toxicity on all four bioassays, five sites showed toxicity on three of the four bioassays, six sites showed two of four, two sites had only one bioassay showing toxicity, and two stations showed no toxicity. Contaminant distribution in Salmon Bay was characterized by "hot-spots" (highly localized) interspersed among a field of more moderate concentrations. These hot spots generally occurred in nearshore areas with cleaner sediments found toward the main channel. Based on a comparison of the sediment chemistry data to the Draft Freshwater Sediment Quality Values, (FSQVs), organic compounds are suspected as the cause of the observed toxicity.

Benthic community structure and concurrent chemical analyses were completed by Metro in the late 1980s and early 1990s for Lake Union and are fully discussed by Dillon (1993a). The benthic community identified in Lake Union is typical of those found in lake systems that experience an annual period of low oxygen.

Chemical concentrations of the Lake Union - Salmon Bay sediments are as high as any found in Washington State. The ecological effects of these high concentrations are unclear. Certain highly localized sites in Salmon Bay (mainly nearshore) have shown toxicity to freshwater organisms in laboratory bioassays. Lake Union appears on the 1998 Washington Department of Ecology's 303d list for excursions beyond acceptable limits for dieldrin and sediment bioassays.

The issue of impacts of contaminated sediments on migrating salmonid smolts still needs further study.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- Water temperature data indicates a linear increase of approximately 2 days per year when water temperature exceeds 20^0 C.;
- An estimated population of about 5900 smallmouth and largemouth bass inhabits the Lake Washington Ship canal during the period of smolt outmigration from April through July. In June, between 50% and 70% of the diet of smallmouth bass consists of salmonid smolts. Chinook salmon are the main salmonid species consumed;
- Since the early 1970's, water temperatures in excess of 20^0 C have been recorded an average of 31 days per year. This statistic has currently increased to approximately 80 days per year. While absolute peak temperature has not significantly increased, the onset and duration of warm water conditions appears to be increasing; and
- The riparian shoreline of Lake Union is highly altered from its historic state. Current and future land use practices all but eliminate the possibility of the shoreline to function as a natural shoreline to benefit salmonids.

E. DATA GAPS

- The nearshore habitat of Lake Union has been greatly altered, but the specific impact these conditions have on migrating juvenile and adult salmonids is unknown;
- Some water quality data related to metals and organic compounds are available for Lake Union but most is almost 10 years old;
- The most effective method(s) and potential effects of reducing the habitat and populations of exotic piscivorous fishes and rebalancing the apparently increased populations of certain native piscivorous fishes are unknown.
- Chemical concentrations of the Lake Union - Salmon Bay sediments are as high as any found in Washington State but the ecological effects of these high concentrations are unclear; and
- The total impacts to juvenile salmonids of the abrupt freshwater to saltwater transition in Salmon Bay requires investigation.

LAKE WASHINGTON

LAKE WASHINGTON

A. PHYSICAL DESCRIPTION

General Description

Lake Washington is the second largest natural lake in Washington State with a surface area of 22,138 acres. It is about 20 miles long with over 50 miles of shoreline (at an elevation of 22 feet). Mercer Island is a large island in the southern part of the lake that has an additional 30 miles of shoreline. Maximum depth of the lake is 214 feet, mean depth is 108 feet, and the lake is shallowest at the north and south ends. The lake is approximately 20 miles long with a mean width of 1.5 miles and drains to Puget Sound via the Lake Washington Ship Canal, an artificial waterway 8.6 miles long. The main inflow to the system is the Cedar River, which contributes about 55 percent of the mean annual inflow. The Sammamish River contributes approximately 27 percent of the surface flow to the lake and enters Lake Washington from the north. Numerous other small streams, including Thornton Creek, Juanita Creek, Kelsey Creek, Lyon Creek and May Creek, also drain into Lake Washington.

The lake is monomictic as it is stratifies once each year, typically between April through October (Anderson 1954; Beauchamp 1990). Mean epilimentic (0-70 feet) temperatures range from 8° C to 16-18° C with a maximum of about 23° C (Beauchamp 1990). During the last decade, the mean temperature in August at 15 feet has ranged from 19.8^{o} C to 22.4^{o} C (Daniel Schindler, UW, personal communication). The lake is homothermal from about December through April with mean temperatures typically ranging from 6 to 8° C (Beauchamp 1987). For the last decade, the mean temperature at 15 feet during the January-February period has ranged from 6.7^{o} C to 8.1^{o} C (Daniel Schindler, UW, personal communication).

Physical Changes

Lake Washington has experienced a series of physical and limnological changes that began in 1916 when the natural outlet of the lake, the Black River, was blocked, and the outlet was changed to the Ballard Locks. At the same time, the Cedar River was redirected into Lake Washington to increase the amount of inflow. These actions lowered the lake's level by about 10 feet, exposed 5.4 km2 of previously shallow water habitat, reduced the lake's surface area 7.0 percent, decreased the shoreline length by about 12.8 percent, and eliminated much of the lake's wetlands (Chrzastowski 1983). Lake level is regulated by the release of water at the Ballard Locks and is not allowed to fluctuate more than about 2 feet. Historically, lake level varied by up to 6.5 feet during flood events.

The shoreline of the lake has been extensively altered. Historically, more commercial development was located on the lakeshore, but as the population in the watershed has grown, the demand for residential waterfront property increased significantly. The majority of the shoreline is now urban, residential (Weitkamp and Ruggerone 2000), with

the exception of a few commercial and industrial developments (e.g., Kenmore Air at the north end and the Boeing Company in the south end). Thirteen incorporated cities now border the lake.

As the watershed has developed, dredging, filling, bulkheading, and the construction of piers, docks, and floats have occurred in shoreline areas. An estimated 82 percent of the Lake Washington shoreline has been bulkheaded (Fresh and Lucchetti 2000). There is 33.2 miles of Lake Washington shoreline within the city limits of Seattle (this is all located along the west shoreline of Lake Washington) of which 85 percent was classified as retained (i.e., hardened) in 1999 (Weitkamp et al. 2000). In 1997, there were an estimated 2,700 piers and docks along the shore of the lake that collectively covered about 4 percent of the lake's surface within 100 feet of shore (E. Warner, Muckleshoot Indian Tribe, unpublished data). Boats moored to these docks will shade an additional, but uncalculated, area. This estimate did not include marinas, moored vessels, commercial developments and bridges. Much of the large woody debris that was likely associated with the lake's shore (Christensen et al. 1996) has been eliminated. The only "natural" shoreline remaining in Lake Washington is in the vicinity of St. Edwards Park, which represents less then 5 percent of the lake's shoreline. A recent survey of the lake's shoreline under the City of Seattle's jurisdiction indicated that "natural vegetation" was present along only 22 percent of the northern shoreline and 11 percent of the southern shoreline (Weitkamp et al. 2000).

Limnological Changes

The limnological characteristics of Lake Washington have undergone dramatic changes during the last 50 years. Many of these changes have resulted directly from fluctuations in phosphorus loadings. Lake Washington received direct discharges of secondary treated sewage effluent from 1941 to 1963. This dramatically increased phosphorus concentrations in the lake, which led to eutrophication of the lake (Edmondson 1991). As a result, blue-green algae became the dominant phytoplankton taxa and dramatically decreased water clarity in the lake. Blue-green algae also helped to suppress the production of some species of zooplankton such as *Daphnia sp*. Except for combined sewer overflows, sewage effluent was completely diverted from the lake by 1968 and the lake subsequently reverted to a mesotrophic state (Cooke et al. 1993). The major sources of phosphorus inputs to the lake are now from tributary streams (King County 1993). As a result of the diversion of sewage, several major changes in the zooplankton community occurred. Most notably, beginning in 1976, *Daphnia* became the dominant pelagic zooplankton taxa.

Cleanup of the lake resulted from the formation of METRO in the 1950's, which rerouted sewage discharges to Puget Sound. The cleanup of Lake Washington due to the rerouting of sewage effluent provides one of the best examples anywhere of a successful, large-scale, regional restoration program.

Other changes in the limnological characteristics of the lake have occurred that are not related to fluctuations in phosphorus loadings. First, *Neomysis mercedis*, a shrimp like

crustacean, decreased dramatically in the mid 1960's, most likely due to a dramatic increase in the abundance of long smelt (*Spirinchus thaleichthys*). Long fin smelt is a highly selective predator of *Neomysis* that increased dramatically in abundance beginning in 1960. Predation by this fish was able to suppress abundance of *Neomysis*. Second, alkalinity levels in the lake increased from an annual mean of 28.6 mg of calcium carbonate/L in 1963 to over 40 mg calcium carbonate/L by 1990 (A. Litt, UW, personal communication). It has been hypothesized that the long-term change in alkalinity in Lake Washington has been caused, at least in part, by urbanization that has altered the chemical output of the land to the streams (S. Abella, UW, personal communication). Third, surface water temperatures in the lake have been steadily increasing, probably as a result of global warming (D. Schindler, UW, personal communication). For example, from 1932 to 2000, there has been a significant increase in mean August water temperature at a depth of 15 feet from about 19 ^{o}C to 21 ^{o}C (Daniel Schindler, UW, personal communication). Fourth, pH spikes as high as 9.4 have been observed recently in nearshore areas at night during late spring and summer (Fresh, WDFW, personal observation).

Exotic Plants And Animals

In addition to changes in the lake's littoral zone and limnology, exotic plants and animals (i.e., non-native) have impacted the Lake Washington ecosystem. Twenty-four non-native fish species (Table 31) have been identified in Lake Washington (Warner and Fresh 1998, R. Tabor pers comm). Some of these species are known to prey on juvenile salmon (e.g., smallmouth bass) while others are potential competitors with juvenile salmonids for food (Fayram 1996; Kahler et al. 2000).

Nine introduced, non-native plant species (Table 31) are currently present in Lake Washington. Certainly one of the most visible, and also likely the most significant is Eurasian watermilfoil (*Myriophyllum spicatum*), an exotic aquatic plant, which was introduced into Lake Washington in the 1970's. This plant has colonized a large percentage of the littoral zone of the lake and replaced much of the native aquatic vegetation present in littoral areas (Patmont et al. 1981). Milfoil is capable of growing to depths of 30 feet (Aiken et al. 1979). Because distribution of aquatic macrophytes in lakes can be limited by the occurrence of seasonally low water levels (Cooke et al. 1993), the stable (i.e., regulated) lake levels have probably promoted milfoil expansion. The plant has altered the physical characteristics of littoral zone habitats, such as changing substrate characteristics (Patmont et al. 1981), and adversely affected local water quality. Frodge et al. (1995) found that high macrophyte densities can cause localized fish mortalities fish due to dissolved oxygen depletion.

Table 31. Introduced fishes and plants of the Lake Washington Basin (WRIA 8)

Fish Species

Common Name	Scientific Name	Population Status	Origin
American shad	*Alsoa spaidissima*	uncommon strays	E N. America
Atlantic salmon	*Salmo salar*	strays, can exceed 1000/yr	N. A. & Europe
Black bullhead	*Ictalurus melas*	extinct	E. N. America
Black crappie	*Pomoxis nigromaculatus*	common	E. N. America
Bluegill	*Lepomis macrocheilus*	common	E. N. America
Brook trout	*Salvelinus fontinalis*	rarely caught	E. NA
Brown bullhead	*Ictalurus nebulosus*	rare, may be extinct	E. N. America
Brown trout	*Salmo trutta*	no observed reprod.	N. Europe
Channel catfish	*Ictalurus punctatus*	rarely caught	E. N. America
Cherry salmon	*Oncorhynchus masou*	extinct	Japan
Common carp	*Cyprinus carpio*	abundant	Asia
Fathead minnow	*Pimephales notatus*	unknown	E. N. America
Goldfish	*Carassius auratus*	intermittent	Asia
Grass carp	*Ctenopharengodon idella*	triploids only	Asia
Lake trout	*Salvelinus namaycush*	extinct	NE NA + AL
Lake whitefish	*Coregonus clupeaformis*	extinct	NE NA + AL
Largemouth bass	*Micropterus salmoides*	common	E. N. America
Pumpkinseed sunfish	*Lepomis gibbosus*	abundant	E. N. America
Smallmouth bass	*Micropterus dolomieui*	common	E. N. America
Tench	*Tinca tinca*	abundant	Europe
Warmouth	*Lepomis gulosus*	no observed reprod.	E. N. America
Weather loach	*Misgurnus angillicaudatus*	no observed reprod.	NE Asia
White crappie	*Pomoxis annularis*	uncommon	E. N. America
Yellow perch	*Perca flavescens*	abundant	NE N. America

Plant Species

Common Name	Scientific Name	Population Status	Origin
Eurasian watermilfoil	*Myriophyllum spicatum*	abundant	Europe & Asia
Reed canary grass	*Phalaris arundinacea*	abundant	Eurasia
Purple loosestrife	*Lythrum salicaria*	common	Europe
Parrotfeather milfoil	*Myriophyllum aquaticum*	rare	S. America
Water primrose	*Ludwigia hexapetala*	uncommon	S. & S. N. America
Yellow iris	*Iris pseudacorus*	common	Europe
Garden loosestrife	*Lysimachia vulgaris*	common	Eurasia
Fragrant water lily	*Nymphaea odorata*	common	E. N. America
Brazilian elodea	*Egeria densa*	uncommon	S. America

B. SALMONID UTILIZATION

Nine salmonid species utilize Lake Washington habitats of which four rarely occur in the lake. Two species, pink salmon and chum salmon, were historically abundant in the Lake Washington system but now are considered extinct in the watershed. Atlantic salmon, an exotic species, occasionally strays from Puget Sound into the Lake Washington Basin; while some adults have been reported from the Cedar River, no juveniles have ever been observed or caught in WRIA 8. The occasional pink or chum salmon reported from WRIA 8 is probably a stray from an adjacent watershed. Two char/bull trout have been reported from Lake Washington (E. Warner, Muckleshoot Indian Tribe, personal communication; K. Fresh, WDFW, personal communication). These fish could have been strays from an adjacent watershed, washouts from the Chester Morse Reservoir population in the Cedar River Basin, or perhaps from Issaquah Creek.

The five salmonid species that use Lake Washington are sockeye, coho, chinook, coastal cutthroat, and rainbow/steelhead trout. Anadromous forms of each of these species are present, so individuals are present in the lake both as adults during migrations to spawning grounds and as juveniles. Sockeye are known to spawn along some beaches of the lake while there are unconfirmed reports of chinook spawning in littoral areas of the lake.

Non-anadromous forms of winter steelhead (rainbow trout), sockeye (kokanee), and cutthroat (cutthroat) also occur in the lake. Resident rainbow trout spend their entire life in Lake Washington. The resident rainbow trout population was sustained with hatchery plants because they rarely successfully reproduce in WRIA 8 (Beauchamp 1987). Recently, however, releases of hatchery rainbow trout have been all but eliminated. Non-anadromous coastal cutthroat trout also occur in Lake Washington and are much more abundant then the anadromous form (Nowak 2000). Kokanee salmon is the freshwater, resident form of *O. nerka* (Foote et al. 1989; Wood 1995). Some progeny from the parents of anadromous sockeye may also remain in Lake Washington for all or a portion of their lives (resident/anadromous sockeye).

The utilization of the lake varies considerably between salmonid species with no two species using the lake in the same way. The following summarizes what is known about use specifically of Lake Washington by the most abundant salmonids in Lake Washington-coastal cutthroat trout, rainbow trout, sockeye salmon, coho salmon and chinook salmon. Although the discussion of the habitat factors of decline focuses on naturally-produced chinook, sockeye and coho (there is a hatchery component to each of these species), we include discussions of the other two species because of the important role they play in structuring the Lake Washington aquatic ecosystem. For each species we focus on the use of two major habitat zones of the lake -littoral and limnetic- since salmonids primarily use these portions of the lake. The littoral zone is defined as the shallow water portion of the lake (less than approximately 30 feet) associated with the shoreline while the limnetic zone is the water column portion of the lake extending down to, but not including the lake's bottom.

The known freshwater distribution of anadromous and resident salmonids is depicted Appendix A.

Chinook Salmon

Juveniles: Adult chinook salmon (*Oncorhynchus tshawytscha*) that spawn in WRIA 8 are classified as "ocean type" fish because they typically spend less than 6 months in freshwater after emerging from spawning gravels before entering estuarine habitats (Healey 1991). In contrast, "stream type" chinook spend more than one year in freshwater following emergence. While in most river basins, the freshwater phase of life for ocean type chinook occurs entirely in riverine environments, Lake Washington chinook salmon are unusual in that they must spend some time between stream and estuarine habitats in a large, natural lake. In Washington State, only Lake Quinault in western Washington and Lakes Wenatchee and Osoyoos in eastern Washington have chinook populations with similar life history rearing trajectories. However, while WRIA 8 chinook are considered "ocean type" chinook, the eastern Washington stocks are considered to be "stream type" chinook.

Based upon data collected in migrant traps located at the mouths of the Cedar River and Bear/Cottage Lake Creek (Dave Seiler, WDFW, personal communication), there are two different life history trajectories of naturally produced juvenile chinook that enter the lake. The first group consists of chinook fry that enter Lake Washington from at least mid-January through mid-March. These fish spend little or no time rearing in riverine habitats before entering Lake Washington where they rear for a number of months before migrating to Puget Sound. While rearing in the lake, the most important area used by chinook fry appears to be the littoral zone (Kurt Fresh, WDFW, personal communication). Chinook juveniles are rarely found in limnetic habitats until after early May. Portions of the littoral zone that are most heavily utilized by chinook include areas around creek mouths and areas that are not heavily developed. Recent studies of microhabitat use of littoral areas (Roger Tabor, personal communication) found that chinook fry prefer areas that have small substrates (sand and small gravel). In the lake, juvenile chinook feed on chironomids (midge larvae, a type of insect) until early spring when they shift to a diet dominated by *Daphnia* (a zooplankton) (M. Koehler, UW, personal communication). A number of predators consume juvenile chinook including bass, sculpins, and coastal cutthroat trout (Warner and Fresh 1998; Weitkamp et al. 2000).

The second group of juvenile chinook that enter Lake Washington are smolts. Smolts enter the lake from mid-May through at least late July and are of a much larger size than fry at the time they enter the lake. These fish rear for a number of months in riverine habitats before entering the lake where they spend much less time than fry rearing; smolts use the lake primarily as a migratory corridor to exit the watershed.

Based upon observations at the Ballard Locks, juvenile chinook migrate from Lake Washington to Puget Sound from late May through summer (see Hiram M. Chittenden Locks and Salmon Bay Chapter). During this period, chinook juveniles can be found using much of the littoral zone of the lake as well as limnetic habitats. Increasing water

temperature probably plays a key role in determining when juvenile chinook depart from Washington in any given year. Changes in water temperature helps regulate the rate of smoltification, the process whereby juvenile salmon convert from freshwater-adapted to seawater-adapted animals (Folmar and Dickhoff 1980). In addition, the littoral zone of the lake eventually warms to the point where water temperatures can be stressful and then eventually lethal to the fish.

Adults: While adult chinook spawn along shoreline areas in other systems (Healey 1991), there are only unconfirmed reports of adult chinook spawning in littoral areas of Lake Washington. Since 1998, some chinook entering Lake Washington have been tagged with ultrasonic transmitters in order to provide information on movements, timing, and habitat use during their passage through the lake. At present, only results of studies in 1998 are available (Fresh et al. 1999).

Adult chinook salmon enter the lake from at least late July through the end of October (Fresh, unpublished data). Differences in timing between years may reflect differences in water temperature as adult chinook entered the lake earlier during the year when water temperatures were cooler (K. Fresh, WDFW, personal communication). The average time spent by adult chinook in Lake Washington in 1998 was 2.9 days (Fresh et al. 1999); data from 1999 is not yet available.

Sockeye Salmon

Juveniles: The ecology of juvenile sockeye salmon in Lake Washington has been studied for over 30 years (e.g., Eggers et al. 1978) largely through the efforts of scientists at the University of Washington. Based upon data collected using a downstream migrant trap at the mouth of the Cedar River (Dave Seiler, WDFW, personal communication), sockeye salmon fry begin entering Lake Washington as early as mid January and are still outmigrating in late May. Downstream migrant trapping usually has been terminated at this time due to declining stream flows that limit trapping efficiency. The peak of the wild fry outmigration is March and April while the peak of the hatchery fry outmigration is February and March. Small numbers of fry occur in littoral areas of the lake in winter and spring, especially in the south end of the lake (Beauchamp 1987; Martz et al. 1996). However, the majority of fry from the Cedar River appear to move quickly into offshore areas of the lake. Studies conducted in the late 1960's indicated that sockeye dispersed into the north part of the lake in summer and fall and then aggregated in the north and south ends of the lake in winter and early spring (Woodey 1972). It is unclear if this same pattern still occurs.

While in the lake, young sockeye feed primarily on a variety of pelagic zooplankton. Presently, the major food source of sockeye juveniles in the lake is *Daphnia* sp., which prior to 1976 was extremely rare but now is the most abundant pelagic zooplankton (Edmondson and Litt 1982). The growth of sockeye in the lake is exceptional and results in some of the largest one-year old sockeye of any population in the world (Burgner 1991).

Although most sockeye rear for approximately one year before leaving the lake, a small number of sockeye leave the lake as age 0 juveniles and a small number of sockeye also rear for more than one year (K. Fresh, WDFW, personal communication; Brian Footen, Muckleshoot Indian Tribe, personal communication). Some of the larger, age 1+ sockeye that are occasionally caught are probably kokanee. Since 1967, the WDFW has annually estimated the abundance of yearling sockeye in late March or early April, shortly before the sockeye leave the lake (this life stage is termed presmolt). These annual estimates have ranged from 0.25 million presmolts to 6.8 million presmolts and were on average greater prior to 1980 than after 1980 (Fresh, WDFW, personal communication). Sockeye are consumed by a variety of predator during their residence in the lake. The most significant predators include northern pikeminnow, cutthroat trout, sculpins, yellow perch, and bass (Weitkamp et al. 2000).

Since the early 1980's, returns of adult sockeye salmon to the Lake Washington Watershed have been declining. The two years with the lowest returns have occurred since 1995 and in most years the population has not replaced itself (Fresh 1994). The most likely explanation for this decline is a reduction in presmolts leaving the lake due to a change in survival in Lake Washington (Fresh 1994). From 1968 to 1980, the presmolt population averaged 3.0 million presmolts and less than 1.4 million since 1981. Using the number of presmolts/spawner as an index of survival in the lake, the average from 1967 to 1979 (brood years) was 16.0 and the ratio averaged less than half of that in subsequent years. Journal articles about the results of studies that have been underway to determine why the survival in the lake is now lower than historically are currently being developed.

Based upon their arrival time at the Ballard Locks, sockeye salmon yearlings probably begin leaving Lake Washington from late April through early June. Beginning in late winter, large numbers of smolting sockeye salmon utilize littoral areas of the lake, especially along the west shore. Apparently, many if not most sockeye smolts shift from limnetic habitats to littoral zones in order to outmigrate from the lake.

Adults: Little is known about the behavior of adult sockeye during their tenure in Lake Washington. Potentially, sockeye adults can enter the lake soon after the first fish arrive at the locks (usually in mid to late May). Some adult sockeye are still present in the lake in late February since some spawning occurs at that time in the Cedar River. Bartoo (1972) reported that sockeye salmon adults were only found in the deeper part of the lake where the mean temperature was 9.0° C.

Some adult sockeye spawn along some of the beaches of Lake Washington (Buckley 1965). Beach spawning sockeye appear to have originated from eggs and fry from the Baker River, a tributary of the Skagit River in northwest Washington, that were planted throughout the watershed in the 1930's and 1940's (Hendry 1995). However, they have rapidly adapted to the local spawning and incubation conditions and are now considered to be distinct from other populations in the system (Hendry and Quinn 1997). Comprehensive surveys of the distribution and extent of beach spawning last occurred in the 1970's. Presently, only limited surveys are conducted in index areas along the north shore of Mercer Island, the Enetai Beach area, Pleasure Point and Coleman Point. Based upon these

index counts, the numbers of beach spawners in most years is less than 1 percent of the total sockeye escapement in the watershed.

Coastal Cutthroat Trout

The population structure of coastal cutthroat trout in Lake Washington is complex with freshwater resident and anadromous forms present (Hall et al. 1997). Further, there may be some coastal cutthroat trout that only dwell in streams while others are adfluvial and spend time both in streams and in the lake. Only a generic description of coastal cutthroat trout utilization of Lake Washington is presented here.

Coastal cutthroat trout do not spawn in Lake Washington. Sexually mature coastal cutthroat are observed in the lake in late winter and spring, especially off the mouths of tributary streams where spawning occurs. The progeny of these fish then enter Lake Washington from tributary streams at fork lengths of 130-170 mm at approximately 1-2 years of age (Scott et al. 1986; Nowak 2000). Smaller coastal cutthroat trout tend to be more prevalent in the littoral zone where they eat primarily invertebrate prey, such as *Daphnia* and *Neomysis* (Beauchamp et al. 1992). Like other salmonids in the system, coastal cutthroat trout are absent from littoral areas after temperatures reach approximately 16-18 C (K. Fresh, WDFW, personal communication). As the coastal cutthroat increase in size they shift to a diet consisting primarily of fish, especially longfin smelt, sockeye salmon and threespine stickleback, and are mostly found in limnetic habitats (Beauchamp et al. 1992; Nowak 2000). Diet of all size classes of coastal cutthroat can vary with time of day, season and year in response to fluctuations in the abundances and distribution of prey species (Beauchamp et al. 1992; Beuachamp et al. 1999). When the lake is stratified, coastal cutthroat trout in the limnetic zone spend most of their time within the thermocline, making forays into surface or benthic habitats to feed (Beauchamp et al. 1992; Nowak 2000).

Although the size of the coastal cutthroat trout population is unknown, anecdotal information (e.g., angler interviews) suggests that the coastal cutthroat trout population in the lake is robust and has increased markedly over the last 20 years (Nowak 2000).

Rainbow Trout

Both anadromous (steelhead) and resident rainbow trout use Lake Washington. Little information exists for adult or juvenile use of Lake Washington by steelhead except that most naturally produced steelhead smolts migrated from the Cedar River into Lake Washington by the end of April, occupied limnetic regions of the lake and fed heavily on *Daphnia* during May (Beauchamp 1995), and had presumably migrated out of the lake before mid-June. The following discussion pertains only to resident rainbow. Resident rainbow trout are not believed to naturally reproduce in the Lake Washington Watershed (Foley pers comm). Beginning in 1979, hatchery plants releases of hatchery fry were made directly into Lake Washington. Up 800,000 fry that were about 100 mm in size were released annually from May to July (Beauchamp 1987); small numbers of large, Donaldson-type rainbow trout have also been occasionally released from the University of

Washington Hatchery. Since 1998 when the stocking program was reduced, releases of rainbow trout fry have been dramatically reduced to less than 30,000 annually (John Kerwin, WDFW, personal communication).

During winter and spring, Beauchamp (1990) concluded that a large percentage of the rainbow trout were found in nearshore areas and that these fish shifted to more offshore habitats in summer and fall. However, Warner and Quinn (1995) found that telemetered rainbow trout were still more closely associated with nearshore areas in summer and fall and only rarely moved into offshore areas. The fish they studied were also primarily surface oriented. Diet of rainbow trout varied with size of the trout, year, time of year, time of day, and habitat the trout occupied (Beauchamp 1987, 1990). In general, small trout ate more invertebrate prey, primarily *Daphnia*, especially in nearshore areas than did larger trout, which ate more fish, primarily longfin smelt.

Coho Salmon

Despite extensive sampling of littoral and limnetic areas in winter, spring and early summer over the last decade, coho fry and subyearlings have been rarely caught, suggesting that few coho fry rear in the lake during their first year of life. Coho salmon are only abundant in Lake Washington in April and May where they occur in both littoral and limnetic habitats. Coho found in the lake at this time are yearling smolts that are migrating from rearing habitats in the streams or hatcheries where they have been rearing to Puget Sound. Similar to sockeye and chinook, some larger coho (2+) are occasionally caught in the lake following the outmigration, suggesting extended rearing is occurring.

C. HABITAT FACTORS OF DECLINE

General

The quality and quantity of Lake Washington's water and physical habitat characteristics have clearly changed over the last 100 years (Edmondson 1994). These changes are a result of the urbanization of the lake and surrounding landscape and the intentional and unintentional introductions of exotic plants and animals (Fresh and Lucchetti 2000). We understand a great deal about how specific anthropogenic changes have altered limnological and physical habitat characteristics of Lake Washington. What is much less clear, however, is the ecological response to specific changes in water quality and habitat. For example, while it is clear that the alkalinity of the lake has increased and there is a reasonable hypothesis for why this has occurred, the effects of this change on the lake's flora and fauna are presently unknown and unstudied. There are situations, however, where our knowledge of ecological responses is considerable, such as the well-documented linkages between the release of sewage effluent into the lake, the proliferation of blue green algae, and changes in the composition of the zooplankton community (Edmondson 1991).

Even more problematic is an understanding of how changes in water quality and physical habitat characteristics have affected salmonids in the lake. In some cases these

relationships have not been well studied (or not studied at all) while in other situations, data is ambiguous. Changes in the lake's limnology and physical habitat characteristics can either directly or indirectly effect salmonids. Direct effects occur when salmonids are directly affected by the change, such as when fish die due to low dissolved oxygen levels around milfoil beds. Indirect effects are much more difficult to detect and measure. An example of an indirect effect is the influence of piers and docks on salmonid predators and prey. A pier itself does not kill a juvenile salmonid outright, rather the structure provides better habitat that allows a predator the greater opportunity to ambush juvenile salmon. Changes in food web relationships that alter salmonid growth is another example of an indirect affect. Six habitat factors associated with Lake Washington that could have contributed to changes in populations of anadromous salmonids in the WRIA were identified, including:

- Sediment Quality
- Degradation of shoreline conditions
- Altered hydrology
- Invasive Plants
- Poor Water Quality
- Water Quantity

SEDIMENT QUALITY

Lake sediments serves as the primary "sink" for a number of organic contaminants and metals. Sediments are believed to be self-capping and not continuing into downstream reaches of the lake due to the depositional nature of the lake bottom. As a result of the urban nature of the lakeshore and the streams that drain into it, and the point and non-point contaminant sources within the watershed, the lake likely receives a significant contaminant load, much of which ends up associated with the sediment. To date, a comprehensive sediment quality evaluation of Lake Washington has not been available. A comprehensive sediment quality evaluation (i.e., chemistry, toxicity testing, benthic community structure) of Lake Washington was conducted in 2000, and data are currently being analyzed. It is unlikely that sediment contamination of the entire lake bottom is a problem. Rather, some specific areas, such as near river mouths or old industrial sites, are probably more contaminated than other areas. For example, sediment in the vicinity of the Quendall and Baxter properties (southeast part of the lake) are contaminated primarily with organic contaminants (e.g., PCBs, PAHs and dioxin) (Beak Consultants 1997).

There are currently only a few direct causal links between bulkheads, piers and other artificial shorezone structures and inputs of hydrocarbons into Lake Washington. The links identified have included the use of treated lumber (e.g.: creosote) and localized increases in internal combustion powered watercraft (hydrocarbon spillage and exhaust). In the absence of a large commercial hydrocarbon spill, the quantity of anthropogenic produced hydrocarbons entering the lake through urban runoff, atmospheric fallout and other inputs is greater than the quantity of hydrocarbons entering the lake habitats through recreational

and commercial boating activities (Latimer and Quinn 1998, Wakeham 1977, Jones et al 1980; Green and Trett 1989).

Polycyclic aromatic hydrocarbons (PAHs) are a byproduct of all internal combustion engines and a primary constituent of creosote and commonly found in aquatic systems near industrialized and urban areas, including Lake Washington. PAHs are known carcinogens, mutagens and teratogens and are known to bioaccumulate in fish tissues (Green and Trett 1989 Several studies have found them as a contaminant of urban runoff (Latimer and Quinn 1998), powerboat exhaust (Smith et al 1987) and from hydrocarbon (fuel) spills. However, relatively little is known about the impacts of PAHs to aquatic organisms. Arkoosh et al (1991, 1998) reported immunosuppression in chinook smolts from exposure to PAHs in urban estuaries (Commencement Bay) and determined that there was a greater mortality of juvenile chinook smolts from the marine pathogen *Vibrio anguillarum* than in smolts from a non-urban estuary.

Lumber used to construct docks, pier and bulkheads along with other structures expected to deteriorate in the freshwater environment are often pressure treated with chromated copper arsenate (CCA). CCA is a mixture of metal oxides, each of which are highly toxic to freshwater organisms in their dissolved ionic forms (Weis et al. 1998). While the pressure treating process is intended to prevent the release of toxic metals into the surrounding environment, contamination of water, sediments and organisms, especially within the first three weeks after installation, is common (Brooks 1994; Weis et al 1998).

Existing contaminated sediments (e.g.: hydrocarbon, CCA, etc.) may be disturbed during the new construction of structures. There is a lack of published research regarding the location and amount of hydrocarbon sediment contamination, including levels, and the effects that any disturbance of contaminated sediments might have on aquatic organisms within Lake Washington. Additionally, household and/or industrial cleaning and preserving chemical agents that may be applied to boats, piers or docks may adversely affect aquatic organisms. The amount of usage, locations and types of such chemicals is unknown.

Finally, there has been a profound conversion of the riparian zone around Lake Washington from historic plant communities to ornamental plantings and lawns with hardened shorelines. The City of Seattle found that almost 85 percent of the shoreline of Lake Washington within their jurisdiction features hardened shorelines or bulkheads (Weitkamp et al 2000). Single family residences along the City of Seattle's Lake Washington shoreline accounted for approximately 50 percent of the land use (Weitkamp et al 2000). Along the Seattle shoreline, apartments and condominiums are also present and the amount of land use in single and multi family usage would certainly be greater without the presence of two large public institutions (the University of Washington and the federal facility at Sand Point) along the shoreline. Fresh and Lucchetti (2000) estimated 82 percent of the Cedar - Sammamish shoreline has been bulkheaded. A recent study of pesticide use in Puget Sound found that more pounds of pesticides are applied in urban areas than in agricultural areas (UGSG Fact Sheet 097-99). The influence of the application of lawn care products associated with the management of ornamental plantings and lawns

behind many of these bulkheads on aquatic systems is not known. Many of these products contain warning labels that indicate the products are hazardous to aquatic organisms. The impacts of the pesticides through spillage and run-off is not fully understood.

Sediment quality is a possible factor of decline and a significant data gap because so little is known about this factor. As noted above, little data on contaminant levels in sediments and the impacts of sediment-associated contaminants in Lake Washington on survival or reproduction of chinook salmon and other aquatic life is currently available. The recent sediment evaluation conducted on Lake Washington, and future work (e.g., risk assessment) will provide some of the necessary information to better evaluate the severity of this issue. It is likely that effects would be indirect and result through contaminant transfer and/or biomagnification through the food web. Sediment-associated contaminants may also have effects on benthic community, which may impact the food supply for some aquatic organisms.

PREDATION

Predation is a natural process that influences the abundance of anadromous salmon populations wherever they are found and so salmonids have evolved characteristics that minimize predation mortality. Thus, for predation to be a factor of decline, predation mortality must increase over historic conditions due to some change or changes in the ecosystem (Fresh 1997). Five changes have occurred in Lake Washington that could potentially increase predation mortality.

First, littoral zone habitats have been extensively modified over the last 100 years due to the change in lake level (in 1916); construction of piers, docks, and bulkheads; removal of LWD; and the expansion of Eurasian watermilfoil (Fresh and Lucchetti 2000). It is highly probable that the types of changes occurring in the littoral zone of Lake Washington have altered the composition, diversity, and abundance of fish communities in the lake (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Weaver et al. 1997). However, it is difficult to predict the net effect of changes in littoral zones on fish populations and whether these changes have actually increased predation mortality of juvenile salmonids. For example, the amount and spatial patterning of attached aquatic macrophytes can directly affect littoral zone fish abundance (Bryan and Scarnecchia 1992, Weaver et al. 1997). A small quantity of macrophytes usually increases the abundance of littoral zone fish. While shoreline development and an increased density of macrophytes may result in more habitat for juvenile salmonids (Beauchamp et al. 1994), these changes may also enhance habitat for predators such as smallmouth bass (Bryan and Scarnecchia 1992). Bass predation could also increase if the “new” habitat provided by piers, docks and bulkheads either provides better spawning habitat and assists bass populations to increase, or it allows predators a better place of ambush their prey (Kahler et al. 2000). In the case of overwater structures, it is unclear whether predators respond to the structure, the shade, substrate alterations, or a combination of these factors.

Second, predation mortality of salmonids could increase if there has been a significant increase in the population of one or more predator species. While it is clear that population

sizes of non-native predators are larger (there were none historically), it is not clear whether populations of native predators have increased. There is some anecdotal evidence that cutthroat trout are considerably more numerous now than historically (Nowak 2000). A large enough increase in the size of the cutthroat population could have resulted in an increased predation mortality of some salmonid species because cutthroat trout (especially large individuals) are highly piscivorous (Beauchamp et al. 1992). Brocksmith (1999) concluded that the northern pikeminnow population had increased 11-38 percent between 1972 and 1997. Further, Brocksmith (1999) found evidence that larger pikeminnow are more numerous than they were historically. Because larger predators consume more prey, this could also increase predation mortality of anadromous juvenile salmonids.

Third, as discussed earlier in this section on Lake Washington, water temperatures in the lake have increased since monitoring began in the 1930s. Further, there is also evidence that water temperatures are warming earlier than historically. While this is probably due to the effects of global warming, it may simply be a long-term trend; a similar increase in water temperatures has also been noted in the Ship Canal/Lake Union (Daniel Schindler, UW, personal communication). An increase in water temperature would be expected to increase metabolic rate of predators, which in turn would increase consumption of prey species. These temperature shifts could increase the temporal and spatial overlap between some predators and juvenile salmonids. With increasing spring and summer temperatures above the thermocline, juvenile salmonids could become increasingly concentrated into a narrow depth band along the slope zone or open water along with their predators. Such an increase in water temperatures in the littoral zone could increase overlap between the littoral zone predators (e.g., smallmouth and largemouth bass) and juvenile salmonids. Bass do not typically recruit to littoral zones until water temperatures exceed 10° C (Pflug and Pauley 1984). If the littoral zone is warming sooner than it did historically, bass may be present in littoral zones for a longer period and thus capable of eating more juvenile salmon because of an increased overlap between predator and prey or it could force juvenile salmonids into deeper water earlier at an earlier time and smaller size.

A fourth factor that could increase predation mortality of anadromous salmonids over historic levels is the introduction of non-native, piscivorous fish (Fresh 1997). Non-native piscivores introduced into Lake Washington (Table 31) include smallmouth bass, largemouth bass, rainbow trout (considered an exotic here because it can only be sustained by hatchery releases), hatchery-produced chinook and coho, and yellow perch. All of these species are known to prey on juvenile salmon (e.g., Beauchamp 1987; Fresh 1997, Fayram and Sibley 2000;). The impact of any one of these predators on anadromous salmonids depends on a number of factors such as the specific salmon prey, year, availability of other species of prey, environmental conditions, and so on. The only species where the extent of predation mortality on salmon has been estimated is for hatchery rainbow trout predation on sockeye salmon juveniles. Beauchamp (1987) concluded that less than 2 percent of the juvenile sockeye in the lake were being eaten by hatchery rainbow trout and that was during a time when hatchery rainbow releases were more than a magnitude greater than present. Impacts of the other exotic predators have not been fully evaluated and are part of ongoing research programs. An assessment of impacts of all predators on sockeye salmon

during lake residence will be forthcoming as part of the completion of the Lake Washington Studies.

The fifth factor affecting mortality is the availability of alternative prey fishes to buffer the impact of predation on young salmonids. Longfin smelt are a major prey species for cutthroat trout, northern pikeminnow, and rainbow trout (Beauchamp 1994). When smelt were abundant, the mortality of sockeye during their lake residence phase was reduced significantly (Beauchamp 1994). Mortality of other juvenile salmon species could potentially be buffered in a similar way. Longfin smelt live for two years and their abundance fluctuates cyclically: even year classes (e.g., progeny spawned in 1998 or 2000) are 10 times more abundant than odd-year classes (e.g., progeny from 1999 and 2001 brood years). Longfin smelt play a tremendously important ecological role in Lake Washington (Chigbu 1993), but how smelt year class fluctuations affect predator-prey dynamics and the food supply of juvenile salmon are not well understood or fully appreciated, and the current status of the smelt population during odd- and even-year cycles is not known.

It is reasonable to assume that the changes discussed above have altered the magnitude of predation mortality of at least some of the salmonid species while they reside in the lake. It is important to note that the impact of any one predator will vary depending upon the prey species of salmon (i.e., sockeye, coho, and chinook) being considered. Most of the changes discussed above will increase predation mortality on anadromous salmonids. However, the situation may be more complicated if some predators also eat the young of other predators and actually act to reduce the numbers of those predators, effectively helping to “reduce” predation. While there is a significant amount of high quality information available for this factor, the role of predation in Lake Washington has a number of key uncertainties including:

- Salmonid consumption estimates are lacking for most predators;
- Predator response to shoreline alterations is unclear; and
- Eurasian watermilfoil influence on predator-prey interactions is unknown.

Additional information will be forthcoming to address some of these uncertainties in the near future. For example, research on the effects of over water structures on smallmouth bass distribution is part of ongoing research by WDFW.

DEGRADATION OF SHORELINE RIPARIAN CONDITIONS

As discussed above, the Lake Washington shoreline has been dramatically altered over the last 100 years. The entire shoreline of Lake Washington has been affected by one or more type of change, including the lowering of the lake due to the “re-plumbing” of the system (see Figure 19). The physical changes that have occurred include the loss of riparian vegetation due to shoreline armoring, loss of LWD, 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).

The addition of bulkheads and overwater structures in shoreline areas of Lake Washington has the potential to increase predation on juvenile salmon and to affect their food supply. This can occur in four ways. First, artificial structures may provide better reproductive habitat for some predators leading to an increase in predator numbers. Presumably, as more overwater structures are built, the smallmouth bass population would increase. For example, R. Malcolm (Muckleshoot Indian Tribe, personal communication) found more smallmouth bass nests associated with artificial structures in Lake Sammamish. Second, human constructed structures in shoreline areas may provide sites that predators can use to more easily ambush and consume young salmon (Kahler et al. 2000). Third, the amount of shallow water refuge habitat available for juvenile chinook and other salmon could be reduced making the young fish more vulnerable to predators. Fourth, shoreline development could affect production of key invertebrate species, such as chironomids, that are important prey items of juvenile salmon (M. Koehler, UW, personal communication). This could occur as a result of substrate changes resulting from bulkheads, loss of insect production from a loss of riparian vegetation, or shading of littoral habitats by overwater structures.

While the physical changes to littoral zone habitats resulting from shoreline development are clear, we lack information linking these alterations to changes in the growth and survival of juvenile salmon. Key information needs include: juvenile utilization of shoreline areas, predator responses to shoreline modifications, and responses of prey communities to shoreline changes. Because of the large amount of uncertainty that still exists in understanding the responses of juvenile salmon to shoreline habitat changes, this factor was rated as probable. Research that is currently underway to address some of these information needs will make it possible to better assess this factor in the future.

ALTERED HYDROLOGY/FLOW

The U.S. Army Corps of Engineers regulates water level in Lake Washington within a range of about 2 feet through operation of the Ballard Locks. Natural fluctuations in lake level were at least 3 times what now occurs. Regulation of the lake level has also influenced the flushing time of Lake Washington; the current flushing rate is 2.3 years.

The lake is currently at its highest elevation from about April through October and at its lowest level from October through April. While stabilization of the lake level from historic conditions has eliminated seasonal flooding, it has resulted in a lake whose hydrological regime is the reverse of what naturally occurs in the Pacific Northwest. Under natural conditions, lake levels should be highest during winter and lowest during summer months. The situation for Lake Washington is the reverse. Effects of this reversal on the lake's ecology are unknown.

Lake level management is hypothesized as a factor of decline because of a lack of data on the effects of stabilizing lake-levels and reversing the hydrological regime on the ecology of the lake. Although no record is available on historic changes in the aquatic macrophyte community of Lake Washington over time, it is likely that stabilizing lake levels have

altered the type and abundance of shoreline vegetation. Natural fluctuations in lake-levels are known to influence the type and distribution of a number of aquatic macrophytes (Cooke et al. 1993). For example, in lakes where water levels fluctuate, seasonal low water conditions effectively serve to limit the shoreward extent of attached macrophytes. Stable water levels, such as those experienced in Lake Washington have probably decreased the diversity of aquatic macrophytes and the aquatic organisms that are associated with them. It is likely that stable lake elevations have enhanced the expansion of Eurasian watermilfoil, further decreasing the diversity and composition of attached macrophytes in littoral areas. While milfoil has colonized much of the lake's littoral zone, no recent estimates have been made of how much of the shoreline it occupies or how much it could be potentially colonize. Patmont et al. (1981) estimated that macrophytes covered approximately 85 percent of the shoreline down to a depth of 5 meters in 1981.

The cumulative impacts of changes in the diversity, species composition, and amount of attached aquatic macrophytes in littoral areas of the lake on salmonids are unknown. However, it is highly probable that the types of changes occurring in the littoral zone of Lake Washington have altered the composition, diversity, and abundance of fish communities in the lake (Bryan and Scarnecchia 1992; Beauchamp et al. 1994; Weaver et al. 1997). Predicting the net effect of changes in littoral zones on fish populations is more difficult. For example, the amount and spatial patterning of attached aquatic macrophytes can directly affect littoral zone fish abundance (Bryan and Scarnecchia 1992, Weaver et al. 1997). Thus, while a low density of macrophytes usually increases the abundance of littoral zone fish, a high density can reduce abundance of fish (Frodge et al. 1995). Moderate densities of aquatic macrophytes could both provide habitat for predators and provide a refuge for young salmon from predators.

WATER QUANTITY

The Cedar - Sammamish Basin was closed to additional water withdrawals by the State of Washington, Department of Ecology, under the authority pursuant to Chapter 90.54 RCW, chapter 90.22 RCW and in accordance with chapter 173-500 WAC in 1979. An exception was made to the Cedar River pursuant to WAC 173-508-060.

WDOE tracks water certificates and claims as a part of their WRATS database. Information from the WRATS database for Lakes Washington, Union and Sammamish is shown in Table 32 below.

Table 32. Authorized water claims, certificates and withdrawal amounts in Lakes Washington, Sammamish and Union (Source: WDOE).

	Certificates	Claims	Total Withdrawal Amount (cfs)
Union	4	3	19.76
Washington	241	389	217.74*
Sammamish	74	153	23.096
Totals	319	545	260.596

* An additional 7000 ac-ft, above the 260 cfs depicted above, of water is allowed under a water application to a water district.

The actual amount of water allowed is likely underestimated because not all of the water claims in the WDOE WRATS database indicate the amount of water allowed to be withdrawn. For instance, of the 153 water claims on Lake Sammamish, 152 of them do not indicate the amount of water withdrawal. In Lake Washington, of the 389 water claims, 380 do not indicate the amounts. Finally, of the three water claims in Lake Union, two do not indicate the amount of water allowed to be withdrawn.

During 1992, WDOE conducted a project where authorized and unauthorized water withdrawals in the Lakes Washington and Sammamish and Sammamish River basins were examined. For the limited area surveyed, they concluded that there were more than 100 unauthorized water users (documented as of October 1992) and greater than 500 water right claims (Anuszewski, 1992b). It was estimated at that time that overall there were up to 4000 unauthorized water users on Lakes Washington, Sammamish and the Sammamish River (Anuszewski, 1992c). Several problems were encountered including a resistance from waterfront property owners and a lack of voluntary compliance. Also, a belief that water is considered a public resource for use by everyone and that not everyone understands that water allocations are regulated. Then, people who have a water claim assume their use of the water is valid (Anuszewski, 1992c).

An estimate of irrigation withdrawals from Lakes Washington and Sammamish by waterfront properties was also made in late 1992 (Unknown Author WDOE 1992). Several assumptions were made during this estimation that included all waterfront properties were single family residences or homes, only single family homes and condominiums were using lake water for irrigation and every waterfront property used lake water for irrigation. These assumptions produced an estimated withdrawal for a 4-month irrigation season of between 19.8 and 37.2 cfs (4,785.0 – 8,974.3 ac-ft) (Unknown Author 1992).

It is hypothesized that these amounts likely overestimate the actual withdrawal. By examining the figures in Table 32, only approximately 10.8 percent of the properties were believed to have existing water rights lakes. Even if this represented only one half of the actual water withdrawals then 21.6 percent properties would have been withdrawing water. This would then yield an estimate of water withdrawals of 4.28 – 8.04 cfs (1,033.6 – 1,938.4 ac-ft). Finally, an additional estimate of 5.8 cfs for the maximum possible water use by waterfront properties on Lake Washington was calculated in 1992 by staff from WDOE (Anuszewski, 1992d).

The exact number unauthorized water withdrawals, the water quantity and the instantaneous water withdrawal by authorized users in Lakes Union, Washington and Sammamish are currently unknown.

INTRODUCED AQUATIC SPECIES - INVASIVE PLANTS

As discussed above, the colonization of the lake by Eurasian watermilfoil has significantly affected the amount, composition, and diversity of attached aquatic macrophytes in the lake. The amount of milfoil in the lake has never been quantified. A July 1999 survey of the Seattle shoreline (i.e., western shoreline only) observed milfoil at depths of 6 to 20 feet (Weitkamp, et al 2000) but it has been reported to grow at depths down to 30 feet (Aiken et al 1979).

The impacts of milfoil on salmonids in Lake Washington are unknown; it is not even clear that it has had a net positive or negative impact. Milfoil has likely eliminated some beach spawning habitat used by sockeye, such as on the north shore of Mercer Island. Of particular concern are the impacts of milfoil on predator prey interactions involving young salmon that are using the lake's shorelines. The local water quality problems caused by milfoil (see Frodge et al. 1995) are not an considered a direct habitat factor of decline because salmon juveniles leave littoral areas before milfoil biomass is seasonally greatest. Depending upon its density, milfoil could provide habitat for predator such as bass that they can use to ambush juvenile salmon or milfoil could provide refuge habitat that shields salmon from predators. Salmon may avoid dense milfoil beds. Any impacts of milfoil are likely species specific and would be expected to be more significant for juvenile chinook than other species of juvenile salmon using the shorezone. Juvenile coho and sockeye have a more limited residence time in littoral areas (late winter and spring) whereas chinook juveniles are present in littoral areas from early winter to mid summer; chinook juveniles are thus more vulnerable to any impacts of milfoil. The effects of macrophytes on other fishes that act as competitors or serve as alternative prey for salmon predators must be considered, because such indirect effects can result in significant shifts in food web dynamics that could change the growth or survival of juvenile salmon.

WATER QUALITY

As previously discussed, massive changes in water quality occurred in Lake Washington due to the effects of adding and then removing sewage effluents (Edmondson 1991). There are a number of water quality related issues that are now of concern including an increase in surface and littoral zone water temperatures, increasing nutrients, high levels of alkalinity, pH spikes at certain times and in specific areas, and increased levels of contaminants. Increasing water temperatures have probably increased overlap between predators and prey in littoral areas and increased metabolic rates of predators, thereby increasing their consumption of salmon. Modeling results show that the potential increase in consumption of salmonids by predators resulting from increases in lake water temperature could be considerable (D. Schindler, UW, personal communication).

While the major, sewage related nutrient problem was fixed, nutrients continue to be added to the lake (King County 1993), primarily as a result of the cumulative effects of urbanization. While these nutrient additions are not presently not of sufficient magnitude to significantly alter the lake's ecology, continued nutrient inputs are likely in the future. Eventually, they could reach a level that has measurable effects on the lake ecosystem.

Effects of the increased alkalinity and pH spikes on the lake's ecology are unknown. The most likely effects of these water quality changes are on the lake's food web (e.g., altering zooplankton and phytoplankton communities).

While it is reasonable to hypothesize that contaminant loadings (e.g., metals and pesticides) are now higher in the lake than historically due to the cumulative effects of urbanization, there is no data to accept or reject this hypothesis. Stormwater runoff (both direct and indirect discharges) enters the lake in a number of places (e.g., tributary streams, directly from roads and bridges) and is a likely source of contaminants. Thus, contaminant loadings may be more of an issue in specific areas near where inputs occur rather than over the whole lake. Many contaminants are present for only a short period in the water column and find their way quickly into sediments. Even if data on contaminant levels were available, we would still need to ascertain if any elevated contaminant levels detected in Lake Washington were having effects on the lake's ecology and impacting survival and growth of salmonids. Additional water quality data (e.g., low level metals and organic compounds) are currently being collected and will help answer some of the questions pertaining to contaminant levels in the lake's water.

BIOLOGICAL PROCESSES

Escapement goals are not set for Lake Washington as a subbasin with the exception of beach spawning sockeye. Counts of beach spawning sockeye are quite limited and the full extent of shorelines by sockeye is unknown.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- An estimated 82 percent of the Lake Washington shoreline has been bulkheaded;
- Anthropogenic actions have lowered the level of Lake Washington by about 10 feet, exposed 5.4 km2 of previously shallow water habitat, reduced the lake's surface area 7.0 percent, decreased the shoreline length by about 12.8 percent, and eliminated much of the lake's wetlands;
- In 1997, there were an estimated 2,700 piers and docks along the shore of Lake Washington that collectively covered about 4 percent of the lake's surface within 100 feet of shore;
- As a result of the diversion of sewage, several major changes in the zooplankton community have occurred. Most notably, beginning in 1976, *Daphnia* became the dominant pelagic zooplankton taxa;
- Twenty-four non-native fish species and nine introduced aquatic plant species have been identified in Lake Washington;
- Five changes that have occurred in Lake Washington potentially have increased predation mortality of salmonids. These include: (1) littoral zone habitats have been extensively modified; (2) predation mortality of salmonids could increase if there has been a significant increase in the population of one or more native predator species; (3)

water temperatures in Lake Washington have increased since monitoring began in the 1930s; (4) The introduction of non-native piscivorous fish species could increase predation mortality of anadromous salmonids over historic levels; and ; (5) changes in abundance or availability of alternative prey fishes (especially smelt) for salmon predators;

- The addition of bulkheads and overwater structures in shoreline areas of Lake Washington has the potential to increase predation on juvenile salmon and to affect their food supply;
- The stabilization of the lake level from historic conditions has eliminated seasonal flooding and resulted in a lake whose hydrological regime is the reverse of what naturally occurs in the Pacific Northwest;
- The colonization of the lake by Eurasian watermilfoil has significantly affected the amount, composition, and diversity of attached aquatic macrophytes in the lake; and
- The potential increase in consumption of salmonids by predators resulting from increases in lake water temperature could be considerable.

E. DATA GAPS

- The relative survival of the early juvenile chinook fry that emigrate from the Cedar River between January and March and rear in Lake Washington is unknown versus the relative survival of juvenile chinook that rear in the Cedar River and enter Lake Washington at a larger size in May and June;
- The impacts of hatchery chinook juveniles released into Lake Washington to the viability of the naturally spawned chinook juveniles is unknown;
- Salmonid consumption estimates are lacking for most predators;
- The response of predators to shoreline alterations is unclear;
- The effects of Eurasian watermilfoil on predator-prey interactions is unknown;
- A large amount of uncertainty still exists in understanding the responses of juvenile salmon to shoreline habitat changes;
- Effects of the hydrologic reversal on the ecology of Lake Washington are unknown;
- The cumulative impacts of changes in the diversity, species composition, and amount of attached aquatic macrophytes in littoral areas of the lake on salmonids are unknown;
- No current estimates are available of the areas or amount of the shoreline Eurasian watermilfoil occupies or how much it could be potentially colonize;
- The impacts of milfoil on salmonids in Lake Washington are unknown, it is not even clear that it has had a net positive or negative impact;
- The potential increase in consumption of salmonids resulting from increases in lake water temperature is unknown and could be considerable;
- The loadings of heavy metals and pesticides are unknown;
- A comprehensive sediment quality evaluation of Lake Washington has not been available;
- The most effective methods and potential effects of reducing the habitat and populations of exotic piscivorous fishes and rebalancing the apparently increased populations of certain native piscivorous fishes are unknown;

- The impacts of pesticides and heavy metals on the biological communities and on salmonid growth and survival is not known; and
- The utilization of Lake Washington shorelines by spawning sockeye and chinook is not fully known.

LAKE WASHINGTON TRIBUTARIES

Lake Washington Tributaries

Introduction

The tributaries of Lake Washington are among some of the most altered hydrological streams in the Puget Sound Region. They typically are low gradient streams, have their origins in rain-on-rain elevations, and exist in heavily urbanized settings and are subjected to the adverse habitat impacts that accompany this setting. These drainage basins generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems. As one moves upstream, habitat conditions show some improvement but still do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival.
The following chapter characterizes the larger of these subbasins and streams. Information on many of the smaller streams is not available

The tributaries of Lake Washington are among some of the most altered hydrological streams in the Puget Sound Region. These streams generally exist in heavily urbanized settings and are subjected to the adverse habitat impacts that accompany this setting. These streams generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water quality problems. As one moves upstream, habitat conditions show some improvement but still do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival.

THORNTON CREEK

A. PHYSICAL DESCRIPTION

The Thornton Creek watershed is heavily urbanized and drains approximately 7,402 acres or 11.6 mi^2 (Thornton Creek Watershed Characterization Report, 2000). The watershed is located in northwestern King County, and overlaps two jurisdictions, the cities of Seattle and Shoreline. The creek flows southeasterly into the northern end of Lake Washington at the Matthews Beach Park.

Sub basins of Thornton Creek include the mainstem, North Branch (08.0042), and South Branch (Maple Leaf Creek (08.0033)). Thornton Creek and its tributaries total over 15 miles in length, and elevation ranges from 8’ to 494’ (SPU GIS). The North Branch drains approximately 4446 acres of Shoreline and Seattle. The headwaters originate near Ronald Bog, which along with Twin Ponds one mile downstream, were ponds created in the 1950’s when peat deposits were mined from the area (Thornton Creek Watershed Characterization Report, 2000). The South Branch drains approximately 2,333 acres of Seattle, and the headwaters originate west of I-5 near the North Seattle Community College. The college and the Northgate area were historically wetlands and a large cranberry bog (Thornton Creek Watershed Characterization Report, 2000).

Logging was the first industry to reach the Thornton Creek Watershed, and the forest was quickly harvested beginning in the late 1880's (Thornton Creek Watershed Characterization Report, 2000). Sawmills were located at the mouth, in the upper South Branch near the current site of Northgate Mall, near the current Pinehurst School, and on the North Branch downstream of the current Jackson Park Golf Course. After the forests were removed, farms, orchards and dairies dominated the area.

A railroad was established by 1885 (Thornton Creek Watershed Characterization Report, 2000). The current Lake City Way was a brick highway by 1905, became the first concrete road in the state in 1922, and fostered the Lake City business district beginning in 1923 (Thornton Creek Watershed Characterization Report, 2000). In 1916, the water level in Lake Washington was lowered nine feet when the Ship Canal was built.

Following World War II the population rapidly increased, jumping from 2,898 in 1920 to 17,500 in 1940, and 43,680 in 1950 (Miholovich, 1977). Developers constructed the first regional shopping mall in 1950, and I-5 was completed in this area during the early 1960's. In 1954 the Seattle City limits were moved to their current location at NE 145th Street, and a sewer system was installed. Growth continued with the Boeing boom in the 1970's, and jumped again in the 1990's. The population grew from 69,000 in 1990 to 75,400 in 2000 (Thornton Creek Watershed Characterization Report, 2000).

The watershed is heavily developed. An estimated fifty percent of the surface area of the basin is impervious, and currently, only about 4 percent of the land remains vacant (Thornton Creek Watershed Characterization Report, 2000). Existing land use consists of 53 percent residential, 23 percent roads, 9 percent commercial and industrial and 4 percent parks and golf courses, 4 percent schools, 4 percent vacant, and (Thornton Creek Watershed Characterization Report, 2000). Residential uses account for approximately half of the impervious surfaces, roads account for 27 percent, and commercial uses, for 16 percent (Thornton Creek Watershed Characterization Report, 2000). The impervious surface were calculated by measuring impervious surface for a sample of common land uses, which were then extrapolated to the entire Seattle area.

Precipitation in the watershed averages 34.9 inches per year, which is slightly higher than the city average of 34 inches (Thornton Creek Watershed Characterization Report, 2000). Thornton Creek and its tributaries flow year-round, and groundwater provides much of the base flow. Flows average 5.7 cfs in the lower South Branch, 8.9 cfs in the lower North Branch, and 11.2 cfs at the mouth (Thornton Creek Watershed Characterization Report, 2000). One hundred-year storm flows are estimated to reach 556 cfs in the lower South Branch, 441 cfs in the lower North Branch, and 576 cfs at the mouth (Thornton Creek Watershed Characterization Report, 2000). Notable flood-prone areas include the confluence, the mainstem, and the upper North Branch at Ronald Bog, and at Jackson Park Golf Course (Thornton Creek Watershed Characterization Report, 2000).). A 72- to 90-inch by-pass pipe diverts up to 350 cfs storm flows from just below the confluence, and drains it directly into Lake Washington. Most stormwater in the basin is conveyed to the creek either through storm drains along busy streets and commercial districts, or through

open channels (drainage ditches) in residential areas (Thornton Creek Watershed Characterization Report, 2000).

Vashon Till covers most upslope areas of the watershed and forms much the North Branch floodplain (Thornton Creek Watershed Characterization Report, 2000). Outwash or alluvium is found along the floodplain of the mainstem. Sandy topsoil is located in the north and south central portions of the basin, and along the central South Branch floodplain.

B. SALMONID UTILIZATION

Sporadic salmonid surveys, for adults and juveniles, have been conducted primarily in the mainstem of Thornton Creek, and to a lesser extent in the lower sections of the North and South branches, up to Lake City Way (WDFW Salmon Spawning Ground Surveys data 1976, 1981, 1984, Muto and Shefler 1983, Ludwa *et al.* 1997, Johnson and Minton 1998, Osterguaard, 1998, Serl 1999, White 1999, Vanderhoof *et al.* 2000, unpublished Volunteer Salmon Watcher Program data 1998-2000, Taylor and Associates unpublished data 2000, and Washington Trout/SPU watershed study in progress). Salmonid species present in Thornton Creek include: chinook salmon, coho salmon, sockeye salmon, coastal cutthroat trout, steelhead, and rainbow trout.

The most commonly encountered salmonid during surveys in Thornton Creek has been coastal cutthroat trout (Ludwa *et al.* 1997, Johnson & Minton 1998, Serl 1999, White 1999, Taylor and Associates unpublished data 2000, Washington Trout/SPU watershed study in progress). However, small numbers of adult chinook salmon have been observed during spawning surveys in Thornton Creek including: 10 in 1976 and 2 in 1981 (WDFW Salmon Spawning Ground Survey Database, WDFW Juvenile Salmon Survey data 1983), 3 in 1999, and 3-4 in 2000 (Washington Trout/SPU watershed study in progress). Other salmon recorded during spawning surveys include: sockeye (about 6 in 2000), coho (about 10 in 1999, and about 85 in 2000) (Washington Trout/SPU watershed study in progress). Although numbers of salmon have been small, cutthroat can be present in high densities, as indicated by thousands of cutthroat fry, which were caught within a 400-foot section of Thornton Creek adjacent to Meadowbrook Pond in September 2000 (Taylor and Associates, unpublished data). Adult steelhead were observed in Thornton Creek in 1991, 1992, and 1995 (personal observation, Bob Fuerstenburg, King County SWM Division and Bob Vreeland, cited from Thornton Creek Watershed Characterization Report, 2000).

Results from smolt trapping results from efforts initiated by WDFW and SPU in 2000, indicate that Thornton Creek has extremely limited capacity to support coho through their first year, as overall, the system provides very few coho smolts, a few per day, (WDFW/SPU unpublished smolt trapping data 2000), compared to other systems of comparable size in the region which produced 100's to 1000's/day for the same sample period (D. Seiler, pers. comm. to K. Lynch, 2000).

Over 300,000 coho fry/fingerlings, originating from Issaquah Creek, Green River, and Skykomish River stocks, were released into Thornton Creek between 1952 and 1990,

averaging about 15,000 fry/year (WDFW 1952-2000, Fish Release Database). About 17,000 summer/fall chinook fry, of unknown origin, were released in Thornton Creek in 1977, and 50,000-130,000 Cedar River sockeye fry/fingerlings were released into Thornton Creek between 1979 and 1982 (WDFW 1952-2000, Fish Release Database). Since 1990, local schools, participating in the Salmon in the Classroom Program, have released up to 200 salmon fry annually (mostly coho from the Green, Skykomish and Issaquah stocks, and some chinook (from University of Washington hatchery). The fry were released at 3 locations including: the river mouth, below the confluence of the North and South branches, and in South Branch at RM 0.3 (WDFW 1952-2000 Lake Washington Gamefish Releases data base, unpublished results of a SPU questionnaire to participating schools). Private property owners operated egg incubators on the North Branch, near NE 133rd Street and 17th Ave NE, for 20,000-25,000 coho eggs obtained from the Issaquah Hatchery in 1999 (WDFW 1995-00 Lake Washington Gamefish Releases data base).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

SPU hired Washington Trout in 1999 to perform a fish passage assessment. In Thornton Creek, culverts and weirs block or impede salmon from accessing the upper sections of Thornton Creek. A fish passage barrier under Lake City Way on the North Branch (culvert assessment, Washington Trout/SPU watershed study in progress) was repaired in 1999 (SPU Urban Creek Legacy CIP). However, salmon passage through the improved culvert has not yet been documented because of a barrier downstream (private weir), which has prevented the upstream migration of adult coho and chinook salmon beyond NE 113th Street (1999 & 2000 spawning surveys, Washington Trout/SPU watershed study in progress). There are two additional barriers on the North Branch upstream of Lake City Way: one at 25th Ave NE, just north of NE 123rd Street, and a second located at NE 125th Street (culvert assessment, Washington Trout/SPU watershed study in progress).

Adult coho have accessed the South Branch up to the culvert under Lake City Way, which is a barrier (1999 & 2000 spawning surveys, and culvert assessment, Washington Trout/SPU watershed study in progress). SPU is planning to repair the culvert in 2001. Culverts near the mouths of Littles, Littlebrook, and Willow creeks, which are tributaries to Thornton Creek, block or partially block fish access (culvert assessment, Washington Trout/SPU watershed study in progress).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Stream and habitat surveys conducted in 1995-96 (Thornton Creek Watershed Characterization Report), and 2000 Washington Trout/SPU watershed study in progress) documented sections of channel and streambank which are subject to incision and erosion. However, little data are available on sediment transportation processes in Thornton Creek. Spawning gravels for salmon are found in the lower South and North branches, and in the reaches adjacent to Meadowbrook Pond in the mainstem (2000 Washington Trout/SPU

watershed study in progress). Williams (1975) and Johnson and Minton (1998) reported larger substrates cemented together by fines in the lower mainstem.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Johnson et al (1998) and Seattle Public Utilities (In Progress) found that pool habitat was limited with very few deep pools, off-channel habitat, instream complexity, riparian cover and refugia habitat was lacking and little LWD is available for channel complexity pool formation. They also found that hydrologic connectivity to the floodplain has been lost due to streambank hardening.

DEGRADATION OF RIPARIAN CONDITIONS

Much of Thornton Creek and its tributaries flow through residential backyards, where forested riparian buffers typically are less than 50 feet wide and are typically fragmented. (Johnson and Minton 1998, SPU 1995/96 habitat surveys unpublished data, SPU/Washington Trout in progress).

ALTERED HYDROLOGY/FLOW

The Thornton Creek watershed has a very high road density, including 4.5 miles of Interstate 5, 3.5 miles of Lake City Way, and a dense grid of residential streets (SPU GIS). Roads account for approximately 27 percent of the total impervious surface in the basin (Thornton Creek Watershed Characterization Report, 2000). Most stormwater in the basin is conveyed to the creek either through storm drains along busy streets and commercial districts, or through open channels (drainage ditches) in residential areas. In most of the watershed, stormwater is conveyed through drainage ditches, which drain directly into the creek through numerous outfalls.

Data from a USGS gaging station located near the mouth of Thornton Creek indicates that the hydrograph rises and falls sharply during storm events. Notable flood-prone areas include the confluence, the mainstem, and the upper North Branch at Ronald Bog, and at Jackson Park Golf Course (Thornton Creek Watershed Characterization Report, 2000). Four detention facilities and bypasses have been installed to reduce flooding, including a 72- to 90-inch by-pass pipe, which diverts up to 350 cfs storm flows from just below the confluence directly into Lake Washington (Thornton Creek Watershed Characterization Report, 2000).

POOR WATER QUALITY-INCREASED TEMPERATURE

High water temperatures are likely to be a problem for fish in Thornton Creek during the summer months. Although many of the records between 1985 and 1997 indicate that water temperatures infrequently exceeded Ecology's 16°C water temperature standard for Class AA streams, many of the samples were taken during the cooler morning hours (King County Metropolitan Services 1994, Minton 1998). Temperatures as high as 22° C were recorded on hot summer afternoons in 1998 (SPU 1998, unpublished data). Stream water

temperatures ranged from 16 to 24° C at thirteen locations throughout the basin, as measured between 3:00 and 5:00 p.m. on August 19, 1998 and 1999 (UW Center for Urban Resources Management Annual Stream Temperature Survey 1998-2000 unpublished data). Although the creek flows through pipes and wooded areas, much of the creek flows through landscaped backyards, where canopy cover is often limited (Thornton Creek Watershed Characterization Report, 2000).

POOR WATER QUALITY-INCREASED OTHER

Existing water quality data for Thornton Creek are from King County/Metro, SPU, USGS and Ecology. Since 1985, King County/Metro has collected a monthly grab sample from the mouth of Thornton Creek (King County, 1994). These have been analyzed for conventional water quality parameters, nutrients and bacteria. SPU collected five stormwater samples in 1992-93 from the mainstem, and analyzed them for conventional water quality parameters and metals (Seattle Drainage and Wastewater Utility, 1995). In a separate study during the summer of 1998, SPU sampled ten locations to examine bacteria levels, temperature, and dissolved oxygen (SPU unpublished data). In joint studies, USGS and WDOE evaluated pesticides in water, sediment and fish tissue in Thornton Creek as part of a nationwide pesticide assessment (Bortleson and Davis 1997).

It is likely that dissolved oxygen levels are a problem for fish in Thornton Creek, although sampling has been limited (Thornton Creek Watershed Characterization Report, 2000). Dissolved oxygen (DO) levels fell below the WDOE 9.5 mg/L DO standard for Class AA streams in approximately 15 percent of the storm flow DO samples, and in most of the dry-weather flow DO samples (Minton, 1998), particularly when air temperatures exceeded 20º C (mean of 6.7 mg/L in five of ten locations sampled, SPU, 1998, unpublished data).

Instream pesticides may be a problem for fish in Thornton Creek, although data are limited. Of the 162 compounds tested for in 1992, the only one above the detection limit in Thornton Creek was an insecticide, diazinon, at a concentration of 0.077 µg/L, which exceeds the National Academy of Sciences and National Academy of Engineering (1973) recommended maximum concentration of 0.009 µg/L (Davis, 1993). Thirteen pesticides were identified in stormwater samples collected in 1998 from three locations in Thornton Creek, and of these, only diazinon was detected at levels above recommended concentrations (Voss *et al.* 1999). USGS sampled for 98 pesticides concentrations in stormwater samples collected from ten urban streams in King County from 1987 to 1995, including three sites on Thornton Creek. Six pesticides were detected at all study sites, and of these, Diazinon, 2,4-D, and MCPP were among the most frequently purchased pesticides in King County. Instream pesticide concentrations were highest during April and May, which overlapped with the period of highest pesticide applications rates, as indicated by store sales (Voss *et al.* 1999). However, almost half of the 23 pesticides that were detected in urban streams were not from retail sales, and may have originated from nonresidential applications, such as, parks, rights-of-way, and recreational areas (Voss *et al.* 1999).

The USGS also analyzed Thornton Creek sediments for pesticides and found high concentrations of organochlorine compounds, which includes DDT (Bortleston and Davis

1997, Voss *et al.* 1999). The USGS also found poly-aromatic hydrocarbons (PAHs) in Thornton Creek sediments at levels that exceeded Canadian guidelines for threshold effects level (TEL), but fell below probable effects level (PEL). Analysis of tissue samples from sculpins in Thornton Creek also indicated a range of organochlorine compounds, with total PCB's and DDT exceeded New York State criteria for protection of fish-eating wildlife (Bortleston and Davis 1997, Voss *et al.* 1999).

Excessive amounts of heavy metals can affect the nervous, respiratory, circulatory, and reproductive systems of fish. Sampling for heavy metals has been sporadic and limited in Thornton Creek. Total metal concentrations are likely higher during storms, although the limited data from Thornton Creek prevents firm conclusions (Minton 1998, in Thornton Creek Watershed Characterization Report, 2000). Zinc, lead, and copper have been detected in all stormwater samples, but only copper exceeded the standard for dissolved metals in one of four stormwater events sampled (Minton 1998, in Thornton Creek Watershed Characterization Report, 2000, neither the sample measurements nor the standard levels were provided). King County (1994) found that Thornton Creek had the highest levels of cadmium, lead, and zinc, and among the highest levels of copper and nickel for sediments collected at the mouths of 20 streams sampled in 1991 and 1992. King County and SPU sampled sediments once per year from lower and middle Thornton Creek in 1991, and 1993 through 1994, and found that none exceeded standards above which minor effects occur (Thornton Creek Watershed Characterization Report, 2000). Lead and mercury were detected in fish tissue (sculpin) obtained from Thornton Creek (Bortleston and Davis 1997, Voss *et al.* 1999).

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek, nor is any reach of the creek an index area. Counts of adult salmonids, primarily for coho have increased in recent years but are generally sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- A comprehensive assessment of fish barriers is currently being conducted;
- Pool habitat is limited with very few deep pools, off-channel habitat, instream complexity, riparian cover and refugia habitat is lacking and little LWD is available;
- The hydrologic connectivity to the floodplain has been lost due to streambank hardening;
- The riparian buffers typically are less than 50 feet wide and are fragmented;
- An estimated fifty percent of the surface area of the basin is impervious, and currently, only about 4 percent of the land remains vacant;
- Roads account for approximately 27 percent of the total impervious; and
- Stream water temperatures ranged from 16 to 24° C at thirteen locations in the basin, as measured between 3:00 and 5:00 p.m. on August 19, 1998 and 1999.

E. DATA GAPS

- The full impacts of pesticides on salmonids naturally produced in the Thornton Creek subbasin is not completely understood;
- Little data are available on sediment transportation processes in Thornton Creek; and
- Sampling for heavy metals and pesticides in the Thornton Creek subbasin is incomplete.

Mc ALEER CREEK

A. PHYSICAL DESCRIPTION

McAleer Creek (08.0049) drains an area of approximately 3.6 square miles and the drainage area includes portions of the cities of Mountlake Terrace, Shoreline, Lake Forest Park, Snohomish County and King County. The McAleer Creek subbasin has its origins in an area that lies within Snohomish County and Mountlake Terrace and drains generally in a southern direction to Lake Ballinger. McAleer Creek has its origins at the outlet to Lake Ballinger near the Snohomish County – King County border east of Interstate 5. The stream traverses generally southeast to its outlet on the northwest shore of Lake Washington, just southwest of the outlet of Lyon Creek (08.0052). The geographic area draining directly to McAleer Creek is a fairly narrow strip along the stream. Most of the basin drains to small tributaries. Five general subbasins were characterized in a 1983 report by Kramer, Chin and Mayo (KCM 1983) for the McAleer Creek Project, a basin plan effort addressing capital solutions to flooding problems in the drainage. This project only considered the area downstream of Lake Ballinger, and little scientific data has been collected on the area upstream of Lake Ballinger - the Hall Creek sub-basin - even though approximately 60 percent of the McAleer Creek watershed lies in this drainage area. The following discussion regards only the portion of the drainage basin that is located downstream of Lake Ballinger.

The three upper sub-basins are located in the general vicinity of the Interstate-5 (I-5) corridor and are characterized by gently sloping terraces draining residential and some commercial areas. East of I-5, the middle basin consists primarily of knolls and deep ravines with erosive soils. This area is primarily residential with a lower density than the areas closer to I-5 in Mountlake Terrace. The lower basin near the outlet to Lake Washington flattens and fans into a floodplain across what is now the Lake Forest Park Mall and Bothell Way. Building density increases here as does encroachment of structures into the creek corridor and floodplain (KCM 1983).

The headwaters of McAleer Creek are at an elevation of 277 feet at the outlet to Lake Ballinger and flow about 3.5 miles to Lake Washington at an elevation of 25 feet. Channel gradient averages 1 percent with a gradient of about 0.25 percent between Lake Ballinger and the first culvert under I-5. Three smaller tributaries join McAleer Creek, one in Mountlake Terrace (North Tributary) and two within Lake Forest Park (Cedarbrook Creek

and Brookside Creek). The upper reaches of the creek consist of broad open terraces where water is constrained in an open channel and then into a series of culverts underneath I-5 corridor (KCM 1983).

Wetland delineation within the basin is unknown at the time of this writing. However, both Brookside and Cedarbrook Creeks originate from headwater wetlands formed at wall-base seeps under erosive sandy soils (B. Lackey, pers. obs., 2000).

B. SALMONID UTILIZATION

Chinook, *O. nerka* expressed as both sockeye and kokanee, coho salmon; and steelhead, rainbow and coastal cutthroat trout have been observed in McAleer Creek (Salmonwatcher data 1998; Muto and Shefler 1983; Ludwa et al. 1997; KCM 1983).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

There is a known fish passage barrier on Brookside Creek (08.00xx) at approximately RM 0.7 due to a steep culvert and an impassable anthropogenic waterfall. Anadromous salmonids are reported to have reached the I-5 culvert in recent years (though not passed through it), however, so mainstem passage is not presently a major problem. This long culvert under the freeway may be a barrier to rearing juveniles as well, preventing the use of Lake Ballinger for rearing. (D. Hennick, pers comm. to B. Lackey,1999).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Transport of suspended sediments has been significant in McAleer Creek. The stream channel throughout the basin shows visual evidence of transport of suspended sediments, and there are areas of extensive mass wasting into the stream channel through the middle portion of the mainstem channel. The incising of streambanks and resulting erosion was one of the major reasons the 1983 McAleer Creek Project Plan was undertaken (KCM 1983). Storm events continue to contribute to erosion in the middle and lower basin. A sizable sinkhole occurred at 33rd Avenue during the 1996/1997 storm event (King County Drainage Services 1997).

No quantifiable information was located during the course of this investigation that showed levels of fines in spawning substrates.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Clearing and land use changes in the riparian areas of these creeks has limited small and large wood recruitment that can provide the vital riparian functions that contribute to channel complexity. Some recruitment of small woody debris still regularly occurs in the middle section of the watershed, but it is not generally of the type (>8" diameter and

coniferous) necessary to provide for sustainable long-term increases in channel complexity or channel forming processes (KCM 1983; B. Lackey, pers. obs. 1999).

DEGRADATION OF RIPARIAN CONDITIONS

The upstream section of McAleer Creek passes through heavily altered I-5 freeway corridor where it has very limited riparian vegetation. After crossing into the city of Lake Forest Park, banks and slopes become much more vegetated, but are also markedly incised as a result from the increased gradient through erosive soils (KCM 1983). Multiple landslide areas are evident with tree falls creating blockages and redirection of flows (KCM 1983). Damage from the December 1996/January 1997 storm event caused road closures and resulted in several slides through this section of the basin (King County SWM Drainage Services Section Reports 1997). The lower basin area becomes less steeply incised, and the riparian areas are again dominated by residential landscaping, primarily lawn, up to the stream channel edge. The lowermost portion of the stream runs through more heavily commercial areas and roadways with similarly little riparian vegetative buffer to the stream (KCM 1983; B. Lackey, pers. obs., 1998).

ALTERED HYDROLOGY/FLOW

McAleer Creek flows year around in the main channel and the upper tributary. Citizens and the citizen based "Lake Forest Park Environmental Quality Commission" report that both Brookside Creek and Cedarbrook Creek flow perennially, though with very low flows in late summer.

The outflow from Lake Ballinger is generally limited to 60 cfs in normal flow conditions. Mountlake Terrace has the ability to modify the level of Lake Ballinger to achieve this flow during periods of heavy rainfall to allow for more storage in the lake. More recently, this strategy has not worked during major flow events. Several times in the last five years, the flow control weir has been overtopped. Three downstream culverts then provide flow control. During the January 1996/December 1997 storm event, the weir was overtopped by six feet, and the 48 inch box culvert under I-5 was under full inlet inundation. A detention facility was constructed by King County in the mid 1980's near the intersection of 15th St. NW and NE 196th St. This structure helps to alleviate downstream flooding during high water flow periods. Increases in impervious surfaces in the Lake Ballinger basin has raised not only peak flows, but also the frequency and duration of these peak flow periods.

The primary issue that caused the initiation of the McAleer Creek Project in 1983 was the increased flooding and erosion problems that were resulting from old and new developments constructed without stormwater retention/detention facilities that would protect the stream from the impacts of a flashier hydrology. That report estimated the basin's total impervious area at 17-20 percent (KCM 1983). These conditions have worsened in the intervening years as total impervious surface area has somewhat increased (B. Bennett, pers. comm. to B. Lackey, 1998).

POOR WATER QUALITY-INCREASED TEMPERATURE

While there is little information specific to McAleer Creek about stream temperatures becoming either barriers to fish migration or negatively affecting migrating or rearing salmonids, volunteer monitoring efforts have identified water temperatures exceeding 68°F on occasion (B. Bennett pers. comm. to B. Lackey, 1998).

POOR WATER QUALITY-INCREASED OTHER

Mountlake Terrace operates a hypolimnetic pipe system in Lake Ballinger that, through a siphon effect, takes water from the lake inlet at Hall Creek and deposits it on the bottom of the lake. A separate outlet pipe takes the oxygen poor water from the bottom of the lake to the weir on McAleer Creek where it is released. The city of Mountlake Terrace maintains the level of Lake Ballinger at pre-determined levels as directed by an adjudicated court agreement with shoreline residents on Lake Ballinger, King County, Snohomish County, the City of Edmonds, and WDOE. This is in part to provide a hydraulic head for the hypolimnetic system, and in part to provide for dead storage during the winter months while satisfying a majority of the residents with an acceptable summer lake level. An oxygen aeration system was recently installed to allow this system to operate through the summer months without adversely affecting dissolved oxygen levels downstream in McAleer Creek. King County is the lead agency and will be conducting tests in 2000 and 2001 to determine the effectiveness of the system.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- Land use practices and the alteration of the riparian zones of these creeks has limited any wood recruitment; and
- A 1983 report estimated the basin's total impervious area at 17-20 percent.

E. DATA GAPS

- Quantifiable information on streambed sediments has not been gathered;
- Water quality information is generally lacking; and
- Very little scientific data has been collected on the area upstream of Lake Ballinger (the Hall Creek sub-basin) even though approximately 60 percent of the McAleer Creek basin is upstream of Lake Ballinger.

LYON CREEK

A. PHYSICAL DESCRIPTION

Lyon Creek (08.0052) drains an area of approximately 2,600 acres flowing from its headwater wetland upper reaches in the cities of Mountlake Terrace and Brier in Snohomish County, through Lake Forest Park to its outlet on the northwest shore of Lake

Washington. The mainstem of the stream is approximately 3.8 miles in length with another 2.2 miles of contributing tributaries. The average slope of the stream channel is between 1 percent and 2 percent (ENTRANCO, 1981).

An understanding of the current habitat conditions and factors of decline for biota in the stream is limited by lack of information. The only known study of any depth in the basin is the Lyon Creek Comprehensive Drainage Plan, a report prepared in 1981 by ENTRANCO Engineers, which focuses mainly on design recommendations to address flooding concerns.

The upper drainage basin is comprised of a westerly fork within the City of Mountlake Terrace and an easterly fork within the City of Brier. The headwaters of both tributaries begin at an elevation of 400 to 450 feet. Just downstream of the confluence of the two forks, Lyon Creek flows into the City of Lake Forest Park. Several smaller tributaries join Lyon Creek within Lake Forest Park prior to its outflow in Lake Washington (ENTRANCO, 1981).

The upper reaches of the creek consist of broad open terraces that drain to moderately incised creek channels. As the creek flows to the south and east through Lake Forest Park, the channel becomes more incised as the terrain grows steeper before draining across a narrow floodplain into Lake Washington. This area within Lake Forest Park before the creek broadens into the floodplain near the lake, has a history of high flow episodes resulting in significant stream bank erosion (ENTRANCO, 1981).

The west fork of Lyon Creek traverses three wetlands within the city limits of Mountlake Terrace. Two of the three wetlands are on Mountlake Terrace city park property. Lake Forest Park has purchased a wetland area that is now Lake Forest Park city park property that drains into a tributary of Lyon Creek just north of Ballinger Way at NE 195th Street.

Portions of the upper reaches of Lyon Creek seasonally dry up in both Mountlake Terrace and Brier. The creek runs year around in both upper forks upstream of the confluence of the two forks.

Mountlake Terrace maintains two regional detention facilities, one on the west fork of Lyon Creek within Mountlake Terrace city park property, and the other at the confluence of the two forks just east of Cedar Way. The Cedar Way facility was constructed in 1987 to help mitigate the effects of a 400 unit apartment complex (Creekside Apartments), and to act as a regional detention facility. A 10 year late comer agreement was established for future development upstream within Mountlake Terrace. That agreement expired in 1997. The other regional facility was constructed by the City in 1989 as part of a road reconstruction project. Biofiltration as well as detention and retention was accomplished with this project.

B. SALMONID UTILIZATION

Sockeye and coho salmon along with coastal cutthroat and rainbow trout have been observed in Lyon Creek (Muto and Shefler 1983; Ludwa et al 1997).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Fish passage barriers are frequent and numerous throughout the system. The 1981 ENTRANCO plan identified 22 impassable barriers, the lowest occurring at RM 0.25 miles. A current assessment would likely find some of the old barriers have been removed and some new ones created. However, fish migratory access is a significant limiting factor to recolonization of any remnant spawning habitat. (ENTRANCO 1981).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Regional detention facilities on both streams show evidence of accumulating fine sediments. Mountlake Terrace has removed accumulated sediments several times in the last ten years at the Cedar River Detention facility on Lyon Creek (ENTRANCO 1981).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Stream banks are mostly hardened resulting in a loss of floodplain connectivity. The system lacks off-channel habitat. LWD recruitment is impaired and in turn limits channel-forming processes from taking place where streambanks have not been armored (B. Lackey, pers. obs.,1998). However, no quantifiable information was located during the course of this investigation.

DEGRADATION OF RIPARIAN CONDITIONS

The Lyon Creek watershed is totally developed. No areas of refugia exist. Much of the stream has been totally cleared of native riparian vegetation, and little LWD recruitment potential remains (ENTRANCO 1981). Current land use practices within the watershed will continue to preclude any LWD recruitment to the stream channel.

ALTERED HYDROLOGY/FLOW

Peak flows have increased from an average of 0.5 to 30 cfs. The watershed was almost entirely converted to residential land use as early as the late 1970's. During that conversion, virtually no stormwater retention/detention facilities were constructed to mitigate the effects of greater basinwide total impervious area on the stream system and aquatic habitat. The 1981 ENTRANCO plan was initiated as a direct result of the lower basin area flooding that resulted from the much altered hydrology in Lyon Creek (ENTRANCO 1981).

POOR WATER QUALITY-INCREASED TEMPERATURE

Three sites measured quarterly reveal stream temperatures in the range of 55° F to 60° F. In addition, periodic pulses of high levels of household chemicals have been identified frequently over the past 20 years (B. Bennett 1998).

POOR WATER QUALITY-INCREASED OTHER

The Lyon Creek basin has primarily residential development and has been identified as having high levels of pesticide runoff during spring and fall "lawn maintenance periods" (King County Wastewater Treatment Division 1999).

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek, nor is any reach of the creek an index area. Counts of adult salmonids, primarily for coho are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- A comprehensive barrier survey has not been initiated. A partial survey conducted over 20 years ago identified 22 impassable barriers with the first one at RM 0.25;

E. DATA GAPS

- An understanding of the current habitat conditions and factors of decline for biota in the stream is limited by lack of information. The only known study of any depth is twenty years old and focuses mainly on design recommendations to address flooding concerns.

JUANITA CREEK

A. PHYSICAL DESCRIPTION

The mainstem of Juanita Creek (08.0230) has its headwater east of SR 405, and then flows to the west and south prior to entering the northeast end of Lake Washington on the western side of Juanita Beach Park (Park). Sediment deposits from the creek are evident at the Park . The Juanita Creek basin covers approximately 6.6mile^2 (17.14 km^2) and includes three main tributaries; Simonds, Upper West, a Lower West, and Totem Lake Tributary (Lower East).

The Juanita Creek subarea is are highly developed. From Juanita Drive to NE 124th Street, Juanita Creek contains numerous armored banks and flows through a highly developed urban area, dominated by multi-family housing with a professional office center. From NE 124th Street to NE 132nd Street, Juanita Creek flows through an area containing both single and multi-family housing. Upstream of NE 132nd Street, the creek flows through the

grounds of a psychiatric hospital, a rehabilitation clinic, a school, Edith Moulton Park, and an area of single family housing. Stream buffers along the mainstem vary from less than 10 to a maximum of 50 feet in these highly urbanized areas (The Watershed Company 1998).

The Simonds Tributary (Upper West) to Juanita Creek joins the mainstem at NE 137th Place. The Lower West tributary enters the mainstem of Juanita Creek from a culvert at NE 124th Street. This tributary is primarily made up of stormwater runoff from surface streets along an area of single family housing, originating from a highly developed plateau further west (the Watershed Company 1998). The Totem Lake Tributary (Lower East) originates from Totem Lake, and flows through culverts under numerous roadways and SR 405. Downstream from SR 405 the tributary flows through areas containing numerous commercial businesses, Juanita High School, and a combination of multi and single family residential housing, before entering the mainstem of Juanita Creek at a culvert outfall at 102nd Ave NE and 129th Place.

B. SALMONID UTILIZATION

During a 1998 survey, The Watershed Company (*Kirkland's Streams, Wetlands and Wildlife Study*, July 1998), captured juvenile coho salmon and coastal cutthroat trout in Juanita Creek. During this electrofishing study done from Feb. 19th to Mar. 17th, 1998, juvenile coho were captured as far upstream as King County's Edith Moulton Park, and adult coastal cutthroat spawners[5] were seen even farther upstream (The Watershed Company 1998). All references below to fish capturing/sightings are from The Watershed Company study unless otherwise noted.

Coastal cutthroat trout and coho salmon are believed to use the entire length of the mainstem of Juanita Creek (approx. 3.2 miles), from Lake Washington to SR 405 (The Watershed Co. 1998). No fish of any kind were captured upstream of SR 405 (The Watershed Co. 1998). The Washington Dept. of Fisheries Stream Catalog (Williams 1975) indicates that coho and sockeye utilized the mainstem.

The Simonds tributary (Upper West) supports both coho salmon and cutthroat trout (The Watershed Co. 1998). No fish were found in the lower West tributary (The Watershed Co. 1998).

The Totem Lake Tributary enters the mainstem of Juanita Creek at a culvert outfall at 102nd Ave NE and 129th Place. Numerous juvenile cutthroat trout were captured at this point but no coho were observed, and no salmonids were detected upstream of Juanita High School (The Watershed Co. 1998).

Volunteers in the Salmon Watcher program watched for salmon during spawning season in Juanita Creek for the first time in 2000. They sighted *O. nerka*, believed to be both kokanee

[5] These were identified as sea run cutthroat by the consultants. The criteria on which this identification was based is unknown.

and sockeye salmon from fixed sites at NE 129th Pl. crossing and 102nd Ave. NE (King County unpublished data).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Juanita Creek contains these identified fish access and passage barriers (The Watershed Company 1996):

- The Simonds tributary (upper West) contains a fish passage barrier at the culvert at 100th Avenue NE. This culvert is within a King County right of way.
- The lower West tributary contains a fish passage barrier at the culvert at NE 124th Street. This culvert includes a 3-foot drop. This culvert is within the city of Kirkland.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

May et al. (1997) found between 20 and 30 percent fines in Juanita Creek segments; among the highest in sampled Puget Sound lowland streams. Otak Incorporated (2000) recently conducted a sediment analysis study of the mainstem of Juanita Creek. In this study, the primary sources of sediment to Juanita Creek were determined to be:

- Erosion of stream banks and high relief slopes adjacent to the banks;
- In-stream sediment deposits; and
- Shallow debris flows and slope failures. This source is most likely a result of stormwater discharging onto the upper or middle portions of a bank, infiltrating and saturating porous outwash souls underlain by relatively impervious silt and destabilizing the slope.

On the west side of Simonds Tributary the section between Juanita-Woodinville Road and NE 137th Place contains fairly severe bank failures.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

In Juanita Creek, channel complexity and connectivity with the floodplain and adjacent stream reaches are reduced due to road crossings/culverts, streambank armoring, channel incision and instability, and historical and on-going clearing and development in riparian areas (May et al. 1997). Changes in land-use practices (i.e.: forest harvest, rural development, and urbanization) over time have limited in-stream large wood recruitment that contributes to channel complexity. Additionally, with less LWD, scour is exacerbated and stream channel beds are less stable. These factors may impact spawning success. In-stream habitat complexity, as characterized by LWD, channel form, pool quality are significantly degraded, measures of these parameters show frequencies lower than values

determined for 'natural' conditions (numbers detailed below) (City of Kirkland and King County *In Prep*).

Juanita Creek had very low frequencies of LWD in all segments surveyed (City of Kirkland and King County *In Prep.*). The low end of published natural ranges for the Puget Sound/ Western slope of the Cascades is 150 pieces/ km (250 pieces/ mile) (Murphy and Koski, 1989; Ralph et al. 1994). Mean frequencies of LWD for all segments were only 19.1 pieces/ km (30.6 pieces / mile). In addition the number of large diameter pieces (> 0.5 m, 1.64 feet) was extremely low.

Comparisons of bankfull width to depth ratios (BFW: BFD ratios) can indicate shifts in channel stability in response to disturbance (Rosgen 1996). Increased discharge increases erosion rates of the streambanks and causes channel widening and increased BFW: BFD ratios. The matrix of properly functioning conditions suggests that a BFW to BFD ratio of 10 is indicative of a stable, properly functioning channel, a value of 10-12 indicates an "at risk" channel, and ratios greater than 12 suggest that conditions are not properly functioning (NOAA 1996). Channel survey data from King County indicate that the Juanita Creek bankfull width to depth ratios did not exceed 10.0 (City of Kirkland and King County, *In Prep.*), although the ratio for segment three was equal to 10.0 The ratios of the other segments ranged from three to six. Stable streambanks are the dominant condition in four of five segments. Streambank armoring was the dominant condition in only one stream segment and ranged from 10 to 57 percent in the five mainstem segments assessed (City of Kirkland and King County, *In Prep.*).

Pool to riffle ratios ranged from two to one-half. Two segments had ratios of one. The pool frequency met the suggested "properly functioning condition" (30/km, NOAA 1996) in four out of five stream segments (City of Kirkland and King County, *in prep.*). The lowest pool frequency was 28/km. Although the pool frequency number was not low, the pool quality was low due to shallow depths and lack of cover. On a scale of 1 to 5, the average pool quality index was 2 (City of Kirkland and King County, *In Prep.*).

The Simonds tributary (Upper West) contains wide buffers, deep pools, and good riparian vegetation to support fish habitat. However, a sanitary sewer line has recently been placed parallel to and under the stream, just upstream of NE 137th Place. Habitat complexity at this location is less diverse, perhaps due to disturbance during construction (The Watershed Company 1996). The Lower West tributary does not contain significant pools or other potential fish habitat.

DEGRADATION OF RIPARIAN CONDITIONS

Riparian buffers on the mainstem vary from less than 10 to a maximum of 50 feet in the developed areas (The Watershed Company 1996). Only three of five stream segments in Juanita Creek contained at least 50 percent forested riparian area, and the majority of the forest was composed of deciduous species (City of Kirkland and King County *In Prep*). Additionally, only one stream segment (out of five) contained notable coniferous riparian forest cover (41 percent cover, City of Kirkland and King County, *In Prep.*). The Simonds

tributary (Upper West) contains buffers approximately 50 feet wide with "good riparian" vegetation (The Watershed Company 1998). These changes in riparian conditions, along with stream wood removal (May et al. 1997) have led to a reduced amount of available wood that could function as LWD and fish habitat (City of Kirkland and King County *In Prep.*).

ALTERED HYDROLOGY/FLOW

Information on the change in hydrology within Juanita Creek attributable to land use changes is lacking. Data from King County gages on Juanita Creek show a rapid rise and fall in discharge during storm events consistent with watersheds with high percentages of impervious surfaces (KCDNR, unpublished data, May et al. 1997). In addition Juanita creek had 2-year peak flow to winter baseflow ratios between 19 and 20 (May et al. 1997).

POOR WATER QUALITY-INCREASED OTHER

Staff from the USGS collected pesticide data from one location on Juanita Creek in 1998 as part of the NWQA study, which tested 11 creeks in King County. Three samples were taken during one spring storm event. A total of 17 pesticides were detected, which was the largest number of pesticides detected from one stream in the study (Voss and Embrey, 2000).

In 1999, King County staff conducted a follow-up study on Juanita, Lyon, and Lewis Creeks. Staff from King County collected samples for pesticides, other organics, metals, suspended solids, and toxicity (*Ceriodaphnia dubia,* and *Selenastrum capricornutum).* Additionally, staff collected one sample on Juanita Creek during four times of the year: spring, summer, early fall, and late fall. All but the sample collected during the summer were collected during storm events. A total of 24 pesticides were detected over the course of the year in Juanita Creek. Toxicity to *S. capricornutum* was observed in the Juanita Creek samples during spring, summer and early fall. In the spring sampling event, much of the toxicity appeared to be associated with copper. The cause of toxicity during the rest of the year was unclear, however it was associated with the particulate fraction of the samples (Wilson et al, 2000).

Observed toxicity to test species represent violations of Washington State water quality standards (State of Washington 1997). Measured levels of diazinon in Juanita Creek during storm events in 1998 and 1999 approached levels that NMFS (Scholz et al, 2000) reported as having an adverse effect on the anti-predator response of chinook salmon.

Levels of fecal coliform bacteria in Juanita Creek exceeded Washington State water quality standards in 68 percent of the samples taken between January 1991 and April 1997 at sites located at RM 0.3 and 1.3, placing the creek on the Washington State Department of Ecology's 1998 303(d) list of impaired water bodies (WDOE, 1998).

POOR WATER QUALITY-INCREASED TEMPERATURE

Single day volunteer measurements in 1999 at 5 sites (University of Washington, Center for Urban Water Resources, unpublished data) found 5 excursions of 16°C. Although, ambient monitoring over the last decade has not documented widespread high temperatures in the sub area.

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek, nor is any reach of the creek an index area. Counts of adult salmonids, primarily for coho, are sporadic.

D. FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- No fish passage barriers have been identified in the mainstem Juanita Creek but barriers exist in the tributaries;
- High levels of fines are present that effectively limit the success of egg incubation;
- Channel complexity and connectivity with the floodplain and adjacent stream reaches are reduced due to road crossings/culverts, streambank armoring, channel incision and instability, and historical and on-going clearing and development in riparian areas;
- Riparian buffers on the mainstem vary from less than 10 to a maximum of 50 feet; and
- The presence of pesticides may limit natural production of salmonids.

E. DATA GAPS

- Information on the change in hydrology within Juanita Creek attributable to land use changes is lacking; and
- The full impacts of pesticides on salmonids naturally produced in the Juanita Creek subbasin is not completely understood.

KELSEY CREEK

A. PHYSICAL DESCRIPTION

The Kelsey Creek Basin is composed of several streams all of which drain in a westerly direction before entering the East Channel of Lake Washington at Interstate 90. The Kelsey Creek Basin includes over 19 miles of open stream, encompassing Mercer Slough (08.0259), Sturtevant Creek (08.0260), Kelsey Creek (08.0259, above river mile 1.71), Valley Creek (North Branch, 08.0266), the West Tributary (08.0264), Goff Creek (08.0265), Richards Creek (South Fork, 08.0261), East Creek (08.0263), and Sunset Creek (08.0262) (Williams, 1975). The mainstem Kelsey Creek has its headwaters in the

Phantom and Larsen Lake wetlands. The stream historically originated from Phantom Creek and Phantom Lake, but early pioneers redirected the Phantom Lake outlet to Lake Sammamish in the late 1880's (KCM, 1993). The northern headwaters of the Kelsey Creek Basin originate in Valley Creek at approximately 300-foot elevation, draining an area north of State Highway 520. The southern headwaters are located in the steep Sunset Creek tributary at about 700-ft elevation on the northern slopes of Cougar Mountain.

The basin area is approximately 10,870 acres with the following landuse: single family residential (37 percent), open space (22 percent), multifamily residential (13 percent), public roads (13 percent), commercial/office (8 percent), institutional/government (7 percent), industrial (<1 percent), and mixed use/other (2 percent)(City of Bellevue Planning and Community Development, 2000). The total impervious area by basin, as determined by City of Bellevue multispectral analyses in 2000, is 42 percent in Kelsey Creek, 32 percent in Valley Creek, 44 percent in West Tributary, 45 percent in Richards Creek and 44 percent in Sunset Creek (City of Bellevue Utilities, 2000). . The Muckleshoot Indian Tribe, Fisheries Department conducted a Landsat analysis of the vegetative cover of the Kelsey Basin in 2000. The analyses of vegetation found seven percent forest canopy and 38 percent green vegetation in the watershed, with the rest of the watershed in impervious area, bare soils, etc. (Eric Warner, pers. comm.). The basin is considered to have reached built-out conditions and future development will be predominantly the redevelopment of existing properties (City of Bellevue Planning and Community Development, 2000). The City of Bellevue operates six in-stream, regional detention facilities in the basin. These detention facilities are gauged structures with upstream-vegetated wetlands (Kramer, Chin & Mayo (KCM), 1976).

According to U.S. Department of Agriculture, Natural Resource and Conservation Service (NRCS) formerly the Soil Conservation Service (SCS) 1972 Soils Maps, glacial deposits (Alderwood gravelly sandy loam) predominate, with large inclusions of mucky peat (Seattle muck), up to 20 feet in depth, dominate the Phantom/Larsen Lake regions. Stream gradients are low, mostly below 3 percent, except in Sunset Creek where gradients in some stream reaches exceed 7 percent. The Lake Hills Greenbelt open space includes peat-dominated wetlands near Phantom and Larsen Lakes and those around Mercer Slough, as well as large open water wetland complexes along Kelsey and Richards Creeks.

B. SALMON UTILIZATION

Adult chinook salmon (*Oncorhynchus tshawytscha*) have been sighted at the headwaters of the mainstem Kelsey Creek, upstream of Larson Lake (WRIA 8 Chinook Distribution Map, 2000). Chinook are known to occur in Valley Creek to river mile 1.8, the southern boundary of the Bellevue Golf Course (WRIA 8 Chinook Distribution Map, 2000). Chinook are also known to occur in the West Tributary/Goff Creek to approximately river mile 4.2, Bel-Red Road. Chinook are known to occur in Richards Creek to approximately river mile 1.5, SE 30th Street. Impassible barriers at state and local culverts reduce distribution in some of the smaller tributaries, including Goff Creek (1.0 additional mile upstream), West Tributary (1.0 additional mile upstream), and Richards Creek (.5

additional mile upstream)(*WRIA 8 Chinook Distribution Map; Menconi and Johnson, 1998*).

Coho salmon (*O. kisutch*) are known to inhabit the areas of chinook distribution. In addition, coho are known to occur to river mile 0.5 in Sturtevant Creek, to an impassible anthropogenic barrier at Interstate Highway 405 (1 additional mile upstream*) (*Griggs, 1971; City of Bellevue Stream Team, 1990; Ludwa et al, 1996; Ostergaard, 1996, Vanderhoof et al, 1997). Issaquah Hatchery coho stock are released, at various life history stages, throughout the basin. In each tributary, amounts can range from school program releases of approximately 250 fed fry to over 140,000 fingerlings (Adam Couto, pers. comm.).

Sockeye salmon (*O. nerka*) are known to spawn up to river mile 5.0 in Kelsey Creek, river mile 4.2 in West Tributary/Goff Creek, and river mile 0.5 in Richards Creek (Vanderhoof, 2001; Ostergaard *1996;* Vanderhoof 1997*).*

Pink salmon (*O. gorbuscha*) and chum salmon (*O. keta*) are not known to reproduce in the basin. However, in 1994, the University of Washington planted 120 fed fry of brood year 1993 in Valley Creek. One chum was sighted at river mile 3.0 in Kelsey Creek in 2000.

Observations by volunteers of adult chinook salmon are only available for approximately 2 miles of the Kelsey Creek and its major tributaries (City of Bellevue unpublished data). These data indicate the following: in 1988-89, returns averaged 114 chinook per year. Returns averaged only 38 chinook per year when counting was resumed over the period 1996-1998.

In 1999, WDFW spawner surveys indicated that the return was 228 chinook, but only 23 chinook salmon were observed in the 2000 spawner surveys (Fresh, pers.com.1999; McMillan, pers.com. 2000).

Juvenile fish surveys were conducted in four of the sub-basins in 1996 and 1997. In 1996, eight fish species were observed in the Kelsey Creek basin: cutthroat, coho, rainbow, sculpins, lamprey, dace, sucker, and bluegill. Coho were observed in all sampling locations, but numbers were low, averaging seven coho per 50-meter reach. Cutthroat trout were present in fairly high numbers in all sampling locations (Ludwa et al, 1996*).* Similar findings were noted, when the study was replicated in 1997 (Kurt Fresh, pers.comm.).

Juvenile salmonid biomass in Kelsey Creek ranged from 1.8 to 6.5 gm^2 (Scott, et al, 1982). Cutthroat trout abundance contributed heavily in the biomass estimate. Coho smolt production was lower in Kelsey Creek, probably due to cutthroat trout abundance relative to the coho populations (Scott, et al, 1982).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

A number of concrete and rock weirs that are partial fish passage barriers (~RM 3.5) were identified by Kurt Fresh, WDFW Fisheries Research Scientist, during spawning surveys in 1999 and 2000 (Fresh pers. comm.). Sixty-two publicly owned culverts on seven creeks in the basin were assessed for fish passage in 1998. Of these, nineteen culverts, primarily on small tributaries in sub-basins, may be partial or complete barriers to salmonid passage as analyzed according to WDFW guidelines (Menconi and Johnson, 1998).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Fine sediments have been identified as a habitat limiting factor for salmonid production in Kelsey Creek, with fine sediment comprising 22 percent of the spawning substrate (Scott, et al, 1982). This sedimentation and interstitial infilling has contributed to low dissolved oxygen transport through salmon redds (Scott, et al, 1982). Ten years later, in a 1995-96 study, fine sediment amounts as high as 39 percent were observed (May, 1996).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Habitat complexity in Kelsey Creek is considered to be simplified compared to other Puget Sound Lowland streams having less urban development (May, 1996). May (1996) determined that the average pool frequency was less than 13 pools per mile. The average amount of large woody debris were fewer than 17 pieces per mile. There was less than 25 percent floodplain connectivity remaining, however approximately 25 percent riparian wetlands existed (May, 1996).

Habitat assessments have been conducted in Richards, East, Sunset, and parts of Kelsey, and Valley Creeks. The methodology for these surveys were based on US Forest Service protocols, but modified for volunteers with professional oversight. Preliminary review of these data indicates a lack of large woody debris and pools throughout the basin. However, analysis of the data has not been finalized (City of Bellevue, unpublished data).

DEGRADATION OF RIPARIAN CONDITIONS

Based on visual observations, urbanization has impacted riparian conditions in Kelsey Creek through road crossings, encroachment of buildings and landscaping, and intrusion of non-native invasive weed species (May 1996). A 1996 study found less than 5 percent mature riparian forests remaining in the basin (May, 1996). The number of storm drain outfalls per reach ranges between 0.6 – 4.5 outfalls per mile (May, 1996).

Multispectral analysis of riparian buffers found approximately 18 percent impervious surface within 50 feet of the stream in Kelsey Creek, due to road crossings and encroachment by development (City of Bellevue, unpublished data, 2000).

ALTERED HYDROLOGY/FLOW

An analysis comparing flows during peak storm events from 1961-1975 to 1961-1983 concluded that the mean peak discharges in Kelsey Creek had increased 1.5 to 1.8 times higher than instantaneous peak discharges before 1983 (Drainage Comprehensive Plan, 1988).

Staff from the University of Washington and the U.S. Geological Survey conducted two of the numerous studies of Kelsey Creek hydrology. The University of Washington evaluated the hydrologic impacts of human development in the Kelsey basin, based on historical land development patterns (Richey et al, 1981). The study showed that although the total volume expressed as a monthly average increased only slightly in Kelsey Creek, the storm peaks increased two to three times over the same historical period. In 1979-80, staff from the University of Washington and the U.S. Geological Survey compared the base flow and storm flow conditions of Kelsey Creek to the then rural Bear Creek (Perkins, 1982; Richey et al, 1981). The two streams response to storm flows was significantly different. Kelsey Creek showed a very rapid response to rain events, while Bear Creek responded much slower. After the storm peak, Kelsey Creek returned to base flow rates in less than 24 hours, while more than 48 hours was required for Bear Creek. Bear Creek summer flows were also greater than 30 percent higher than Kelsey Creek on a unit area basis (Richey et al, 1981).

Flow gage data are available on Kelsey, Valley, West Tributary, and Goff Creeks, but flow analyses have not been conducted for those streams. Flow studies have been conducted on Kelsey and Richard Creeks. Mean daily discharges (MDD) at the USGS station on Mercer Creek from 1945-1979 found a 1.34 maximum to mean flow ratio and 1.96 maximum to minimum flow ratio (City of Bellevue, unpublished data).

POOR WATER QUALITY – INCREASED TEMPERATURE

Scott et al (1979-80), found that 25 of 76 samples exceeded 60° F. During synoptic summer temperature surveys conducted by staff from the University of Washington in 1998-1999, Kelsey Creek temperatures ranged between 61-63° F, Valley Creek ranged 54-61° F and Richards Creek ranged from 55-61° F (CUWRM, 1999).

POOR WATER QUALITY – INCREASED OTHER

Kelsey Creek (mainstem) is currently on the WDOE 303(d) list for exceeding allowable water quality criteria for fecal coliform bacteria and three pesticides-Dieldrin, Heptachlor Epoxide, and DDT. Mercer Slough is listed on the 303(d) list for low dissolved oxygen (DOE, 1998)

Staff from the United States Geological Service (USGS) examined urban stream for the presence of pesticides, including the West Tributary and Mercer Slough. Eighteen

pesticides were detected, some at levels that may be detrimental to aquatic life (USGS, #097-99, 4/99).

In studies from 1979 through 1981 by the staff and students from the University of Washington, salmonid embryonic bioassays, fish biomass and population estimates, outmigrant studies, and respiratory anomalies studies on salmonids in comparison studies between Kelsey Creek and Bear Creek were conducted (*Scott et al, 1982*). Their conclusions stated that low intragravel dissolved oxygen levels were of concern for salmonid embryonic survival in Kelsey Creek.

The City of Bellevue has studied stormwater chemistry at approximately ten-year intervals (Bellevue Utilities, 3/95). These studies indicate a stability of water pollutants with the exception of decreasing lead concentrations and increasing heavy metal concentrations. Storm flows are of greatest concern for heavy metals. Copper was noted as exceeding acute toxicity criteria in 50 percent or more of the stormwater samples taken at each site. Zinc exceeded EPA's acute toxicity criteria 61 percent of the time in storm flows (Bellevue Utilities, 1995). The water quality standards for acute toxicity criteria are currently being reviewed.

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek, nor is any reach of the creek an index area. Counts of adult salmonids, primarily for chinook, sockeye and coho have increased in recent years. The Benthic Index of Biotic Integrity (B-IBI) for Kelsey Creek ranges from 12-20, indicating impaired biological processes. The B-IBI is a methodology to measure the diversity, abundance, and pollution tolerance of invertebrate organisms living on the stream bottom.

D. KEY FINDINGS AND IDENTIFIED HABITAT LIMITING FACTORS

- A comprehensive barrier survey identified nineteen impassable barriers in the smaller headwater tributaries of the Kelsey Creek subbasin;
- Fine sediment levels in spawning gravels can be as high as 39 percent;
- LWD (<17 pieces/mile), pool frequency (<13 pools/mile) and floodplain connectivity (< 25 percent) all serve to limit salmonid productivity;
- A multispectral analysis of riparian buffers found approximately 18 percent impervious surface within 50 feet of Kelsey Creek;
- Storm peak flows in Kelsey Creek have increased two to three times from historic levels; and
- Stream water temperatures and the presence of pesticides may limit the natural production of salmonids.

E. DATA GAPS

- The full impacts of pesticides on salmonids naturally produced in the Kelsey Creek subbasin is not completely understood.

COAL CREEK

A. PHYSICAL DESCRIPTION

Coal Creek (08-0268) flows northwesterly into the East Channel of Lake Washington just south of Interstate 90 (I-90). Coal Creek has a basin area of approximately 5,820 acres with an estimated impervious area of 21.0 percent (City of Bellevue Utilities, 2000). Four local governments, King County, Bellevue, Renton, and Newcastle have authority for land use planning in the basin. The headwaters of Coal Creek originate on the slopes of Cougar Mountain at an elevation of approximately 1400 feet and flows through a series of steep narrow ravines before emptying into Lake Washington at Newport Shores. The land use is predominantly single family residential and parks, including the Cougar Mountain County Park in the headwaters and Coal Creek Regional Park that includes the majority of the riparian corridors for Coal Creek and Newport tributary (City of Bellevue GIS , 2000).

Euro-Americans began to settle this basin in the late 1800's with extensive coal mining activities in the basin at the turn of the century (McDonald, 1987). The mining activities changed the course of streams, channelized reaches, and dumped mine tailings along streambanks (McDonald, 1987). Headwater streams of the south fork originate from a caved-in section of mine that is believed to originate from an extensive mine drainage system (Skelly and Loy, 1985).

The use of the land for urban development within the Coal Creek basin has altered the creek's natural hydrologic characteristics, increasing the frequency, duration and peak of flood events, streambank erosion, and streambed sedimentation (Coal Creek Basin Plan, 1997). The channel was diverted southward in the late 1940’s, then northward again in the late 1950’s, due to the construction of an airstrip in the delta area of the stream. In the 1960’s, as a feature of the residential development, two large canals were excavated just south of the stream mouth to allow moorage and waterfront amenities for inland properties (Coal Creek Basin Plan, 1997).

B. SALMON UTILIZATION

In the Coal Creek Basin only limited fish utilization surveys have been conducted. These surveys include volunteer spawner surveys, volunteer spot observations and professional spot observations, with occasional juvenile electrofishing surveys for reach utilization studies. The system has very few returning adult salmonids of any species, although the supplementation of coho has occurred (Ostergaard, 1996; Vanderhoof, 2000). In the years

1994-97, WDFW reported planting between 9,000-13,800 zero age coho into Coal Creek (Couto, pers.com.). One hundred adult coho pairs were released into Coal Creek in 2000 by WDFW. Coho, chinook, sockeye, steelhead, and cutthroat trout adults have been observed in the basin (Griggs, 1971; Paulsen, personal observation, 1996-99; Williams, 1975).

The known freshwater distribution of anadromous and resident salmonids is depicted Appendix A.

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

No fish passage impediments were identified in Coal Creek or its tributary as a part of this investigation.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Coal Creek has extensive sedimentation problems. The two dominant sources of sediment are: (1) streambank erosion and (2) the occasional catastrophic failure of tailing slopes that remain from the old coal mining activities in the creek's headwaters and landslides of the steep slopes above the creek (Sturtevant, 2000). Since 1997, the City of Bellevue has maintained two sediment retention ponds in the system, one immediately upstream of Interstate Highway 405 and another immediately upstream of Coal Creek Parkway. The City of Bellevue removes an average of 1900 cubic yards of sediment annually from these sediment ponds (Sturtevant, 2000). From 1958-1983, the average delta deposition was estimated at 3,600 cubic yards per year. Between 1983 and 1984, the average annual delta deposition increased to 5,350-10,000 cubic yards per year (Sturtevant, 2000). For 1991-96, the annual deposition rate averaged approximately 5,000 cubic yards per year, with fluctuations based on rainfall patterns (Sturtevant, 2000). After 1996, when the sediment ponds were completed, the average annual delta deposition rate was estimated at 3,900 cubic yards per year, assuming annual sediment pond maintenance (Spearman, 1996). While the sediment ponds are helping control excessive delta formation, they provide no protection for spawning and rearing habitat upstream. May (1996), estimated greater than 50 percent fines in the reach downstream of Interstate Highway 405 and 25 percent fines in the upstream reaches of the watershed.

Sediment sources have been identified through basin planning efforts as the major concern for Coal Creek. A 1998 JFE effort identified and photographed eight slide or large erosion areas in the area between Coal Creek Parkway and the cinder mines (City of Bellevue, unpublished data, 1998). In addition, mine tailing deposited on floodplain terraces during high flows remain a large sediment source (Sturtevant, 2000).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

The Newport Shores development radically changed the outlet area of the stream, including diverting the channel near the mouth twice and excavating two canals to connect interior lots with Lake Washington (Coal Creek Basin Plan, 1987). The reach between Lake Washington and Interstate Highway 405 was channelized and hardened during this period.

A stream habitat assessment was conducted by the City of Bellevue in 1996 for the lower watershed to river mile 2.0 (City of Bellevue unpublished data, 1996). In 1998, a second habitat assessment was conducted by the City between river mile 2.0- 5.0 in the upper watershed (City of Bellevue unpublished data, 1998). Woody debris larger than .33 ft diameter and 6.5 feet long was frequently encountered in the middle reaches of Coal Creek, but decreased in abundance in the upper 4,500 feet surveyed. The lower reach, downstream of Highway 405 was largely devoid of large woody debris. The middle reach area averaged approximately 1.8 pieces of LWD per channel width. The upper area averaged 1.1 pieces of LWD per channel width (City of Bellevue, unpublished data, 1998). The last 4500 feet of the surveyed area also had the highest stream gradient and the lack of large woody debris in this reach could be a contributing factor to the sediment transport and erosion problems in the watershed. Overall, more than half of the wood encountered in the system was influencing sediment storage. Much of the LWD was derived from mature deciduous trees and recruitment potential is predominantly deciduous (City of Bellevue, unpublished data, 1998).

DEGRADATION OF RIPARIAN CONDITIONS

The Coal Creek Basin has 15 percent impervious area within the 100-foot riparian area around the stream (City of Bellevue, unpublished data, 2000). Most of this encroachment is located near the mouth of the stream in the Newport Shores Development. Upstream of Interstate Highway 405, the riparian area is protected by the Coal Creek Regional Park to the headwaters with only short encroachments by private residences and road crossings. The riparian vegetation is primarily mature deciduous, with maple and alder the dominant species (City of Bellevue, unpublished data, 1996, 1998).

ALTERED HYDROLOGY/FLOW

The U.S. EPA's Hydrological Simulation Program-FORTRAN (HSP-F) was used to evaluate the hydrology of Coal Creek as part of the development of the 1987 Coal Creek Basin Plan. The results from using this model indicated a higher than expected base flow for a watershed of its size. It was found that base flows in Coal Creek, as well as others in the Cougar Mountain area are augmented by approximately ten percent by flows from mine tunnels (Coal Creek Basin Plan, 1987).

POOR WATER QUALITY – INCREASED TEMPERATURE

During University of Washington synoptic summer water temperature surveys in early August 1999, Coal Creek temperatures ranged from 60° F in the upper watershed to 73° F

(University of Washington, Center for Urban Water Resources, unpublished data). The highest temperature, 73° F, which is possibly a barrier to migration and an impact to dissolved oxygen levels, was located near the mouth of Coal Creek. Monthly samples taken by the King County ambient monitoring program from January 1995 through March 2000, show temperatures at a middle reach of Coal Creek upstream from Interstate Highway 405 ranging from 9 to 63° F (O'Laughlin, 2000). Water temperatures likely limit natural production of salmonids in Coal Creek.

POOR WATER QUALITY – OTHER

Baseflow conductivity was monitored by Bryant (1995) and found to have exceptionally high conductivity (449 uS/cm) compared to other urban basins, probably due to residual effects of earlier coal mining activities. Over three years of sampling by Bryant did not indicate any problems with dissolved oxygen.

In a 1995 water quality study by the City of Bellevue, specific conductivity and hardness were found to be significantly higher in Coal Creek than in other sampling areas within the city. It was not known whether these differences were due to the different soil chemistry characteristics within the basin or non-point sources of pollution (City of Bellevue, 1995).

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek nor is any reach of the creek an index area. Counts of adult salmonids, primarily coho, are sporadic.

Benthic invertebrates are used as an indicator of stream ecosystem health since invertebrates have varying sensitivities to pollution (Karr, 1999). Since 1971, macroinvertebrates studies on Coal Creek have been conducted by numerous students at the University of Washington and by professionals contracted by the City of Bellevue. In 1971, using a pollution sensitivity methodology (EPT) identified to family, the dominant invertebrate species in riffles were the pollution intolerant types: stonefly, caddisfly, and mayfly (Comis, 1971). Identification to genus or species allows one to calculate metrics based on taxonomic composition (total taxa richness, richness of mayflies, stoneflies, and caddisflies), reproductive pattern (long-lived taxa richness), habit (clinger taxa richness), tolerance to disturbance (percent tolerant individuals and intolerant taxa richness), and feeding group (percent predator individuals). May (1996) reports that undeveloped, reference streams in the Puget Sound Lowlands have a B-IBI score of greater than 33, while heavily impacted streams tend to be below 15 B-IBI. In a 1999 Bellevue study, the Benthic Index of Biotic Integrity (B-IBI) rating ranged from 32 at the cinder mine area to 22 downstream of Coal Creek Parkway (Fore, 1999). The results from Coal Creek show water quality impacts are observed, but only to a moderate degradation of the benthic invertebrate community.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Coal Creek has extensive sedimentation problems;
- Sediment sources have been identified and include eight slide or large erosion areas in the area between Coal Creek Parkway and the cinder mines. In addition, mine tailing deposited on floodplain terraces during high flows remain a large sediment source;
- The outlet area of the stream has been changed, including diverting the channel southward in 1940, northward again in 1950, then excavating two canals to connect interior lots with Lake Washington;
- The Coal Creek Basin has 15 percent impervious area within the 100-foot riparian area around the stream;
- It was determined through modeling that base flows in Coal Creek, as well as others in the Cougar Mountain area are augmented by approximately ten percent through flows from old coal mine tunnels;
- Water temperatures likely limit natural production of salmonids in Coal Creek;

E. DATA GAPS

- The full extent of usage by salmonids of Coal Creek requires additional investigation;

EAST LAKE WASHINGTON SMALL TRIBUTARIES

A. PHYSICAL DESCRIPTION

The East Lake Washington Small Tributaries subarea encompasses over 4,000 acres the vast majority of which is within areas of urban development. The subarea also includes more than seven miles of streams draining westerly into Lake Washington (Bellevue Utilities, 2000). The streams, arranged from north to south, include: Yarrow Creek (08-0252), unnamed (08-0257), an unidentified creek, Meydenbauer Creek (08-0258), and Lakehurst Creek (08-0281) (Williams 1975). Kelsey Creek, Juanita Creek, May Creek, and Coal Creek, which are also located in this geographic area, are reported separately and are not included in this sub-area.

B. SALMONID UTILIZATION

Yarrow Creek historically supported coho salmon (Williams 1975). Kokanee were presumed to use Yarrow Creek based on historical records of a Native American village located near its mouth (Buerge 1984; Tobin and Pendergrass, 1993).

Williams (1975) listed creeks 08.0257, 08.0258, 08.0281 as having “unknown” utilization by salmon.

Interviews with current residents along stream 08.0257 indicate that coho salmon may have used the stream until the 1970s (Schulze, pers com). Volunteers release approximately 80,000 coho juveniles into stream 08.0257 annually (Newbill, pers com).

Interviews with early residents in Bellevue indicate that salmon and trout were commonly caught historically throughout Meydenbauer Creek (McDonald 1984). Several adult sockeye were observed in lower Meydenbauer Creek in 2000 by City of Bellevue staff (Morgenroth pers com).

C. HABITAT FACTORS OF DECLINE

GENERAL

All of these creeks are typical highly urbanized creeks and exhibit the problems commonly associated with creeks of that nature in the Puget Sound lowland ecosystem.

FISH ACCESS AND PASSAGE BARRIERS

Migratory fish passage is blocked on Yarrow Creek at river mile 0.2 at the culvert under NE Points Drive (Menconi and Johnson, 1998). Blockages to anadromous passage have been noted on Stream 08.0257, but the extent and location of the blockages were not provided in the original communication (Schulze, grant application 1999). Meydenbauer Creek is also blocked to anadromous salmonid migration at river mile 0.2, by an impassable culvert under 102nd St SE (Menconi and Johnson, 1998). Lakehurst Creek is totally blocked from migratory fish access due to the terminal reach being constrained in a pipe 1000 feet long with over a 10 percent gradient (Bellevue Utilities, 2000).

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

In a 1971 study, the City of Bellevue identified Yarrow Creek as having moderate to severe erosion potential. The increase in sediment due to human activities and the subsequent impact on salmon habitat is unknown at this time.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No information was available on loss of channel complexity/connectivity for these bodies of water.

DEGRADATION OF RIPARIAN CONDITIONS

A Bellevue multispectral analysis study in 2000 documented encroachment of impervious surfaces of 23 – 36 percent within 100 feet of Yarrow, Meydenbauer, and Lakehurst Creeks (Bellevue Utilities, 2000).

ALTERED HYDROLOGY / FLOW

No information on flow regimes, either high or low, were available for these creeks.

WATER QUALITY – TEMPERATURE

None of these creeks currently are listed as impaired water bodies on the 1998 WDOE 303(d) list with the exception of Yarrow Creek which is listed for exceeding fecal coliform standards.

WATER QUALITY - OTHER

Degraded water quality has been documented in Meydenbauer Creek (Pitt and Bissonnette, 1984; Bellevue Utilities, March 1995). Known water quality degradation includes copper, zinc, chemical oxygen demand, and petroleum concentrations that exceed Washington State water quality standards for chronic aquatic impacts (Pitt and Bissonnette, 1984; Bellevue Utilities, 1995).

BIOLOGICAL PROCESSES

Escapement goals are not set for these creeks nor is any reach of any of these creeks an index area. Counts of adult salmonids, primarily coho, are sporadic and often conducted by volunteers.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Degraded water quality has been documented in Meydenbauer Creek and includes high levels of copper, zinc, chemical oxygen demand, and petroleum concentrations that exceed Washington State water quality standards for chronic aquatic impacts;
- There are numerous barriers to adult anadromous salmonid migration in these creeks.

E. DATA GAPS

- The increase in sediment due to human activities and the subsequent impact on salmon habitat is unknown at this time;
- No information was available on loss of channel complexity/connectivity for these bodies of water;
- The full extent of utilization by salmonids of these streams is unknown;

CEDAR RIVER AND CEDAR RIVER TRIBUTARIES

CEDAR RIVER AND CEDAR RIVER TRIBUTARIES

A. PHYSICAL DESCRIPTION

The Cedar River sub area was reviewed and for the purposes of this report was divided into the following reaches: 1) the Upper Cedar River (from the its headwaters along the Cascade Crest to the Landsburg Diversion Dam); 2) the Lower Cedar River (from the Landsburg Diversion to the mouth at the City of Renton); and 3) major tributaries to the Cedar River.

Rainfall averages 42 inches at Renton, 54 inches at the Landsburg Diversion Dam and continues to increase with elevation in the upper portions of the watershed. Elevation in the subarea reaches a maximum of 5,400 feet at Tinkham Peak. Snowfall represents the dominant portion of precipitation in the upper third of the subarea.

The Cedar River provides approximately 57 percent of the inflow to Lake Washington and about 25 percent of the phosphorus load.

UPPER CEDAR RIVER

The Upper Cedar River includes all of the land area draining surface water upstream of the point where the City of Seattle diverts a drinking water supply from the Cedar River (Landsburg Diversion Dam). The Landsburg Diversion Dam is currently an anthropogenic fish passage blockage; however, it is anticipated that this area will be accessible to anadromous species by 2003 under provisions of the Cedar River Habitat Conservation Plan (HCP). This drainage area encompasses approximately 79,951 acres (125 mi^2), including 79,452 acres owned by the City of Seattle (99.4 percent) and the remaining 499 acres owned by other parties (City of Seattle, 2000a). Approximately 25 miles in length and variable in width, the Upper Cedar watershed extends from the Diversion Dam at an elevation of 543 feet eastward to Meadow Mountain near the Cascade Crest at 5,414 feet, a gain in elevation of 4,871 feet (City of Seattle, 2000a).

The Cedar River Municipal Watershed is almost entirely forested with coniferous forest typical of the west slope and foothills of the central Washington Cascades. Such forest covers approximately 85,477 acres (94.4 percent) of the municipal watershed, 71,588 acres of which has supported commercial timber harvest (mostly clearcut logging) for the last 120 years (City of Seattle, 2000a). The forests that exist within the watershed today are a mosaic of multi-seral-stage forest ranging from recently harvested areas to native old growth (190-850 years) that reflect a history of multiple ownership, the spatial and temporal pattern of logging activity, and a varied history of forest regeneration, including natural regeneration, planting, silvicultural treatment, and to a limited degree, the effects of fire (City of Seattle, 2000a).

The Upper Cedar River extends 14.0 miles upstream from the City of Seattle's water supply diversion dam at Landsburg near the western boundary of the Cedar River Municipal Watershed to the Masonry Dam at the outlet of the Chester Morse Lake/Masonry Pool reservoir complex. Two major valley segment types predominate in this 14-mile reach (see below).

The 12-mile section of the Upper Cedar River upstream from the Landsburg Diversion Dam (RM 21.7) to the Cedar Falls Powerhouse (RM 33.7) is characterized by a low gradient channel, this section is associated with a narrow floodplain where valley bottom widths range from 1-2 times the active channel width. Narrow, discontinuous alluvial terraces naturally and moderately confine the channel. Boulders are a common constituent of the sideslope and channel bottom matrix in localized reaches within this section. Channel substrates are typically large and less than 5 percent of the active channel area is comprised of channel bars. Step pool channels dominate this section, although reaches dominated by plane-bed pocket water are also common (Foster Wheeler, 1995). Holding habitat is provided by deep, bedformed pools and large boulder clusters create large deep pockets of water for cover. Although currently inaccessible to anadromous salmonids, spawning areas in this section of the river are abundant, associated with glide waters, pool tails, and channel margins and gravel deposits rarely embedded or compacted. Concentrations of large woody debris are limited and off-channel habitats are rare and open to direct surface flows during periods of high water (Foster Wheeler Environmental Corporation 1995).

The 2-mile section of the Upper Cedar River above the Cedar Falls Powerhouse (RM 33.7) to the Masonry Dam (RM 35.7) is characterized by a bedrock dominated, tightly confined canyon (Canyon Reach) in which gradients range from 4-10 percent and channel substrates are composed mainly of large boulders and large cobble with bedrock outcrops scattered throughout (Foster Wheeler Environmental Corporation, 1995). Boulder cataract and step pool channel morphology predominates, with large boulder clasts providing the primary roughness elements. Large sized substrate characterizes the channel in this section. The natural high gradient and tight confinement of this section limits the development of extensive spawning areas. Pool tails of the large channel spanning pools, however, have localized potential spawning habitat (Foster Wheeler Environmental Corporation 1995). Relatively large numbers of young of the year rainbow trout have been observed by City of Seattle personnel (D. Paige, personal communication) in this reach downstream of Lower Cedar Falls, a reach that will be accessible to anadromous species in the future under provisions of the Cedar River HCP. Channel spanning clasts of boulders and bedrock constrictions provide the dominant structural elements forming pools and steep step pools are common. Partial natural upstream migration barriers to both juvenile and adult fish are frequent, in the form of steep cascades, bedrock chutes and waterfalls. The potential upstream migration of all species of anadromous salmonids is blocked by the natural barrier of Lower Cedar Falls (RM 34.2).

Several major tributary basins drain into the mainstem of the Upper Cedar River between the Landsburg Diversion Dam and the Masonry Dam, including Upper Rock Creek (2,917 acres) at RM 23.9, Williams Creek (1,564 acres) at RM 29.6, and Steele Creek (788 acres)

at RM 31.7 on the north side and the largest, Upper Taylor Creek (10,950 acres) at RM 29.5 on the south side. Because of its large drainage area, Taylor Creek provides approximately 15 percent (about 100 cfs annually), of the flow of the Upper Cedar River at the Landsburg Diversion Dam (Hart Crowser 1983).

LOWER CEDAR RIVER

The lower Cedar River includes the area below the Landsburg Diversion Dam for approximately 21 river-miles and drains a 66 square-mile area. It has a variety of environments ranging from mainstem habitats to small headwater stream systems. The mainstem environments and the four major fish-bearing tributaries (Taylor, Peterson, and Rock creeks and the Walsh Lake Diversion) provide the majority of the current spawning habitat for chinook, sockeye and steelhead in the Cedar - Sammamish Watershed. The system also provides significant spawning and rearing habitat for coho salmon and cutthroat trout. Most of the lower Cedar River basin is rural and forested, with the exception of the cities of Renton and Maple Valley where the basin is urbanized (King County, 1993). Of particular note under the ESA, is that the river's chinook and steelhead populations are believed to be native stocks (Marshall et al. 1995 and WDF et al. 1993).

According to geographic information analysis performed by King County in 1999, 89.4 percent of the Lower Cedar River basin is within the local jurisdictional boundary of King County, 7.8 percent is within the local jurisdictional boundary of the City of Renton, 2.1 percent is within local jurisdictional boundary of the City of Maple Valley, and 0.8 percent is within the local jurisdictional boundary of City of Kent as municipal watershed. Forested land cover totals 60.6 percent of the Lower Cedar River, 21.3 percent is determined to be low density development; 7.7 percent is designated as medium density development and 0.9 percent is high density development. Human population in the Lower Cedar River watershed is currently estimated to be 61,704 with an expectation to grow to 70,172 by the year 2020 (WRIA 8, 1999).

B. SALMONID UTILIZATION

The known freshwater distribution of anadromous and resident salmonids is depicted Appendix A. The Cedar River subarea is utilized by coastal cutthroat trout (*Oncorhynchus clarki clarki*), coho salmon (*O. kisutch*), chinook salmon (*O. tshawytscha*), sockeye salmon (*O. nerka*), winter steelhead (*O. mykiss*), and native char (bull trout) (*Salvalinus confluentus*). Bull trout, cutthroat trout and rainbow trout have been observed in the upper reaches, but adult salmon are currently not able to migrate past the Landsburg Diversion Dam.

Escapement Goals

Specific species escapement goals for chinook and coho stocks were developed in the 1970's based upon available habitat/production estimates. Currently the escapement goal in the Cedar River for chinook salmon is 1,200 adults, sockeye is 300,000 adults, and for winter steelhead it is 417 adults. A separate escapement goal for adult coho to the Cedar

River has not been set, rather the goal is 15,000 adults for the entire Cedar – Sammamish Basin.

LOWER CEDAR RIVER MAINSTEM CONDITIONS

Over the past 150 years, much of the 21.7 miles of mainstem aquatic habitat in the Lower Cedar River downstream of the Landsburg Diversion Dam has been dramatically altered by human activities. Agriculture, coal mining, railroad construction, and light rural development in the late 1800s initiated changes in the condition of in–stream and riparian habitat. Forests were harvested and land clearing associated with early agricultural and rural residential development in the floodplain was considered a main contributor to extensive erosion in the 1887 flood (Paul 1937). The City of Seattle constructed the Landsburg Diversion Dam in 1901 to divert water for municipal use (City of Seattle, 2000a). In 1914 the City also built Masonry Dam, further upstream at RM 37 for water supply, flood control storage, and hydroelectric generation (City of Seattle, 2000a). The Landsburg Diversion Dam removes approximately 22 percent of the flow (mean from 1949-1998) from the Lower Cedar River for municipal water supply (City of Seattle et al, 1999a and 1999b). During years of drought, the percentage of water removed will be higher.

Prior to this time, railroad construction operations had also constructed levees and eliminated access to some river meanders to protect the track and lessen the need for bridges. By 1936, the mainstem average channel width was reduced by approximately 30 percent from the estimated 1865 average of 250 feet to 170 feet. It is hypothesized that this reduction is largely due to water withdrawal and flow regulation, since constructed levees and revetments bordered only about 16 percent of the river length at the time (King County, 1993).

King County (1993) in the *Cedar River Current and Future Conditions Report* describes historic efforts of flood control and flood management in the Cedar River. Following the diversion of the Cedar River in 1912 from the Green/Duwamish River (WRIA 9) system into a 1.6-mile canal draining north to Lake Washington, the river's banks in this reach were developed for industrial and commercial land uses within the City of Renton. In the 1930s, and culminating in flood control efforts by the US Army Corps of Engineers and King County in the 1960s, an extensive network of levees and revetments along the river was constructed to control flooding and prevent bank erosion. This has resulted in 64 percent of the lower Cedar River having a revetment or levee along at least one bank. These flood control structures constricted the average channel width an additional 35 percent by 1989, when compared to the 1936 condition, to its present average of 110 feet. In all, the surface area of the river channel decreased by approximately 56 percent (320 acres) between 1865 and 1989. Following these flood control efforts, pockets of urbanization and industrialization of the lower reaches and surrounding plateaus have been developed, although much of the valley floor upstream of Renton is still relatively rural in nature.

Renton Reach (RM 0.0 to RM 1.6): The Renton reach is entirely artificial, is completely constrained between levees and revetments, and was regularly dredged to prevent flooding from its completion in 1912 until the mid–1970s. Portions of this reach were again dredged in 1999 for the first time since the mid-1970s. This reach is essentially one long riffle with little habitat complexity. This reach is affected by urban and industrial uses along the river that contribute to local water quality problems and eliminate the potential for connection with a natural floodplain or the establishment of a riparian corridor and significant LWD accumulations in the channel. This reach is the depositional area for many of the river's sediments, and as a result, the substrates tend to have higher levels of fine sediments than upstream substrates. Despite its limitations, this reach of river serves as a migration route for many salmonid fishes and is used extensively for spawning and limited rearing by sockeye, chinook, and coho salmon and steelhead and cutthroat trout as well as long fin smelt. Spawning success has not been evaluated in this reach. A riverside park extends along much of this reach and is used extensively by the public for viewing spawning fish, especially sockeye salmon (King County, 1993).

Lower Cedar River Mainstem (RM 1.6 TO RM 16.2): Approximately 14.6 miles of mainstem habitat are included in this reach. The river channel throughout most of this reach is confined and stabilized by levees and revetments, all of which contribute to a loss of connectivity of the river with its floodplain and poor riparian conditions. This has resulted in a mainstem channel dominated by riffle environments and riparian areas that are either devoid of large trees or, if forested, are dominated typically by alders and large cottonwood, rather than conifers (King County, 1993).

Middle Cedar River Mainstem (RM 16.2 - RM 21.6): This reach contains 5.5 miles of mainstem extending from the Dorre Don Creek (RM 16.2) to the Diversion Dam at Landsburg (RM 21.6). The valley is naturally more confined by bluffs in this reach than in the lower river reach. However, the river channel is less constrained by anthropogenic revetments and floodplain encroachment by development is less prevalent. Significant loss of floodplain has occurred in the Upper and Lower Dorre Don area (right bank; RM 15.8–17.0) and the Arcadia/Noble area (both banks; RM 18.2–18.8) resulting in degraded floodplain and riparian conditions for those reaches (King County, 1993).

Riparian conditions are primarily forested and conditions improve as one moves closer to the Landsburg Diversion Dam, with progressively more and larger conifers. The majority of large pools in the Cedar River mainstem occur in this reach, generally along the base of high bluffs. Several of these bluffs, especially in the vicinity of the mouth of the artificially created Walsh Lake Diversion channel, are important sources of spawning gravel. The water supply diversion dam at Landsburg (RM 21.8) is operated so that the Tainter gates are opened during flood flows allowing gravel from the upper river to move past that point (King County, 1993).

VALLEY FLOOR HABITATS

The Cedar River valley-floor contains an array of aquatic habitats that are outside of the mainstem channel, but within the river’s floodplain. Some of these features, such as wall–

base tributaries, are often the most productive salmonid habitats of river systems of the Pacific Northwest (Peterson and Reid, 1984). Typically they are formed in swales or channels left behind by past river channel migrations. In many instances they are small highly complex habitats that are currently out of the direct influence of mainstem flood flows, while others are important in the routing of floodwaters across the valley floor. Such habitats are typically subject to some instability due to flooding. Many such habitats have been damaged or lost to changes in land use practices within the floodplain and new habitats are rarely created because revetments or levees prevent river channel migration in most places (King County, 1993).

King County (1993), in the *Cedar River Current and Future Conditions Report,* identified a total of 68 individual valley floor associated aquatic habitats, including tributary streams and inventoried wetlands were identified along the Cedar River valley floor in the summer of 1992. There are a total of 25 wall–base tributary (WBT) streams, making them the most numerous habitat feature, followed by percolation side channels (PSC; 14 sites), and high flow side channels (HFSC), and riparian wetlands (RW), with six sites each. Many of the WBTs are part of larger wetland systems, reflecting their spring fed nature. Their steep gradients and short lengths limit existing or potential fish use of many WBTs, whereas PSCs typically provide much more existing habitat and have considerable potential for enhancement due to their larger size, lower gradients, and closer connection with the mainstem channel.

Cavanaugh Pond (also sometimes referred to as Wetland 6) at RM 6.4 and a WBT at RM 11.5 are the result of unintentional human actions. A spawning channel created at RM 5.0 was destroyed during the landslide of February 28, 2001. All of these were used extensively by salmonids. Several additional opportunities exist downstream of RM 9.0. A summary of wetlands is in Table 33.

Table 33. Summary of wetlands along the mainstem lower Cedar River

Wetland Number/Name	Location	Size (acres)	Type	Water Source	Salmon Utilization	Concerns
# 6 / Cavanaugh Pond	RM 6.4-6.85	14	1	Tributary 0312	Sockeye spawning	sedimentation
# 37 / Cedar Grove Park	RM 8.3 – 9.1	30	2	Ground water	none	Buffer zone
# 105	RM 10.5 – 10.6 and 08.0316	9.2	2	Surface water	Unknown, probable juvenile	Buffer Zone
# 132	RM 13.1 and L. Taylor Ck.	25.9	2	Surface water	Sockeye & coho spawning	Sedimentation, clearing, runoff.
# 118	RM 14.3	5.3	2	Surface water	none	Clearing, grading
# 83	RM 21.8	14	1	Ground water	None	Clearing, invasive plant species
# 69 and 70	RM 20	5.5 and 2.5	2	Ground and surface	Unknown, possible juvenile	Loss of land

TRIBUTARY CONDITIONS

Lower Taylor Creek

The Lower Taylor Creek system is used by anadromous fish and, between RM 1.8 and RM 2.0, has a population of fresh water mussels. Portions of the subbasin are composed of a network of relatively low–gradient stream channels containing habitat that is of good quality with some isolated pockets of excellent habitat. Riparian systems are generally well vegetated, although still immature. In high–gradient reaches, habitat is further stabilized by patches of small to moderate sized boulders. Hydrology of the system has not been greatly affected due to the relatively low level of development throughout the drainage.

The mainstem of Lower Taylor Creek drains a series of wetlands, formed in a shallow valley between Carey Creek, a tributary of Issaquah Creek to the northeast, and the Cedar River Basin. This valley also contains State Route 18 (SR–18), which parallels much of the mainstem of Taylor Creek. Two fish–bearing tributaries (#'s 0327 and 0328) contribute to Lower Taylor Creek prior to the mainstem's drop to the valley floor. Habitat throughout these systems is dominated by several wetlands, most notably Wetland 58, which is in the vicinity of the Taylor Creek Golf Course, between RM 2.25 and 2.6 (King County, 1993).

The confluence of Lower Taylor Creek with the Cedar River is contained in Wetland 132, a large riparian wetland complex with high quality fish habitat (King County, 1993).

Additional habitat in the Lower Taylor Creek system is found in Tributary 0321, which enters Taylor Creek at RM 0.45, north of SE 206th Street. This tributary has excellent habitat between RM 0.2 and 0.8, where there is a riparian area of large second growth cedars and the channel has LWD.

Peterson Creek

King County (1993), in the *Cedar River Current and Future Conditions Report,* describes Peterson Creek as being utilized by several species of anadromous salmonids indigenous to the lower Cedar River. It contains generally good to excellent habitat that is well–buffered largely by an extensive lake and wetland network in its upper basin and a mostly undeveloped riparian corridor throughout much of its length. The riparian corridor varies in its state of vegetational succession and stability throughout much of the subbasin. Good to excellent habitat conditions exist in the lower 0.5 miles. Large deciduous trees and relatively large second growth conifers nearing late seral stage in structure and function dominate much of the vegetation in this lower ravine (King County, 1993).

From RM 0.5 to RM 1.2, long riffle reaches dominate Peterson Creek. Some good to excellent reaches of habitat exist, especially where accumulations of stable LWD occur.

Above Peterson Lake, Peterson Creek splits into three channels, with the mainstem draining Spring Lake and an un-named right bank tributary (0328B) draining Lake Desire. There is a third unnamed and unnumbered tributary that drains from the west and is largely contained in a pipe as a result of activities by the City of Seattle to drain water away from Lake Youngs. This third channel does not have fish and is not examined further in this review (King County, 1993).

Both of the larger channels are contained in a large Class 1 wetland system (Wetland 28) that dominates much of the valley area downstream of the lakes. The stream habitat in this reach is protected by the surrounding wetlands; banks are densely vegetated, mostly with deciduous woody plants (King County, 1993). The channels are low gradient and substrates are dominated by silt with abundant LWD that contributes to habitat complexity (King County, 1993).

Lower Rock Creek

Lower Rock Creek is the largest subbasin within the Cedar River Basin, over 12 square miles in size with a total stream length of approximately 8.0 miles. Because of intermittent stream flows, only the lower 2.6 RM are accessible for anadromous salmonids. During a typical water year, the reaches of Lower Rock Creek upstream of RM 2.6 only flow from early December until early July.

Lower Rock Creek is considered to be excellent habitat throughout most of its length and is among the best habitats in western King County (G. Lucchetti, personal communication and King County, 1993). Habitat conditions in Lower Rock Creek, with few exceptions, represent a complex interplay between soil and vegetation, with relatively minor recent human intervention (King County, 1993).. Natural system stability is enhanced by a relatively low gradient, a storm hydrology dampened by large amounts of glacial outwash soils in the subbasin, and a series of uninventoried riparian wetlands between RM 2.6 and 8.0 (King County, 1993). The Rock Creek drainage has been only sparsely developed. Much of the riparian vegetation has a high proportion of large second growth coniferous trees. Most of the stream has high volumes of LWD. In many reaches the habitat can best be typified as continuous "debris complexes”, within which complex pool and riffle habitats have developed (King County, 1993).

A wetland system associated with Lake 12 occurs in the headwaters of Lower Rock Creek. The King County wetland inventory shows these as two separate Class 2 wetlands. However, field inspections reveal a single 134–acre system composed of open water (Lake No. 12), emergent and scrub–shrub wetland areas along the lake shoreline, and a large complex of cedar/hemlock wetlands, as well as scrub–shrub wetlands, marsh, and open water habitats east of the lake. Water from the lake flows sluggishly east through a maze of fallen trees and shallow pools, then through a marshy area and a small pond west of 290th Avenue SE. A short distance upstream from the road, the topography becomes steeper and Lower Rock Creek begins in a defined channel at RM 4.5. From the area's peat stratigraphy (Rigg, 1958), it appears that a sedge–cattail marsh flourished at this location

several thousand years ago, after which a forested wetland began to form; perhaps resembling the swamp that now exists (King County, 1993).

Another wetland system (27-acre Wetland 93) is a forested/scrub–shrub system bordering Lower Rock Creek from RM 4.5 to 4.0. It is separated from the east end of the wetland associated with Lake 12 (Wetland 92) by the toe of the adjacent north slope west of 290th Avenue SE. The vegetation consists of dense thickets of willows, salmonberry, snowberry, hardhack, vine maple, and Pacific ninebark. Deer and elk sign were especially abundant in this wetland, and several songbird species were sighted (King County, 1993). The King County stormwater and wetlands research project notes use of this wetland by 56 bird species (King County, 1993).

HABITAT FACTORS OF DECLINE

Cedar River Mainstem

The upstream passage of fish at the Landsburg Diversion Dam is currently prohibited and has eliminated the natural production of anadromous salmonids in this reach. The Seattle HCP will provide for passage of both adult and juvenile chinook, coho, winter steelhead, and sea-run coastal cutthroat trout past the dam. Passage is being designed and should be operational by 2003.

The passage and spawning behavior of salmonids may be affected by the channel-spanning sockeye salmon broodstock collection weir installed at river mile 6.5. This weir is in operation from mid-September through November. The weir has been operated annually since the early 1990's and for the last two years (1999 and 2000) specific broodstock collection protocols were used that had been developed to ensure both broodstock collection and upstream passage of anadromous salmonids not required for broodstock. For these last two years, weir construction and operations and the potential effects on fish passage, behavior, and spawning distribution have been intensively monitored. Long-term standards for weir operations ensuring no negative effects on spawning behavior and fish passage are still being developed (City of Seattle, 2000a).

The City of Seattle removes approximately 22 percent of the Cedar River flow (mean of 1949-1998) at the Landsburg Diversion Dam from the Lower Cedar River (City of Seattle et al, 1999a and 1999b). Flows from the Upper Cedar River watershed are managed under provisions of the City of Seattle's HCP. Multiple aspects of flow and hydrology in the Cedar River and the rest of WRIA 8 are being explored by the WRIA 8 Flow Committee, which is a subcommittee of the WRIA 8 Technical Committee. Altered hydrology and flow in the Cedar River resulting not only from the Landsburg diversion, but also from issues such as ground water withdrawals, development in the riparian areas, armoring of streambanks, degradation of riparian conditions, and channelization are part of the analyses.

Fewer areas of intact riparian plant communities exist in the Lower Cedar River basin than in the past. Within these remaining areas, there are an insufficient number of large coniferous and deciduous trees for effective LWD recruitment.

The mainstem middle Cedar River reach that is 5.5 miles long and extends from the Dorre Don Tributary 0336 (RM 16.2) to the Diversion Dam at Landsburg (RM 21.6) is characterized by inadequate riparian vegetation (King County, 1993)

The Upper Cedar River above Landsburg Diversion Dam has an excellent intact riparian corridor with many large coniferous and deciduous trees. Currently all LWD that floats downstream and accumulates on the upstream face of the Dam is permanently removed from the river by the City of Seattle because of legal liability issues (City of Seattle, 2000a).

The Cedar River valley floor contains a wide array of aquatic habitats outside of the mainstem channel, but within the river floodplain. An evaluation of each site's habitat potential and existing limitations has indicated that deficiencies of LWD and/or poor condition of the riparian environment are problems in 37 of the 68 sites examined.

Levees and revetments and flow alterations have cut off some sources of gravel. A reduction in the river's ability to access and release gravels suitable for spawning from the banks and floodplain could affect spawning success. The amount of fine sediment deposition is unknown. A multi-agency sponsored comprehensive look at the spawning gravel situation is in varying stages of development and implementation.

A habitat concern on the lower mainstem Cedar River is the effect on long–term gravel recruitment and pool habitats caused by efforts to stabilize the toes of steep banks to prevent catastrophic landsliding. Large, deep pools tend to form at the base of many of these slide areas, often providing excellent habitat. This slide contributes gravels and fine sediments and has added some LWD to the river channel. Habitat at the base of this slide is excellent due to LWD accumulations and a complex channel shape. Stabilization of the toe of this bank in order to reduce catastrophic inputs of sediment could eliminate a source of gravel and LWD and reduce local habitat quality (King County, 1993).

In fact, two left bank revetments, one located directly downstream of Molasses Creek (RM 3.8) and another directly downstream of Peterson Creek (RM 13.9) have been constructed in recent years at slide areas to prevent future catastrophic failure. However, both sites were also potential sources of spawning gravel for the river, although the site at RM 3.8 was also adding fine material that could potentially reduce spawning habitat quality in downstream reaches. Solutions for stabilization of steep banks along the Cedar River should incorporate evaluations of the function of these banks in gravel recruitment and in the formation of pool habitats for juvenile rearing and adult holding habitat for salmonids (King County, 1993).

Another habitat concern on the lower Cedar is the possible disruption of the natural downstream flow of gravel, cobble, and boulders by the Landsburg Diversion Dam (G.

Lucchetti, personal communication). This possible disruption could cause an altered array of substrate particle sizes, especially in the reach immediately downstream of the diversion dam. In 2001, Seattle, King County, Renton, and the Corps of Engineers are planning a study to examine this potential problem more closely.

Primary non-point pollution sources occur in the Cedar River Renton reach and tributaries in this vicinity. Non-point sources of pollution exist that originate from developed and developing areas and includes petroleum products, metals, fecal coliform, solids and pesticides/herbicides. The Logan Street outfall regularly discharges water with high concentrations of heavy metals (e.g.: copper, lead, zinc) that exceed acute toxicity standards. In addition, this outfall contributes high levels of suspended solids, turbidity, total phosphorus and fecal coliform bacteria. River channel sediments are contaminated with heavy metals and petroleum hydrocarbons. Surface water discharges from the Boeing Company outfall have been shown to contain semi-volatile organics, PCBs, high levels of total phosphorus and fecal coliforms. Semi-volatile organics (e.g.: coal tar derivatives, phthalates and PCBs have been found in the vicinity of this outfall in river channel sediments. Outflow from the Stoneway batch plant has been shown to have high pH levels (up to 11.9) and the outfall from the Renton Municipal Airport has been shown to contain semi-volatile organics and the herbicide 2,4-D. River sediments sampled in the vicinity of the Renton Municipal Airport outfall have contained semi-volatile organics and PCBs (King County 1993).

These contaminated sediments are mobile, moving downstream through the system and in to Lake Washington. Sediments in the lower Cedar River are moved either from streambed scour or from present and historic dredging activities at the mouth of the Cedar River. The mouth of the Cedar River was dredged as recently as 1998.

Lower Cedar River Tributaries

Field reconnaissance combined with review of standard reference material including aerial photographs, National Wetlands Inventory maps, U.S. Geological Survey quadrangles, King County Wetlands Inventory and Sensitive Areas Folio documented change and/or loss in channel complexity and connectivity for the tributary systems as summarized below. The field-based portion of this assessment occurred from October 1991 to June 1992 as part of the preparation of the *Cedar River Current and Future Conditions Report* (King County 1993) and during site visits in 2001 (Kerwin, pers obs.).

Hydrologic modeling (HSPF and SEAFM) of pre-development, current, and future conditions was undertaken as part of the preparation of the *Cedar River Current and Future Conditions Report* (King County 1993). The modeling results, in combination with analysis and review of aerial photographs and field reconnaissance during 1987 and 1990-1991 documented altered hydrology/flow for the tributary systems are summarized in this chapter.

Dorre Don Creek (08.0036)

Seasonal low or no flow periods limit salmonid utilization of this creek. A culvert at RM 0.17 limits anadromous and resident fish access to upstream reaches. Despite this ephemeral flow, resident rainbow and coastal cutthroat trout were sampled by WDF (Muto and Shefler, 1983) in pools below 244th Street (approximately RM 0.8) in 1982.

The lower stream reaches travel through residential yards, through at least two culverts and over highly porous gravels that permit all but the highest of stream flows to infiltrate.

King County (1993) identified one 77-acre Class 1 wetland in the headwaters of Dorre Don Creek. This wetland was composed of forested, scrub-shrub, shallow marsh and open water habitats. The unusual diverse plant communities of this wetland include Sitka spruce and red alder forested components and historic remnant patches of Sphagnum, bog laurel, Labrador tea, and cranberry, all of which are indicative of a historic bog or fen.

No information was located during the course of this investigation that provided quantified numbers for habitat criteria.

Dorre Don Creek experience increased peak flows due to insufficient retention and detention (King County, 1993). Dorre Don Creek could be compromised due to stormwater runoff from developed areas (King County, 1993).

Ginger Creek (08.0300 and 08.0300A)

A natural falls prevents fish access upstream of RM 0.17. Downstream of these falls utilization by salmonids is limited due to high stream gradients and changes to hydrology by upstream urbanization. A culvert at the mouth of the creek may also act as a partial barrier depending on stream flows.

Maplewood Creek (08.0302) and Tributaries

This creek enters the Cedar River at RM 3.4 and has historically been utilized by coho salmon (Williams 1975). Coastal cutthroat can be found in the upper reaches (King County 1993). The lower 800 feet of the creek is contained within a 72-inch diameter culvert as it passes under the railroad grade, SR-169 and partially thru the Maplewood Golf Course. The stream channel within the vicinity of the Maplewood Golf Course is largely a drainage ditch .

Downstream of RM 0.5 any functioning riparian habitats are lacking. At approximately RM 0.5 the creek enters a steep wooded wall based ravine. Timber harvests have limited LWD recruitment. Although no volume or piece counts were located, a site visit in 2001 showed LWD to be lacking or non-existent.

High stream flows thought to be caused by upstream urbanization (King County 1993) are thought to be the cause of increases in sedimentation. Instream habitat in the upper reaches

of the ravine is heavily impacted by channel scour, a naturally unstable geologic condition exacerbated by increased stream flows, and lateral bank sliding.

Molasses Creek (08.0304) and Tributary

This small tributary enters the Cedar River along the right bank at RM 4.05 with utilization by coho and sockeye salmon (Williams 1975, WDFW Spawning Ground Database). Coastal cutthroat can be found in the upper reaches and wetlands (King County 1993). No quantified information was located during the investigations for this report. However, King County (1993) did investigate this tributary and identified three wetlands of significance in the drainage basin.

The headwaters of this system originate from two Class 1 wetlands, a 12-acre and a 7.7-acre wetland both bordered by residential developments. A Class 2 wetland (37 acres in size) was identified in the middle reaches of the mainstem creek. Downstream of this later wetland is a stream reach surrounded by landscaped lawns and/or the stream is contained in culverts (one culvert is in excess of 0.25 miles long).

Beginning at approximately RM 0.8, the stream enters a steep ravine with a riparian zone of mixed conifers and deciduous trees. King County (1993) reported several functional sized pieces of LWD in this reach, which aided in stabilizing the stream bank and forming pools.

Madsen Creek (08.0305) and Tributaries

This tributary system enters the Cedar River along the left bank at RM 4.50 with utilization by coho (Williams 1975, WDFW Spawning Ground Database), historic use by sockeye, steelhead and coastal cutthroat trout (King County 1993). Current fish utilization is limited to coastal cutthroat trout and an occasional report of steelhead (King County 1993).

The lower reaches of this system flow through artificial channels that are largely drainage ditches. Runoff from developments has caused additional sedimentation in the lower 0.8 stream miles and there is a general lack of channel complexity with no functioning riparian zone (King County 1993).

A sediment control pond was constructed in 1974 at RM 0.8 to trap fine sediments and protect a local mobile home park from flooding. While successful in the later goal, the facility failed in the former and continues to pass sediments downstream. This pond also has a high flow bypass system that has been observed to attract adult salmon and has the potential to trap juvenile salmonids due in part to lack of any screening devices (King County 1993). Downstream reaches have become braided on the bank terrace immediately upstream of its confluence with the Cedar River.

Upstream, from RM 0.8 to 2.15, the stream flows through a naturally steep and deep ravine. The riparian zone is characterized by immature deciduous trees. In 1992, the instream woody debris is often small and poorly positioned (King County 1993) and there

was a lack of deep complex pool environments. High amounts of sediments from upstream sources have disturbed much of the habitat. The origins of these sediments is believed to be from a systemic erosional process caused by changes in hydrology in turn caused by development of upstream lands. This condition is then exacerbated by lack of LWD, riparian zones that are not properly functioning and the placement of sewer lines throughout the ravine. The placement of these sewer lines has caused channel relocation, bank hardening and LWD removal (King County 1993). Additionally, Madsen Creek has eroded the soils that support the pipe on several occasions causing the pipe to break and spill raw sewage into the creek. Currently, several portions of the pipeline have been exposed and there are plans to armor the creek bank and stabilize the channel to support the pipeline. Only limited sediment sampling has been conducted in this tributary but the herbicide 2,4-D has been detected downstream of the Fairwood Golf Course.
Upstream of RM 2.15, Madsen Creek flows in close proximity to residential subdivisions, is channelized though and around landscaped yards. Madsen Creek has the highest measured load of suspended solids and phosphorus relative to other tributary streams in the Cedar River watershed.

Unnamed tributaries (08.0314, 0314A, 0314B, 0315, 0315A, 0316, 0317, AND 0318)

These tributaries are typical small wall based streams, with high gradients, often times intermittent flows and with fish utilization confined to the lower most reaches. Known fish utilization is confined to coho salmon and coastal cutthroat trout.

Encroachment by a gravel mining operation and mobile home park were identified as a concern by King County (1993).

Cedar Hills Tributary (08.0316)

The Cedar Hills Tributary is numbered in the Cedar River Conditions Report (King County 1993) as 0316A. This stream is not identified by Williams (1975). Williams (1975) lists a small spring seep creek that flows into the Cedar as 08.0316 (located downstream of Cedar grove Road at approximately RM 10.7), but it is thought that this is an error and that Williams (1975) really meant to designate 08.0316 to the larger creek generally referred to as the Cedar Hills tributary or 08.0316A (located just upstream of Cedar Grove Road at approximately RM 11.4).

The Cedar Hills Tributary lacks channel complexity due to permanent forest clearing and gravel mining (King County, 1993).

Riparian habitats along the Cedar Hills Tributary are degraded due to permanent forest clearing and gravel mining (King County, 1993).

The hydrology of the Cedar Hills Tributary has been altered because of increased peak flows due to forest clearing and gravel mining (King County, 1993).

Water quality in the Cedar Hills Tributary is impacted due to gravel mining and a composting operation (King County, 1993).

Peterson Creek (08.0328)

Peterson Creek is used by chinook, coho, sockeye, winter steelhead and coastal cutthroat trout (King County 1993, WDFW Spawning Ground Database). A small dam occurs at the outlet to Peterson Lake that has historically been identified as a fish barrier but appears to pass fish today. Because of some uncertainty, it is identified as a partial barrier.

Generally, the riparian areas of Peterson Creek have been degraded due to land clearing (King County, 1993). From RM 0.0 to 0.5 the riparian zone is generally considered good to excellent. Large conifers and deciduous trees, generally mid too late seral in age dominate the riparian zone. In this same reach, there is also a high incidence of landslides that are responsible for delivering sediments and wood (both large and small) to the stream channel. It is unclear if these landslides are at a rate greater than historic levels given the natural instability of the adjacent soils.

The riparian zone from RM 0.5 to RM 1.2 is still recovering from past logging and is not yet naturally contributing significantly to the addition of LWD (King County, 1993). The stream channel is dominated by long riffle reaches but has localized areas where relic LWD is contributing to some pool development.

From RM 1.2 to the mouth of Peterson Lake (RM 1.6), the stream channel has been extensively channelized, straightened and/or relocated. This channel reach is dominated by runs and glides with a riparian zone consisting of small deciduous trees (mostly alders).

Water quality in Peterson Creek may be compromised due to impacts of local urbanization but no data was located during the course of this investigation.

Peterson Creek experiences increased peak flows due to insufficient retention and detention (King County, 1993).

Lower Rock Creek (08.0339)

Rock Creek is utilized by chinook, coho sockeye, winter steelhead and coastal cutthroat for spawning, rearing and transportation (King County 1993, WDFW Spawning Ground Database). Salmonid access is partially blocked in Lower Rock Creek due to seasonal low flows.

Existing impacts to Lower Rock Creek include logging, which has left some reaches with immature riparian areas and relatively little LWD in some lower reaches of the stream. Other impacts to stream habitats have resulted from land use practices. Current impacts to Wetland 91 (Lake No. 12) include vegetation removal, filling, soil compaction in residential yards along three–quarters of the lake shoreline, and human disturbance from recreational use of the lake. This lake is also is impacted by the public boat launch near the

southeast corner of the lake. This boat ramp appears to have been built on fill in the wetland. The use of the lake by recreational motorboats subjects the lake to oil and gasoline spills (King County 1993).

The City of Kent maintains a system of wells near the Summit–Landsburg road crossing (RM 1.7) used for domestic water. Downstream of these wells, the Lower Rock Creek hydrologic regimes are impacted from residential development at the headwaters and from water withdrawals by these wells. Instream flow problems, at least partially caused by the City of Kent's water withdrawals are particularly problematic during the late–summer and early–fall months when the wells take as much as three quarters of the expected baseflow. In mid–October, 1992, when sockeye and chinook salmon were in the mainstem of the Cedar River, the lower reaches of Lower Rock Creek was estimated to have a flow of only 1.9 cfs, leaving many riffles and pools too shallow for the passage and holding of adult sockeye and chinook. This lack of water during traditionally low–flow periods further crowds and stresses juvenile coho salmon and steelhead and coastal cutthroat trout that use Lower Rock Creek habitat for extended freshwater rearing.

Walsh Lake Diversion Ditch (08.0341)

The 4.4-mile channel of the Walsh Lake Diversion Channel (08.0341) is completely artificial, primarily simple and linear due to its channel relocation and construction (King County, 1993).

The Walsh Lake Diversion is the outlet of Walsh Lake and drains the Walsh Lake Basin. Most of the Walsh Lake Basin is located within the boundaries of the Cedar River Municipal Watershed and drains approximately 4.5 square miles of land. Historically the outlet of Walsh Lake flowed into upper Rock Creek and then into the Cedar River upstream of the Landsburg Diversion Dam (City of Seattle, 2000a and 2000b). However, because of contamination from the historic town of Taylor, in the early 1930's the City of Seattle diverted the Walsh Lake outlet away from Upper Rock Creek via a 4.4-mile drainage ditch into the Cedar River downstream of the Landsburg Dam water supply intake (City of Seattle, 2000a and 2000b). In general, the Diversion channel flows almost due west, paralleling the Cedar River to the north on a high plateau, until RM 0.65, where it begins a steep descent to the valley floor (City of Seattle, 2000a and 2000b).

The lower reach of the Walsh Lake Diversion Channel (RM 0.0–0.18) is characterized by gently sloping bank topography and vegetation dominated by deciduous forest with dense underbrush. The major habitats in this lower reach are pocket water, high– and low–gradient riffles, and only a few pools that are absent of any LWD. Although surface substrates range from small gravel to small boulders, cobble–sized rocks dominate. There are a number of locations in which the channel is poorly defined and meanders from year to year through different sections of the riparian forest (K. Kurko, personal communication). Evidence of meandering in the recent past includes the presence of several well-vegetated gravel bars outside of the present channel, indicating that habitat formation is still very dynamic (King County, 1993). Gravel deposits on the sediment fan in this reach are very

permeable, and combined with the poorly defined channel, may be two factors that predispose this section of stream to go dry during low flows.

Upstream from the diversion channel's mouth, the gradient rises steeply. This high–gradient reach of the Walsh Lake Diversion Channel (RM 0.18–0.65) is typified by steep, generally unvegetated and eroding soil banks up to 40 feet high. These features indicate the extent of channel downcutting since flows were first diverted over the edge of the valley (King County, 1993). Despite this instability there is some good pool habitat formed by LWD that has fallen into the channel. This LWD is also serving to create a stair–step channel profile and to stabilize and store sediments. A relatively high percentage of boulder and cobble substrates are providing a basic level of streambed and habitat stability (King County, 1993).

Several species of salmonids utilize the lower Walsh Lake Diversion Channel up to RM 0.8. At this point, a high gradient, high velocity chute forms a partial migration barrier. This partial barrier is located on private property at approximately RM 0.8 (City of Seattle, 2000a). Regular spawning surveys upstream of the barrier initiated by the City of Seattle in 1997 have only observed a few spawning coho salmon (K. Kurko, personal communication).

A short portion (RM 1.1–1.2) of the Walsh Lake Diversion Channel east of the Issaquah–Hobart Road was lined with an impervious material to reduce subsurface flow to the nearby Hobart Landfill. A leachate collection system was installed on the landfill, in part to prevent contamination of surface water in the diversion channel (King County, 1993)

Flows in the lower mile of Walsh Lake Diversion sometimes go subsurface during late summer and early fall (King County, 1993 and D. Beedle, personal communication).

In areas (RM 1.2 to 2.0) where the channel meanders away from the access road and has been allowed to flood and erode the adjacent banks there are reaches of fair to good habitat, including lateral and backwater pools. Consequently the channel is able to achieve a natural meander pattern and recruit and retain LWD (King County, 1993).

Much of the upper 2.4 miles of the Walsh Diversion Channel on the high plateau are simple and straight. In this section, the Diversion is immediately adjacent to a major access road in Seattle's Municipal Watershed. This road also serves as a levee to prevent the Walsh Lake Diversion from spilling back into Upper Rock Creek and is regularly maintained by the City of Seattle. Habitat in this section of the Walsh Diversion is considered poor since there is little instream habitat complexity and very little gravel in this reach, although there is a relatively constant flow and overhanging vegetation along at least one bank (King County, 1993).

At RM 4.4, the Diversion flows out of Walsh Lake. Walsh Lake is about 60 acres in size and is up to 35 feet deep. Walsh Lake is home to a small population of kokanee of unknown genetic origin (City of Seattle, 2000b). The kokanee spawn every October in

Webster Creek, which is the main inlet stream that flows into Walsh Lake (City of Seattle, 2000b).

Taylor Creek (08.0351)

Habitat conditions in Lower Taylor Creek (08.0351) limits natural salmonid production due to clearing, bank hardening, road proximity (King County, 1993). In Lower Taylor Creek, stream crossings under SR–18 and two private roads constrict the stream channel and contribute to a loss of floodplain connectivity as a result of stream maintenance to protect the crossings (King County, 1993). At RM 1.2, Lower Taylor Creek reaches the Cedar River valley floor and parallels Maxwell Road where the stream is confined to a ditch-like feature. Habitat in this area has been affected by surrounding agriculture and rural development, and channelization and road maintenance activities conducted to reduce local flooding (King County, 1993).

In the mainstem of Lower Taylor Creek, localized effects of agriculture, road crossings, and rural development along stream channels, especially on Tributary 0326 between RM 0.45 and RM 0.7, are the main impacts to habitat in these reaches of the creek (King County, 1993). In Lower Taylor Creek, habitat throughout much of the drainage has suffered somewhat due to the immature condition of its riparian system and limited quantities of LWD; these deficiencies suggest that the habitat could be significantly improved in complexity and stability over current conditions and that the system may be at risk of much more dramatic habitat degradation (King County, 1993).

From RM 1.8 to 1.2, Lower Taylor Creek flows through a shallow ravine, which is much less steep in channel slope than ravines of surrounding Cedar River tributaries and has habitat problems much less dramatic to date. Potential habitat values in the ravine are reduced by low quantities of LWD and a largely immature riparian system (King County, 1993). Lower Taylor Creek Tributary 0321 enters Taylor Creek at RM 0.45, north of SE 206th Street. Below RM 0.2, the tributary stream channel is relatively straight and clean and flows through a pasture, although a dense border of blackberries provides some protection from local grazing of banks. Above RM 0.8, Tributary 0321 and two others (0323 and 0323A) are degraded by a combination of agriculture and encroachment of rural development, resulting in poor quality riparian areas, or in some cases, a complete lack of streamside cover (King County, 1993).

The altered hydrology and flow regimes in Lower Taylor Creek result from increased peak flows due to SR-18 and insufficient retention and detention attributes (King County, 1993).

The water quality of Lower Taylor Creek has been degraded due to higher nitrite concentrations that are likely from nearby hobby farms (Warner et al, Draft 1999) and multiple crossings of SR-18 (King County, 1993).

D. IDENTIFIED HABITAT LIMITING FACTORS AND KEY FINDINGS

- The majority of the existing mainstem Cedar River habitat has been disconnected from historic floodplains through the construction of revetments. This is turn results in a loss of channel habitat complexity and a reduction in the supply and stability of spawning gravels.
- The amount of available fish habitat in the lower mainstem Cedar River has been reduced by approximately 56 percent due primarily to water diversion and flood control activities. This number is now eight years old and likely underestimates current conditions.
- The loss of off-channel rearing habitat is particularly severe for juvenile chinook. Historically, this habitat would have been utilized by juvenile chinook for rearing which in turn would have resulted in a larger and later timing outmigrant from the Cedar River. Because of the loss of this habitat this life history trajectory has been reduced. This loss of habitat forces juvenile chinook to migrate as very young fry into Lake Washington, a life history trajectory which may not favor their survival.
- The number and size of fish bearing tributaries to the lower mainstem Cedar River are naturally quite limited. This makes the importance of those few all the greater. The anadromous fish accessible Madsen, Molasses and Maplewood Creeks have all suffered severe impacts caused by encroaching urbanization. Habitat in the upper stream reaches are fragmented by road and drainage networks associated with housing developments. In the middle (ravine) reaches, habitat quality has been reduced and streambanks destabilized due to a number of urban associated factors including: high sediment loads; poor riparian zone; low levels of LWD; placement of sewer lines; and increases in stormwater runoff.
- Madsen Creek habitats have continued to be adversely impacted through the placement of sewer lines placed in the ravine. This has led to water quality degradation, stream channel relocation and stabilization projects and limitations to lateral stream channel migration.
- Land use activities have contributed to water quality and quantity problems in streams 08.0316 and 08.0316A.
- Due to existing land use activities the fish habitat in Taylor Creek is suffering from poor riparian zones and low LWD amounts and recruitment potential.
- Rock Creek is limited in natural fish production capabilities by water withdrawals. These withdrawals can remove approximately 75 percent of the summer base flow, which eliminates access to adult chinook and sockeye and reduces juvenile rearing habitats for coho, steelhead and cutthroat trout.
- Large woody debris recruitment is currently rated poor along almost 100 percent of the lower Cedar River, and land use practices generally preclude active recruitment. Large amounts of LWD are removed at Landsburg Dam due to liability concerns.
- The Walsh Lake Diversion Ditch was constructed in the 1920's for the purpose of diverting what at the time was thought to be contaminated water away from the City of Seattle potable water intake at Landsburg Dam. There currently is no evidence that a risk situation exists and this ditch could be redirected back to its' historic channel where it would be accessible to anadromous salmonids.

E. DATA GAPS

- No program exists which routinely monitors for or documents the presence and location of exotic species in the Cedar River.
- There are probably sufficient data to characterize temperature, DO, pH, and ammonia at each of the sampling locations for purposes of assessing preliminary areas of concern for salmonids. However, as noted above, the current sampling locations do not yield adequate spatial coverage. There are also temporal limitations to most of the temperature data, because they are not continuous data, and thus do not reflect maximum daily temperatures and duration of temperature exceedences that have the greatest potential to impact salmonids.
- The spatial availability of water quality data is highly variable across the subarea. There is a paucity of sampling locations for the mainstem of the lower Cedar River for which King County data are available. Sparse coverage in some stream reaches and tributaries could potentially overlook some areas with impaired water quality in the Cedar River, and result in greater uncertainty in this assessment.
- Data are also lacking for many of the other water quality parameters that may adversely affect salmon. Available TSS data do not include any information on the duration of exposure, which is needed to evaluate accurately potential effects on salmonids. In an urban watershed with extensive commercial and industrial development characteristic of the Lower Cedar River, other parameters that could be of concern include metals, pesticides and herbicides, PAHs, and phthalate esters. There is a shortage of data available for these parameters in the water column. Most of the existing data is for sediments.
- The majority of the ambient metals data in the Cedar River Subarea were collected as part of the stormwater monitoring program; therefore, baseflow metals concentrations are generally unknown
- The distribution and abundance of macroinvertebrates (aquatic insects) in running waters have long been recognized as important tools in describing and assessing the condition of aquatic ecosystems. Unlike chemical data that yield a snapshot of aquatic conditions at the time of sampling, aquatic insects provide an integrated view of overall water quality conditions at a given location. Unfortunately, very little aquatic insect data (as measured by B-IBI) in the Cedar River subarea is available. Thus, this is a data gap for the subarea as a whole.
- There is need to define closer links between water quality data and site conditions with the historic, current, and potential future distribution of salmonids.
- Turbidity and total suspended solids (TSS) are possible factors of decline in terms of water column impacts. No data were available for the duration of exposure, so it is difficult to determine the extent to which TSS is of concern. TSS may be a concern in terms of sedimentation in some areas, but this was outside the scope of this study, and would be better characterized by analysis of sediment deposition or embeddedness.
- No existing quantitative data on the extent or quality of side channel habitat in the mainstem lower Cedar River subarea was located during the course of this investigation.

- Available data are insufficient to assess the reduction in floodplain area throughout the subarea.
- There are no existing data on the quality of habitat provided by off-channel habitat.
- Only very limited quantitative field data is available on pool:frequency ratios, pool quality, channel morphology, substrate or bank conditions in the mainstem or tributaries.
- No data is available on LWD in the lower Cedar River (RM 0.0 to RM 21.5).

UPPER CEDAR RIVER SUBBASIN

INTRODUCTION

With issuance of the incidental take permit on April 21, 2000, the City of Seattle's Cedar River Habitat Conservation Plan (HCP) was finalized and implementation began. The HCP is a multi-species, ecosystem-based plan that addresses 83 species of fish and wildlife that are found, or may potentially be found, within the Cedar River Municipal Watershed including spotted owls, marbled murrelets, common loons, bull trout, steelhead trout, and chinook and coho salmon, as well as many species of amphibians and invertebrates (City of Seattle, 2000 a).

Major elements of the Seattle's 50-year HCP that specifically apply to the Upper Cedar River are summarized below in this chapter.

A. PHYSICAL DESCRIPTION

The Upper Cedar River (Landsburg Drainage) Subbasin includes all of the land area draining surface water upstream of the point where the City of Seattle diverts its drinking water supply from the Cedar River (Landsburg Diversion Dam). This drainage area encompasses approximately 79,951 acres (125 mi^2), including 79,452 acres owned by the City of Seattle (City) (99.4 percent) and the remaining 499 acres owned by other parties.

The subbasin is approximately 25 miles in length and variable in width, and extends from the Diversion Dam at an elevation of 543 feet eastward to Meadow Mountain near the Cascade Crest at 5,414 feet, a gain in elevation of 4,871 feet. Hydrologic subdivisions within the Upper Cedar River subbasin contain 7 major tributary basins which range in size from 4,521 to 16,635 acres and include: 1) South Fork Cedar (4,521 acres); 2) North Fork Cedar (6,388 acres); 3) Taylor Creek (10,950 acres); 4) Chester Morse Lake (11,548 acres); (5) Rex River (14,622 acres); (6) upper Cedar River (15,287 acres); and 7) lower Cedar River (16,635 acres). Hydrologic subdivisions within the 7 major tributary basins include 24 smaller tributary subbasins (minimum) that range in size from 322 acres (Damburat Creek) to 11,207 acres (lower Cedar River reach).

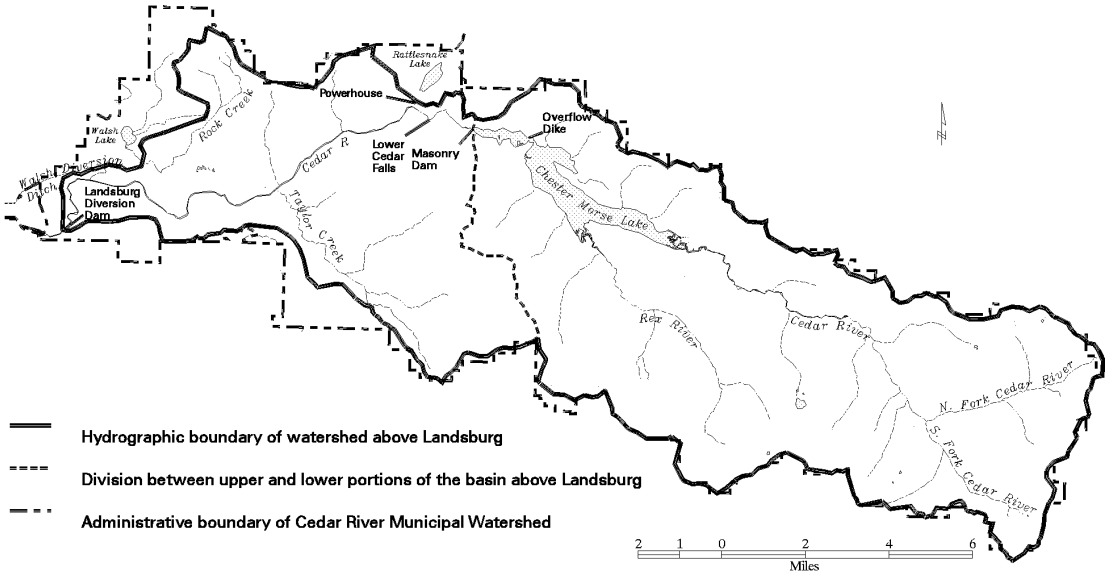
The Walsh Lake Ditch Subbasin is located immediately adjacent to the Upper Cedar River Subbasin and drains an additional 3,133 acres (2,981 acres City-owned; 152 acres non-City) to the Cedar River via the Walsh Lake Ditch. This major tributary drainage, however, does not contribute surface water drainage to the Upper Cedar River Subbasin, nor to Seattle's water supply system, because the ditch confluence with the mainstem Cedar River is located 2.2 miles downstream of the Landsburg Diversion Dam.

Virtually all of the surface drainage area of the Upper Cedar River Subbasin and the Walsh Lake Ditch Subbasin is within the 90,546-acre Cedar River Municipal Watershed that is managed by Seattle Public Utilities (SPU) as the major source of drinking water for the residents of the City of Seattle and much of the surrounding region (including 26 regional purveyors). Of the 90,546 acres of land and water within the municipal watershed, 82,443

acres (91 percent) drain directly to the Cedar River and 8,103 acres (9 percent) drain to adjacent hydrologic systems (e.g., Snoqualmie, Sammamish, and Raging rivers) (see Figure 42).

Since 82,433 acres (99.2 percent) of the surface area of the Upper Cedar River Subbasin and the Walsh Lake Ditch Subbasin are encompassed by the Cedar River Municipal Watershed, the habitat conditions described below are, with minor exception (651 acres), representative of these two major hydrologic subdivisions.

Figure 42. Upper Cedar River subbasin (from the Cascade Crest to Landsburg Diversion Dam).



The Cedar River Municipal Watershed is almost entirely forested with coniferous forest typical of the west slope and foothills of the central Washington Cascades. This forest covers approximately 85,477 acres (94.4 percent) of the municipal watershed, 71,588 acres of which has supported commercial timber harvest (mostly clearcut logging) during the last 120 years. The forests which exist within the watershed boundary today are a mosaic of varying seral stage forests ranging from recently harvested areas to native old growth (190-850 years) that reflect a history of multiple ownership, the spatial and temporal pattern of logging activity, and a varied history of forest regeneration, including natural regeneration, planting, silvicultural treatment, and to a limited degree, the effects of fire.

Of the forested area within the watershed (85,477 acres), 13,889 acres (16.2 percent) of unharvested, native old-growth forest remains. The second-growth forest is composed of 91 acres (0.1 percent) of late-successional forest (120-189 years), 1,074 acres (1.3 percent)

of mature forest (80-119 years), 54,592 acres (63.9 percent) of mid-seral, closed-canopy forest (30-79 years), 15,610 acres (18.3 percent) of early seral, open-canopy forest (0-29 years), and 222 acres (0.2 percent) has not been classified to age. Approximately 5,069 acres of land within the municipal watershed (5.6 percent of the total area) falls into non-forested classifications (e.g., wetlands, open water, talus, developed, etc.).

Table 34 provides a tabular summary of existing forest age within the municipal watershed (as of 1997) characterized in multiple-year intervals and Figure 1 (in Appendix C) depicts that age distribution over the landscape of the Cedar River Municipal Watershed (see below). The map also presents essentially a visual representation of when and where timber harvest occurred within the watershed during the past century. In these contexts, "old growth" is defined as unharvested forest greater than or equal to 190 years old.

Table 34. Cedar River watershed HCP, existing forest age[1]

Forested Stand Age (years)[2]	Lower[3] Watershed (acres)	Upper[4] Watershed (acres)	Total (acres)	Total (%)
0 - 9	1,037	900	1,937	2.1
10 - 19	600	5,435	6,035	6.7
19 - 20	669	6,969	7,638	8.4
30 - 39	2,323	5,281	7,605	8.4
40 - 49	3,179	7,588	10,767	11.9
50 - 59	3,239	3,231	6,470	7.1
60 - 69	11,417	6,462	17,879	19.7
70 - 79	11,094	777	11,871	13.1
80 - 89	950	0	950	1.0
90 - 99	99	13	112	0.1
100 - 119	12	0	12	0.0
120 - 189	91	0	91	0.1
Old growth (190 +)	734	13,155	13,889	15.3
Age undetermined	36	185	222	0.2
Subtotal	35,481	49,996	85,477	94.4
Non-forest and other landscape elements				
Non-forest	317	2,192	2,509	2.8
Developed	319	26	346	0.4
Open water	339	1,876	2,214	2.4
Subtotal	975	1,902	5,069	5.6
Grand total	36,456	51,898	90,546	100.0%

[1] Table modified from "Resource Maps for the Final Cedar River Watershed Habitat Conservation Plan", City of Seattle, April 2000.
[2] Based on 1997 as year of baseline age.
[3] Refers approximately to the area draining to the Cedar River downstream of the Masonry Dam.
[4] Refers approximately to the area draining to the Cedar River upstream of the Masonry Dam.

Figure 2 shows the existing age of forests in the Cedar River Watershed HCP area and can be found in Appendix C.

HISTORIC PERSPECTIVE AND MANAGEMENT OVERVIEW

The City of Seattle initiated land purchases within the Landsburg Drainage and Walsh Lake Drainage subbasins in 1889 after a major fire within the City exemplified the need to establish a reliable water supply. Subsequently, the City began diverting water from the Cedar River at Landsburg in 1901 to meet its municipal and industrial water supply needs. Today, the Cedar River is the primary source of drinking water (66 percent) for over 1.3 million people in the greater Seattle metropolitan and surrounding area.

The first hydroelectric generating station to serve Seattle's City Light Department is also located at Cedar Falls within the municipal watershed. The original system, constructed in 1904, included a wooden Crib Dam at the outlet to Cedar Lake (later renamed Chester Morse Lake), a woodstave penstock, and the powerhouse, which at the time provided a substantial portion of the electrical power needs for Seattle. After construction of the Masonry Dam (1915-1918), addition of a second turbine and penstock, and replacement of the original penstock, the plant continues to operate today, supplying the equivalent of about one percent of the City's electrical power demand.

Major components of the water and power supply systems include the Landsburg Diversion Dam (RM 21.8), the Cedar Falls Powerhouse (RM 33.7), the Masonry Dam (RM 35.7) that impounds about 1,982 acres at high pool elevation of 1560 feet, Masonry Pool (extending 1.5 miles from the lake outlet channel), and the Overflow Dike (replaced the Crib Dam in 1987) at the outlet to Chester Morse Lake. It is significant to note that since its construction in 1900, the diversion dam at Landsburg has completely blocked the upstream migration of anadromous fish.

During much of the last century what is now the Cedar River Municipal Watershed, although managed primarily as a drinking water supply source for the City, has existed under multiple ownership and been managed under cooperative agreements pertaining mostly to timber harvest, road construction and use, and land exchanges. Since the late 1890s, ownership of lands within the watershed has included homesteaders, railroads, private timber companies (e.g., Weyerhaeuser, Scott Paper), and government agencies (e.g., U.S. Forest Service). Several towns (e.g., Taylor, Barneston) and many logging camps were also present within the watershed. During the 20th Century, through the processes of condemnation, purchase, and land exchange, culminating with a major land exchange with the U.S. Forest Service in 1996, the City has gradually gained ownership and management control of virtually the entire hydrographic drainage of the Upper Cedar River Subbasin and the Walsh Lake Drainage Subbasin (see above).

Historically, management of the municipal watershed included its primary purpose, the supply of uncontaminated and high quality drinking water to Seattle, but also included the commercial production of timber and electrical power. In 1985, however, a moratorium was placed on commercial timber harvest on City-owned lands within the municipal watershed and in 1986 a 17-member panel (Watershed Advisory Committee), composed of

City personnel, private citizens, agency representatives, and members of environmental organizations, was appointed by the Mayor to examine existing management procedures, explore other uses of the municipal watershed, and make recommendations to guide the direction of future management of the municipal watershed.

The Watershed Advisory Committee met more than 30 times during the 2-year Secondary Use Analysis, reviewing past management policies, exploring alternative management options, soliciting public input, and developing a Draft Environmental Impact Statement (May 1988). After public review and comment, the Committee developed policies, adopted by the Seattle City Council in 1989 (Ordinance #114632) for future management of the Cedar River Municipal Watershed that affirmed the primary use of the watershed, to provide high-quality drinking water for the public, but also included general policies to guide management of seven secondary uses including: 1) long-term timber harvest; 2) wildlife and plant communities; 3) fisheries resources; 4) scientific research; 5) historic and cultural resources; 6) education; and 7) limited recreational opportunities. In an effort to preserve the high quality water supply, any unsupervised public access to the municipal watershed is prohibited except in limited areas that are outside the hydrographic drainage of the Upper Cedar River Subbasin (e.g., Rattlesnake Lake Recreation Area, Landsburg Park).

As implementation of the Secondary Use Policies proceeded during the early 1990s, issues concerning management of threatened and endangered species of fish and wildlife under the federal Endangered Species Act (ESA), relative to future operation of the City's water supply system and management of the municipal watershed, were identified. As a result, development of the City's Habitat Conservation Plan for the Cedar River Municipal Watershed (HCP) under Section 10 of the ESA (covering both listed and unlisted species) was initiated in 1992-93 and was completed by the City and signed by all signatory parties early in the year 2000.

The HCP is a 50-year agreement through which the signatories seek to provide regulatory certainty for both current operation and future planning related to the municipal water supply (storage in Chester Morse Lake and diversions from the Cedar River) and hydroelectric generating capability of the Cedar Falls system, while providing for the protection and conservation of fish and wildlife species, and their habitats, that may be potentially affected by normal operation of those facilities in the interest of the public.

This HCP is a multi-species, ecosystem-based plan that addresses 83 species of fish and wildlife that are found, or may potentially be found, within the Cedar River Municipal Watershed including spotted owls, marbled murrelets, common loons, bull trout, steelhead trout, and chinook and coho salmon, as well as many species of amphibians and invertebrates. The major elements of the 50-year HCP and effects that will specifically benefit all aquatic and riparian ecosystems include, but are not limited to, the following:

1. Elimination of timber harvest for commercial purposes within the watershed will virtually eliminate large scale habitat impacts, reduce the overall level of habitat

disturbance, and substantially reduce disturbance specifically resulting from road use associated with log hauling;

2. Because no commercial timber harvest will be conducted in the municipal watershed, all lands outside limited developed areas, including all aquatic and riparian ecosystem elements (forested and non-forested), are protected in reserve status;

3. Protection of all riparian forest, as well as all upland forest, with recruitment of substantial mature and late-successional forest over time in riparian and upland areas, will improve the habitat quality of forests associated with all streams, wetlands, and the reservoir complex and its tributaries;

4. Passage facilities for chinook salmon, coho salmon, steelhead trout, sea-run cutthroat trout, and bull trout (and possibly lamprey species) will be constructed at Landsburg to restore passage at the Landsburg Diversion Dam and allow these anadromous species limited access to 12.5 miles of high quality mainstem Cedar River habitat and approximately up to 9.7 miles of potential habitat in smaller tributaries (based on current distribution of resident salmonids) within the Upper Cedar River Subbasin in the municipal watershed;

5. Water supply intake structures at Landsburg will be screened specifically to exclude and prevent the impingement of outmigrating salmonids, especially juvenile fish;

6. Structures at stream crossings in the forest road system within the municipal watershed that impede fish passage (primarily culverts) will be removed, upgraded, or replaced to restore passage of both resident and anadromous species;

7. Seasonal flow levels specified in the HCP and designed to protect salmonid species during all life history stages will be maintained in the mainstem Cedar River, including the Canyon reach upstream of the Cedar Falls Powerhouse;

8. Continued closure of the municipal watershed to unsupervised public access will be maintained, thus essentially eliminating disturbance and/or mortality of fish and wildlife species resulting from recreational/sport activities (e.g., fishing mortality of salmonids);

9. The natural maturation of second-growth forests into mature and late-successional seral stages will reestablish more natural ecosystem function in aquatic and riparian system of the watershed;

10. Silvicultural treatments, such as restoration planting (about 1,400 acres), restoration thinning (about 11,000 acres), and ecological thinning (about 2,000 acres) will be designed to accelerate the development of natural functions in riparian forests (e.g., conifer underplanting) and mature, late-successional and old-growth structural characteristics in second-growth forests in some areas;

11. Instream habitat restoration projects, such as projects to retain and/or add large woody debris to deficient streams, are expected to improve microhabitat conditions (e.g., temperature regimes and instream habitat complexity) in many reaches;

12. Road improvements and decommissioning, and improved road maintenance, will reduce sediment loading to streams and other aquatic habitats;

13. Removal of approximately 240 miles of road (38 percent of present system) over the first 20 years (with the potential for additional road removal later), will thereby provide additional stream and forest habitat with reduced disturbance levels;

14. About 520 miles of road will be maintained per year at the start of the HCP, diminishing as roads are removed over time to about 380 miles per year at year 20;

15. Improvement (e.g., drainage to forest floor) will be made to about 4 to 10 miles of existing road per year (occasionally more in some years), reducing the potential for sediment input to streams; and,

16. Guidelines and prescriptions will be designed to reduce sediment production and delivery to aquatic systems during watershed management activities; and

17. A monitoring and research program to ensure compliance with the HCP, to determine effectiveness of mitigation, to identify trends in habitats and key species populations, to test critical assumptions in the plan, and to provide for flexible, adaptive management of conservation strategies.

The Upper Cedar River Subbasin has been divided arbitrarily at the Masonry Dam for the purposes of this subbasin summary. This point was chosen as it represents the point of regulation of flow from the Chester Morse Lake/Masonry Pool reservoir complex to the Cedar River downstream to Landsburg. The limit to upstream migration of anadromous fish is 2.5 miles downstream of the Masonry Dam at Lower Cedar Falls (RM 34.2). The Walsh Lake Diversion Ditch Subbasin, which is separate from the Upper Cedar River Subbasin and does not contribute flow to the water supply system, is discussed briefly in Section I-B below. Also, in the three major sections below, emphasis is placed on mainstem stream segments and tributaries that are of particular significance to the water supply system (e.g., flow volume, potential disturbance impacts), will be accessible to anadromous fish after passage is provided at Landsburg, or that have known populations of resident salmonids.

SECTION I-A: MASONRY DAM TO LANDSBURG DAM

ECOLOGICAL OVERVIEW:

Major Tributary Basin – Lower Cedar River

The Cedar River extends 14.0 miles upstream from the City of Seattle's water supply diversion dam at Landsburg near the western boundary of the Cedar River Municipal Watershed to the Masonry Dam at the outlet of the Chester Morse Lake/Masonry Pool reservoir complex. Two major valley segment types predominate in this 14-mile reach (see below). Presently, no anadromous fish can ascend the Cedar River upstream of the diversion dam at Landsburg, however, prior to construction of the dam in 1901, they could potentially migrate the 12.5 miles of the mainstem upstream to the anadromous barrier at Lower Cedar Falls (RM 34.2). Restoration of access for several anadromous species to this mainstem reach, as well as approximately 9.7 miles of potential tributary habitat is one of the provisions of the HCP (see below).

The 12-mile section of the mainstem Cedar River upstream from the Landsburg Diversion Dam (RM 21.7) to the Cedar Falls Powerhouse (RM 33.7) is characterized by a low gradient channel, associated with a narrow floodplain where valley bottom widths range from 1-2 times the active channel width. The channel is moderately confined by narrow, discontinuous alluvial terraces. Boulders are a common constituent of the sideslope and channel bottom matrix in localized reaches. Channel substrates are typically large and less than 5 percent of the active channel area is comprised of channel bars. Step pool channels dominate this section, although reaches dominated by plane-bed pocket water are also common (Foster Wheeler, 1995). Holding habitat is provided by deep, bedformed pools and large boulder cluster create channel large, deep pocket waters for cover. Spawning areas are abundant, associated with glide waters, pool tails, and channel margins and gravel deposits rarely embedded or compacted. Concentrations of large woody debris are limited and off-channel habitats are rare and open to direct surface flows during periods of high water (Foster Wheeler Environmental Corporation 1995).

The 2-mile section of the mainstem Cedar River upstream of the Cedar Falls Powerhouse (RM 33.7) to the Masonry Dam (RM 35.7) is characterized by a bedrock dominated, tightly confined canyon (Canyon Reach) in which gradients range from 4-10 percent and channel substrates are composed mainly of large boulders, boulders, and large cobble with bedrock outcrops scattered throughout (Foster Wheeler Environmental Corporation 1995). Boulder cataract and step pool channel morphology predominates, with large boulder clasts providing the primary roughness elements. Large sized substrate characterizes the channel in this section. High gradient and tight confinement of this section limits the development of extensive spawning areas. Pool tails of the large channel spanning pools, however, have localized potential spawning habitat (Foster Wheeler Environmental Corporation 1995). Relatively large numbers of young of the year rainbow trout have been observed by SPU personnel in this reach downstream of Lower Cedar Falls, a reach that will be accessible to anadromous species in the future under provisions of the HCP. Channel spanning clasts of boulders and bedrock constrictions provide the dominant structural elements forming pools

and steep step pools are common. Upstream migration barriers to both juvenile and adult fish are frequent, in the form of steep cascades, bedrock chutes and waterfalls. Upstream migration of all species is blocked at Lower Cedar Falls (RM 34.2) within this section of the mainstem.

Several major tributary basins drain to the mainstem of the Cedar River between the Landsburg Diversion Dam and the Masonry Dam, including Rock Creek (2,917 acres) (08.0345) at RM 23.9, Williams Creek (1,564 acres) (08.0377) at RM 29.6, and Steele Creek (788 acres) (08.0379) at RM 31.7 on the north side and the largest, Taylor Creek (10,950 acres) (08.0351) at RM 29.5 on the south side. Because of its large drainage area, Taylor Creek provides substantial flow, approximately 15 percent (about 100 cfs annually), to the lower Cedar River and consequently to the water supply system (Hart Crowser 1983).

Rock Creek, Williams Creek, and Steele Creek will be accessible to anadromous fish after fish passage is restored at Landsburg. Each of these tributaries is situated mostly in the glacio-fluvial terrace terrain that characterizes much of the lower municipal watershed. Very few significant changes in the channel conditions of these tributary streams were evident during review of historic photos.

The Rock Creek basin, with a drainage basin of 2,917 acres, is the largest of these systems. The basin ranges in elevation from 570 feet at the confluence with the Cedar River 2.0 miles upstream of Landsburg to approximately 2,600 feet at a large, headwater, wetland complex on Brew Hill in the northwest corner of the municipal watershed. The majority of the drainage occurs within the rain-on-snow (37 percent) and snow-dominated (36 percent) zones. Channel gradients in headwater and upper reaches are moderate, ranging from 8 to 20 percent and associated with narrow inner gorges. Mid-stream reaches are typically incised as much as 70 feet, characterized by gradients of 4-8 percent and step-pool and boulder cataract channel types with large boulders and large woody debris in the channel adding roughness and playing a major role in development of channel morphology. Southeast of Walsh Lake, the Rock Creek channel is low gradient, unconfined, substantially widened, and flows through a series of wetland complexes. This segment acts as a natural depositional zone, is highly sinuous and locally braided, and bank cutting along with extensive gravel bars and seep channels being common. The channel bed is dominated by gravels and fine sediment areas are common in low velocity reaches. Substantial amounts of large woody debris are present and beaver activity has significantly influenced the channel structure. Spawning sites for smaller size resident trout are common in the lowest reaches of Rock Creek with spawning and rearing sites and over-wintering areas for both small and large salmonids becoming more available in middle reaches, especially associated with off-channel ponded areas and beaver ponds. Habitat availability and quality decrease in both upper and headwater reaches (Foster Wheeler Environmental Corporation 1995).

The Williams Creek subbasin (1,564 acres) has its headwaters at the highest level of the glacio-fluvial terrace, and has incised most of its length through glacial outwash and drift, in some places to the level of bedrock formation. The stream corridor morphologies of

Williams Creek are similar to those of the Rock Creek drainage with the exceptions that the major wetland influenced channel types are at the headwaters of the system, little evidence of accelerated sediment transport is evident from upper reaches, and stream power developed from peak flow events appears to be considerably less than that of Rock Creek (Foster Wheeler Environmental Corporation 1995). Cutthroat trout currently utilize the entire system to the level of the headwater wetland complex. An impassable barrier is reported to occur in the upper middle reach.

The Steele Creek subbasin (788 acres) also has its headwaters in bedrock formations and has cut through the glacio-fluvial terrace before reaching the Cedar River, but differs substantially from Rock Creek in basin size and subsequent lower stream power. Stream corridor morphology is similar to the high gradient, tightly confined channels of Rock Creek, however, the headwater reaches of Steele Creek show less evidence of inner gorge landslides or proliferation of accelerated sediment transport into the lower fish bearing reaches. Unlike Rock Creek, there are no large wetland complex channels in the Steele Creek subbasin. Despite high gradients, fine sediment is a common part of the channel bed matrix, owing to the geologic surface over which the channel flows. Despite the high gradients, cutthroat and/or rainbow trout currently utilize the stream to middle reaches (Foster Wheeler Environmental Corporation 1995). A seasonal flow barrier (subsurface flow) exists annually in Steele Creek immediately upstream of the confluence with the Cedar River during the driest summer/fall period.

Major Tributary Basin – Taylor Creek

The Taylor Creek subbasin, situated on the south side of the mainstem Cedar River, includes the South (08.0368), Middle (08.0351), and North (08.0355) forks of Taylor Creek, as well as Seventeen Creek (08.0352) and Sandy Creek. Because of its relatively large size (10,950 acres), elevation gain, and history of both natural and human caused disturbance regimes, the Taylor Creek subbasin exhibits a broad range of valley segment types and the most varied channel morphologies of tributaries to the lower Cedar River within the municipal watershed. As is the case for northern tributaries described above, the mainstem of Taylor Creek and the secondary tributary channels of Seventeen Creek and Sandy Creek, are almost entirely within the glacio-fluvial terrace deposits associated with the continental glaciers. The general characteristics of the secondary channels include generally moderate to high gradients, narrow box canyon inner gorge reaches, occasional small, inner gorge slope failures, and groundwater seepage commonly from mid-slope of 20-30 foot deep inner gorges. Substrates are characterized by gravels and cobbles, despite the relatively high gradients of the secondary channels, although sand is also common in bed substrate. Flows in this type of channel may be shallow or ephemeral and concentrations of wood tends to deepen pools and elongate steps (Foster Wheeler Environmental Corporation 1995).

The mainstem of Taylor Creek is characterized by two distinct segment types. The lower 2,000 feet has incised into the glacial deposits, the stream corridor is tightly confined and bordered by unconsolidated glacial material, and large boulders are common in the sideslope and channel bottom matrix. Valley bottom slope exceeds 8 percent gradient in

this reach and the channel is typified by step-pool and boulder cataract features. Deep, channel-width pools formed by boulder steps or clusters of large boulder constrictions are common (Foster Wheeler Environmental Corporation 1995). Fish passage is restricted to all except the lowest section of this reach, and consequently all other upstream reaches, by a natural waterfall migration barrier 0.2 miles upstream from the mainstem Cedar River.

In contrast, the upstream reach of the Taylor Creek mainstem is characterized by a low to moderate gradient channel and a narrow floodplain. Channel gradients typically range from 2 to 4 percent and the valley width ranges from 1 to 3 times the active channel width. The majority of this reach is bordered by alluvial terraces and boulders are common in localized reaches in the sideslope and channel bottom matrix. The channel is large and slightly sinuous with point and lateral bars developed where channel confinement decreases. Lateral shifting of the channel is apparent in several sections and channel substrates are typically composed of small and large cobble material (Foster Wheeler Environmental Corporation 1995).

An aerial photo assessment of the mainstem and secondary tributaries (Seventeen Creek) of the Taylor Creek subbasin, (does not include the forks), indicates substantial change has taken place within these two lower reaches since timber was harvested in this area 60-70 years ago (see below). Localized high water tables and channel migration in these mainstem reaches have influenced forest regeneration substantially, especially immediately adjacent to the stream channel, and resulted in a diverse pattern of coniferous and red alder dominated deciduous forest in riparian zones. Large flood events in January 1965 (largest on record) and in November 1990 have also had substantial influence on the channel configuration. Evidence of dramatic channel widening and braiding, considerable delivery of sediment from upper subbasins, debris flows, mass wasting events, and repeated remobilization of sediment (e.g., migration of bars, alder regrowth) is present throughout these mainstem reaches. Some channel widening and minor inner gorge bank sloughing is evident in the Seventeen Creek corridor (Foster Wheeler Environmental Corporation 1995).

The North Fork Taylor Creek subbasin has formed along the interface of the glacio-fluvial terraces of the lower watershed and the central Cascade mountainous terrain to an elevation of approximately 2,850 feet in headwater reaches. A majority of the drainage occurs within the rain-on-snow (45 percent) and snow (39 percent) zones. Channel gradient in the relatively steep upper elevation reaches typically exceeds 15 percent, whereas in the 2.0 mile reach immediately upstream of the confluence gradient averages 4 percent. The drainage pattern is dendritic, more developed than other basins in the municipal watershed, and with the Middle Fork, may be unique due to its unique geologic history, which may include a lack of alpine glaciation during the most recent glacial epoch (Foster Wheeler Environmental Corporation 1995). Effects of debris torrents, channel widening, sediment deposition and storage, and periodic re-mobilization of sediment are all evident in this subbasin.

Three broad geomorphologic zones are represented within the North Fork drainage. The dendritic network of incised channels in tributary headwater reaches are high gradient,

most exceeding 20 percent, and associated with narrow inner gorges. Debris flow deposits in some areas indicate long-term debris flow activity. Stream channels are commonly steep and stairstepped, occupy narrow, confined valleys, and flows are generally shallow and ephemeral. Hillslope terraces, large boulder clasts, large woody debris and bedrock form steps in the otherwise consistently steep channels. The mid-drainage, mainstem reach is moderate gradient and acts as a depositional zone for material derived from steep headwater and other tributary branches, as evidenced by the presence of coarse-grained alluvial fans in which flows periodically go subsurface during seasonal low flow periods. Widespread channel aggradation, widening, and meandering is evident. The channel is braided in isolated reaches, split channels are common, both point and lateral gravel bars are present, and channels have shifted recently. Seep channels and intergravel flow are evident and large accumulations of woody debris that plays a critical role in channel roughness are also present.

The lower 1.3 mile reach of the North Fork mainstem transverses a gently sloping outwash and ice-contact glacial terrace, and exhibits two distinct corridor segments: 1) a channel deeply incised (up to 70 feet) and confined in an inner gorge in the lowest portion of the reach upstream of the confluence with the Taylor mainstem; and 2) a channel in the upper portion of the reach that exhibits little channel incision into the glacial terrace, but that has incised 3 to 8 feet into floodplain or outwash deposits. In the downstream segment, the valley bottom slopes range between 4 and 6 percent, large boulders are common, the channel is typified by step-pool and boulder cataract types, deep, channel-wide pools are common and large woody debris is abundant in some reaches, although it appears typically to play only a minor role in controlling channel morphology (Foster Wheeler Environmental Corporation 1995). In the moderately confined, upstream segment, however, large woody debris has played a crucial role in development of channel complexity. Channel material consists mainly of gravel, with small cobbles a common component in the faster current riffles. Fine sediment is abundant in velocity shadows of margin alcove pools. The stream segment is characterized by forced-pool riffle channels. Substantial amounts of large woody debris have resulted in complex arrangements of bars and associated pools and riffles and wood obstructions are essential for initiating pool scour (Foster Wheeler Environmental Corporation 1995).

The Middle Fork of the Taylor Creek subbasin is similar to the North Fork in its location relative to geologic formations, its dendritic configuration in steep, confined headwater segments, and similar moderation of gradient after reaching lower glacial terrace deposits. In contrast, however, the Middle Fork headwaters emanating from the south exhibit lower gradient hillslopes, the channels have incised into deep seated earth flows in lower reaches, and inner gorge landslides are common within these deeply incised segments. Channel gradients are relatively low and little floodplain confinement is evident in lower segments of the mainstem Middle Fork. Unlike the North Fork, however, the channel has not incised into the glacial terrace, or been confined, in the lowermost segment. The channel is unconfined and low gradient as it flows across a wide alluvial terrace to the confluence with the South Fork Taylor Creek (Foster Wheeler Environmental Corporation 1995). Effects of inner gorge failures, mass wasting, debris avalanches, debris flows, substantial channel widening, sediment deposition and storage, and frequent re-mobilization of

sediment are all evident in this subbasin. Major effects including channel widening, shifting, braiding, and avulsion are especially evident in lowermost segments.

The South Fork of the Taylor Creek subbasin is similar to the lower one-third of the North Fork drainage. The South Fork mainstem is located in a U-shaped trough similar to the mid-segment of the North Fork. In contrast to the North Fork, however, the South Fork headwater segments do not exhibit evidence of inner gorge landslides or proliferation of debris flows in mountainslope tributaries. The lowermost stream segment upstream of the confluence with the Taylor mainstem is low gradient and is minimally confined. Channel gradients of the steep mountainslope tributaries on the north moderate in lower reaches on the mountain footslopes, whereas tributaries to the south exhibit shallow incision and maintain high gradients. Some evidence of channel widening and a small debris slide associated with a forest road is apparent. Tributary debris flow activity and flood flow disturbance, however, were not detected in the South Fork drainage system (Foster Wheeler Environmental Corporation 1995).

Because relatively little commercial timber harvest has been conducted in low elevation sections of the municipal watershed since the early to mid-1990s, especially within the Cedar River riparian corridor, virtually the entire 14-mile reach of the Cedar River mainstem between Landsburg and the Masonry Dam is bordered by mid-seral, closed canopy stage second-growth coniferous forest (30-79 years old) with the 60-69 and 70-79 year old age classes predominating. Only very few short reaches support forests less than 30 years old and forests less than 20 years old is present adjacent to, or in close proximity to the mainstem, at only two sites. Patches of mixed conifer/deciduous or deciduous forest are present immediately adjacent to some reaches of the mainstem, particularly where disturbance to streambanks or drainage from slopes is poor. Mature coniferous forest (80-119 years old) is present along at least one bank through a 1.0-mile reach of the mainstem immediately upstream of the Landsburg supply and treatment facilities. Notably, many large Sitka spruce that represent a specific potential for large woody debris recruitment to the mainstem are present adjacent to the river and dispersed along the corridor from Landsburg to Cedar Falls (approximately 12 miles). These Sitka spruce are thought to have originated in 1932 during the period when the City planted 30,000 conifer trees along stream segments in the Cedar River Watershed, presumably to replace alder which was deemed undesirable because of it's heavy leaf drop and potential adverse effects on water quality.

Forest vegetation adjacent to most reaches of tributary streams in the lower elevation sections of the subbasin has also recovered substantially from the effects of historic logging activity, and as is the case for the mainstem, the tributaries currently flow through mid-seral, closed canopy stage second-growth coniferous forest, mixed conifer/deciduous, or deciduous forest types (30-79 years old) with 60-69 and 70-79 year old age classes predominating. Of the northern tributaries, upper Rock Creek flows through predominately 70-79 year old forest with the lower 2.5 miles flowing through younger, 40-49 year old forests. Williams Creek is border by 70-79 year old forest in upper reaches and by 60-69 year old forest in lower reaches near the confluence with the Cedar River. Steele Creek flows through mostly 60-69 year old age class forest throughout its length.

The major southern subbasin, Taylor Creek, because of its relatively large size (see above), elevation gain, and resultant harvest history, currently presents a more diverse pattern of second-growth forest age class distribution within the basin as compared with other lower elevation drainages in the Upper Cedar River Subbasin. The mainstem of Taylor Creek is bounded on the north by predominately 70-79 year old forest and on the south alternately by 60-69 and 50-59 year old second growth. The South Fork flows through 70-79 year old second growth over most of its length, whereas the Middle and North forks flow through forest representing several age classes with the youngest classes in upper and headwater reaches. Seventy to seventy-nine year old forest predominates in lower to mid- reaches of both the Middle and North forks. Forest in mid- to upper and headwater reaches of the Middle Fork are characterized by 40-49 year old age classes. Forest in mid- through headwater reaches of the North Fork exhibit the broadest range of age class variation with 70-79 (south) and 40-49 year old second growth (north) in mid-reaches grading to a mosaic distribution of 50-59, 40-49, and 30-39 year old forest in headwater reaches of the drainage.

Salmonid Populations: The resident fish population in the section of the mainstem Cedar River from the Landsburg Diversion Dam to the Masonry Dam is dominated by rainbow trout with cutthroat trout *(O. clarki)* as a subdominant component of the population (approximately 1 percent). In the tributaries north of the mainstem, however, cutthroat trout appear to be predominant with rainbow trout as a secondary component to the population. In addition, hybridization between rainbow and cutthroat trout is readily apparent in these northern tributaries. In contrast, Taylor Creek appears to support mainly a cutthroat trout population with more limited rainbow influence. When passage for anadromous fish is restored to the reaches upstream of Landsburg, all of the tributaries to the north of the Cedar River will be accessible, but only the lower 0.2 mile of the Taylor Creek system will be accessible because a natural barrier (falls) blocks further access.

MAJOR CURRENT ACTIVITIES:

Cedar River Watershed Habitat Conservation Plan (HCP)

As part of developing the HCP, agreements were negotiated with a number of parties to resolve issues concerning river flows below Masonry Dam, fish passage at Landsburg, and other mitigation measures. As a result, the HCP includes provisions to allow re-introduction of federally threatened chinook *(O. tshawytscha)* along with coho salmon *(O. kisutch*), and steelhead trout *(O. mykiss)* to the 12.5-mile reach between Landsburg (RM 21.7) and Lower Cedar Falls (RM 34.2). Fish of these three species ascending the Cedar River will gain access to the reach upstream of Landsburg by means of fish passage facilities that will be installed at the pipeline crossing the Cedar River immediately upstream of the Issaquah/Hobart road bridge and at the Landsburg Diversion Dam. Sockeye salmon (*O. nerka)*, however, will not be passed upstream at Landsburg because the large number of fish in spawning runs, and the resultant volume of carcasses releasing nutrients to the Cedar River upstream of the supply system intake could potentially cause degradation of water quality. Sockeye will continue to be propagated at Landsburg in an

expanded hatchery facility and fry will be released downstream to rear in Lake Washington before entering Puget Sound.

Priority Chinook Needs

Within the Upper Cedar River Subbasin, the priority need for chinook salmon is access to additional high quality spawning and freshwater rearing habitat. The addition of fish passage facilities at Landsburg will provide access for chinook to 12.5 miles of the mainstem Cedar River, thereby restoring access to the natural historic range of this species in the upper Cedar River.

Other Major Issues

Large Woody Debris Management Plan (mainstem Cedar River upstream of Landsburg):

The objectives of the plan for the Cedar River between Cedar Falls and the Landsburg Diversion Dam are to maintain drinking water quality, personal safety, and the integrity of river crossings and Landsburg facilities, while optimizing the amount of large wood in the Cedar River to improve fish habitat and promote more natural stream functions. The plan will be initiated in year one of the HCP and includes the following major elements:

1. Monitoring of current conditions once per year.
2. Assessing stability of pieces during high flow events.
3. Repositioning and securing pieces whenever feasible and safe.
4. Assessing log jams relative to the potential for controlled breaching.
5. Breaching log jams to prevent unacceptable bank scour and greater turbidity.
6. Removal of wood from facilities to preserve structural integrity and safety.

Section I-B: Walsh Lake Ditch Subbasin

ECOLOGICAL OVERVIEW

As indicated above, the Walsh Lake Ditch (08.0341) Subbasin is located immediately adjacent to the Upper Cedar River Subbasin in the northwest portion of the municipal watershed, draining 3,133 acres (2,981 acres City-owned; 152 acres non-city) to the Cedar River via the Walsh Lake Ditch. This subbasin, however, does not contribute surface water drainage to the Upper Cedar River Subbasin, nor to Seattle's water supply system, because the ditch confluence with the mainstem Cedar River is located 2.2 miles downstream of the Landsburg Diversion Dam.

The subbasin includes two small tributaries, Webster Creek (08.0341)and Hotel Creek (08.0342), which drain into Walsh Lake (68 acres). Flow exits Walsh Lake in a natural channel for approximately 0.5 mile before entering the channelized reach, the Walsh Lake Diversion Ditch, near the stream's historic point of confluence with Rock Creek (08.0345). Flow typically continues from this point an additional 2.6 miles (approximate) westerly

through the municipal watershed, exiting at the western boundary under the Issaquah-Hobart Road and continuing to the Cedar River (2.2 miles downstream of Landsburg Diversion Dam). An emergency control structure is located on the ditch near the point of historic confluence with Rock Creek. This structure allows a portion of ditch flow to be temporarily diverted to Rock Creek during peak flow events that if not diverted, could potentially compromise the ditch levee, thereby causing adverse impacts to Rock Creek and the water supply system.

The lower reach of the Walsh Lake Diversion Ditch (RM 0.0–0.18) is characterized by gently sloping bank topography and vegetation dominated by deciduous forest with dense underbrush. The major habitats in this lower reach are pocket water, high– and low–gradient riffles, and only a few pools that are absent of any LWD. Although surface substrates range from small gravel to small boulders, cobble–sized rocks dominate. There are a number of locations in which the channel is poorly defined and meanders from year to year through different sections of the riparian forest (K. Kurko, personal communication). Evidence of meandering in the recent past includes the presence of several well-vegetated gravel bars outside of the present channel, indicating that habitat formation is still very dynamic (King County, 1993). Gravel deposits on the sediment fan in this reach are very permeable, and combined with the poorly defined channel, may be two factors that predispose this section of stream to go dry during low flows.

Upstream from the diversion channel's mouth, the gradient rises steeply. This high–gradient reach of the Walsh Lake Diversion Ditch (RM 0.18–0.65) is typified by steep, generally unvegetated and eroding soil banks up to 40 feet high. These features indicate the extent of channel downcutting since flows were first diverted over the edge of the valley (King County, 1993). Despite this instability there is some good pool habitat formed by LWD that has fallen into the channel. This LWD is also serving to create a stair–step channel profile and to stabilize and store sediments. A relatively high percentage of boulder and cobble substrates are providing a basic level of streambed and habitat stability (King County, 1993).

Forest vegetation in the Walsh Lake Ditch Subbasin is virtually as described for the Upper Cedar River Subbasin in Section I-A above with the exceptions that 1) the townsite of Taylor (coal and clay mining) and activities associated with homesteading were more concentrated in this smaller subbasin and more clearly evident in vegetation communities in some specific areas and 2) forest tracts in substantially older age classes, including old growth (greater than 190 years old), are present. Lower reaches of Webster Creek flow through 60-69 and 80-89 year old forest, mid-reaches through 70-79 year old forest, upper reaches through 80-89 year old forest, and headwater reaches flow through old-growth forest greater than 190 year old. Virtually the entire length of Hotel Creek is surrounded by 70-79 year old second-growth forest.

Salmonid Populations

The Walsh Lake Ditch Subbasin drainage system exhibits the greatest diversity of fish species of all the major and minor drainage basins in the City of Seattle municipal

watershed. Resident salmonid species include cutthroat trout throughout Webster and Hotel creeks, in Walsh Lake, and in the Walsh Lake Diversion Ditch. A kokanee population of unknown size and origin is present in Walsh Lake and spawning activity has been observed in Webster Creek upstream to the first forest road stream crossing.

Because the Walsh Lake Diversion Ditch joins the Cedar River downstream of the Landsburg Diversion Dam, portions of this relatively small subbasin are, to some degree, accessible to an unknown number of anadromous fish, at least during some years and under certain flow conditions. The lower reach of this channel downstream of the Cedar River Municipal Watershed is reported to support coho, sockeye, and chinook salmon, as well as steelhead trout (King County 1993). A partial fish barrier in the Walsh Lake Diversion Ditch downstream of the municipal watershed's western administrative boundary blocks migrating sockeye salmon, however, some coho salmon are able to pass and have been observed occasionally, in relatively small numbers, in the Walsh Lake Diversion Ditch above this point, including some spawning activity in the lower reaches of Webster Creek (downstream of forest road).

Other non-salmonid species known to be present in Walsh Lake include largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), and northern squawfish (*Ptychocheilus orgeronensis*), and downstream of Walsh Lake and in the Walsh Lake Diversion Ditch, largemouth bass, riffle sculpins (*Cottus gulosus*), torrent sculpins (*Cottus rhotheus*), redside shiner (*Richardsonius balteatus*), and speckled dace (*Rhinichthys osculus*). Riffle and torrent sculpins are also present in Webster Creek, however, only riffle sculpins have been found in Walsh Lake itself. Western brook lamprey (*Lampetra richardsoni*) are also present and known to spawn in Webster Creek.

Other Major Issues

Walsh Lake Diversion Ditch Rehabilitation

The City of Seattle and King County have each committed $270,000 toward stream and habitat rehabilitation projects within the Walsh Lake Ditch Drainage Subbasin.

Section II- - Cascade Crest to Masonry Dam

ECOLOGICAL OVERVIEW

The reservoir complex, including the Masonry Pool (187 acres) and Chester Morse Lake (1,537 acres) extends approximately 6.6 miles upstream from Masonry Dam to the eastern extent of the willow dominated vegetation zone on the Cedar River delta when lake level is at an elevation of 1,555 feet. (approximately 7 feet below maximum operating level). Masonry Pool extends approximately 1.4 miles upstream from Masonry Dam to the Overflow Dike and Chester Morse Lake extends approximately 5.2 miles further eastward from the Overflow Dike. Lake and Pool levels are controlled by adjusting flows released through the Overflow Dike and Masonry Dam, respectively. As the Overflow Dike is currently configured, the two bodies of water are joined at surface elevations greater than

1550 feet (typically during late spring refill prior to summer drawdown) because water flows over the dike unrestricted to the Pool. At surface elevations less than 1550 feet, levels in the Pool can be adjusted independently of the level of Chester Morse Lake (typically during summer and early fall drawdown periods).

The current management operations of Chester Morse Lake can result in a maximum elevation change of approximately 30 feet from the normal spring operating level (1,562 feet; full pool) to the gravity flow drawdown limit of 1,532 feet. Typical annual fluctuations under normal operating conditions are between 22 and 26 feet. During severe droughts or system emergencies, a substantial amount of water remaining in Chester Morse Lake below the outlet elevation at approximately 1,532 feet (i.e., dead storage) can be accessed using temporary pumps mounted on barges anchored in the relatively deep, southwest corner of the lake. The maximum depth of Chester Morse Lake is approximately 137 feet (lake elevation 1563 feet) near its center, west of Little Mountain. Masonry Pool levels can fluctuate as much as 70 feet from the normal spring operating level, although the normal annual fluctuation is approximately 30-35 feet. At its lowest level, Masonry Pool is essentially a flowing channel. Surface elevations in Chester Morse Lake and Masonry Pool may, however, approach 1,570 feet during severe storm and runoff events in fall and winter seasons with subsequent annual fluctuations being substantially greater than under normal conditions.

Approximately 60 percent of the water draining from upper watershed subbasins into the reservoir complex leaves the system through the Masonry Dam tunnel and penstocks, drops 600 feet in elevation, flows through turbine generators at the Seattle City Light powerhouse at Cedar Falls, and subsequently returns to the Cedar River at RM 33.7. The remaining 40 percent leaves the reservoir as seepage, largely through the glacial moraine situated at the outlet of Chester Morse Lake (north to Mt. Washington) and along the north shore of Masonry Pool. Most of this seepage is returned to the Cedar River west and downstream of Cedar Falls as groundwater, local tributary streams, and springs. About 12 percent of the water leaving the reservoir in this manner, however, flows to the Snoqualmie River basin as seepage, as overflow from Rattlesnake Lake, or by way of Boxley Creek.

Major Tributary Basin – Chester Morse Lake

In contrast to the mainstem Cedar River downstream of the Masonry Dam, all tributaries that drain directly to the reservoir complex, including the Cedar and Rex rivers, or that enter the Cedar and Rex rivers upstream of Chester Morse Lake are characterized by natural flow regimes, modified only by the effects of past logging activities, forest roads, and in some areas, abandoned railroad beds. These effects include, but are not necessarily limited to, reduced volumes of large woody debris, increased sediment inputs, active bedload movement, and in some areas, segmentation from anthropogenic barriers (e.g., stream crossing structures).

The stream corridors of McClellan (08.0418), Green Point (08.0417), Otter (08.0395), and Damburat (08.0394) creeks draining directly to Chester Morse Lake from the north, and Roaring Creek (08.0424) to the east draining to the mainstem Cedar River, are

characterized generally by very steep and tightly confined valley wall and headwater channels over most of the stream corridors that moderate, in most cases, to gradients between 4 and 10 percent only in relatively short, lower reaches where the channels cross mountain footslopes and alluvial deposits near their confluences with Chester Morse Lake or the river (Foster Wheeler Environmental Corporation 1995). With the possible exception of Roaring Creek, each of these tributaries exhibits ephemeral and/or subsurface flow annually in some reaches during driest summer/fall periods, especially in segments immediately upstream of their confluences with the reservoir.

McClellan Creek is a high gradient valley wall tributary, originating near the ridge crest separating the Cedar River and Snoqualmie River watersheds, that extends over a vertical relief of nearly 3,300 feet. McClellan Creek is characterized mostly by tightly confined channels with consistently steep sideslopes and gradients generally exceeding 20 percent, including in the mainstem except near the confluence. Only 0.2 mile of the stream, in lower segments, exhibits gradients less than 8 percent. The basin is situated almost entirely in volcanic and volcaniclastic geologic formations. More than 70 percent of the drainage basin lies within the highland and rain-on-snow zones that accumulate 4 feet or more of snow annually. Most of the channel reaches are considered sediment transport reaches or, in some areas, also appear to serve as source reaches. Bedrock scour and boulder contact channels are common in the upper basin. Large woody debris appears to play only a minor role in controlling channel morphology. Material delivered through mass wasting, debris avalanches, tree uprooting, and small inner gorge failures is evident in depositional reaches in many upper stream segments. Deposition of coarse sediment is evident in the mainstem segment immediately downstream of the segment containing secondary tributaries, presumably resulting from a high magnitude flood or debris flow prior to 1958. Steep, stairstepped and boulder cataract conditions dominate this mid-channel segment. Also, channel avulsion has also led to the formation of two channels in this segment. The lowest channel segment is shallowly incised into a coarse-grained alluvial fan and is confined through entrenchment into a large cobble/boulder matrix. The channel is also characterized by step-pool conditions that exhibit channel spanning bars of boulders and large cobbles forming a series of steps followed by channel width pools. Large woody debris acts to increase channel complexity and to increase scour depth of pools. Nearest the reservoir, the channel assumes a forced-pool characteristic, is comprised of mainly cobbles and gravel, and wood is the key roughness element initiating scour. An alluvial cone is present at the reservoir confluence (Foster Wheeler Environmental Corporation 1995). Effects of episodic debris torrents, debris flows and small landslides associated with forest roads, recurring flood events, minor debris avalanches, channel widening, temporary sediment storage, and continuing downstream sediment transport are all evident in specific areas of this subbasin.

The stream corridor conditions in Otter Creek are similar to those described above for McClellan Creek except that the gradient remains steep throughout the stream course to its confluence with Chester Morse Lake. The stream gradient moderates immediately upstream of confluence with lake, becoming less than 10 percent where it flows across an historic alluvial cone deposit. A debris flow 1.0 mile upstream from the confluence

appears to have played a major role in shaping channel morphology in lower stream reaches (Foster Wheeler Environmental Corporation 1995).

The stream corridor conditions in Green Point Creek are also similar to those described above for McClellan Creek except that the gradient remains steep throughout the stream course to within approximately 500 feet of its confluence with Chester Morse Lake. The stream gradient moderates in that 500-foot segment, becoming less than 10 percent where it flows across an historic alluvial cone deposit. A debris flow 1.2 mile upstream from the confluence appears to have played a major role in shaping channel morphology in lower stream reaches (Foster Wheeler Environmental Corporation 1995).

The stream corridor conditions in Damburat Creek, especially in upper segments, are also similar to those described above for McClellan Creek, except that the stream gradient moderates in lowest reaches, becoming less than 4 percent where it flows across mountain footslopes, alluvial deposits, and the alluvial cone at the confluence with Chester Morse Lake. Episodic debris torrent events appear to have played a major role in shaping channel morphology in lower stream reaches (Foster Wheeler Environmental Corporation 1995). Effects of such episodic debris torrents, debris flows and small landslides associated with forest roads, and recurring flood events are all evident in specific areas of this subbasin. Extensive beaver activity and associated structures are evident near the lake confluence.

The stream corridor conditions in Roaring Creek, especially in upper segments, are similar to those described above for McClellan Creek and channel gradients exceed 10 percent. The mainstem channel moderates in lower segment, however, the lowest 50-foot reach immediately upstream of the confluence drops very steeply to the mainstem Cedar River and constitutes a permanent barrier to upstream passage of fish. In addition, flooding or mass wasting in the upper basin has resulted in channel avulsion, leaving one notable relic channel that flows parallel to and west of the current main channel for nearly 600 feet to its confluence with the Cedar River floodplain (Foster Wheeler Environmental Corporation 1995).

The stream corridor of Rack Creek (08.0399) is representative of tributaries draining directly to Chester Morse Lake from the south, including secondary tributaries, Shotgun Creek (08.0404) and Echo Creek (08.0402). Rack Creek is based in volcanic geologic formations and is characterized generally by steep topography throughout a dendritic drainage pattern that extends through 2,800 feet of elevation gain above the reservoir. A majority of the valley segments in Rack Creek exceed 20 percent gradient and less than 0.5 mile of the stream, mostly near the confluence with the reservoir, exhibits a gradient less than 8 percent. Alluvium, derived mostly from alluvial fans emanating from steep first order drainages, underlies the lower 0.5 mile of the mainstem of Rack Creek. Debris avalanches and debris flows are the dominant form of mass wasting/erosion in the upper one half of the drainage. The lower half of the drainage is dominated by both mass wasting and fluvial erosion. Shallow rapid landslides are common within the some inner gorge reaches (Foster Wheeler Environmental Corporation 1995). Effects of mass wasting in inner gorges (possibly flood-related) and road failures (upper basin and mid-slope segments), debris torrents, and channel widening are all evident in specific areas of this

subbasin. Rack Creek exhibits ephemeral and/or subsurface flow annually in some reaches during driest summer/ fall periods, especially in segments immediately upstream of its confluence with the reservoir.

The stream corridor morphology of the Rack Creek drainage is relatively variable although most stream segments within the corridor are very steep and tightly confined valley wall and headwater tributary channels. The upper basin drains a shallow cirque basin where tributary segments in the upper cirque exceed 20 percent and steep, stairstepped and boulder-cataract channel types are prevalent. Channel gradients moderate over the valley floor of the cirque (800 feet) and this segment exhibits evidence of sediment deposition. Over the next 4,000 feet (mid-slope) the channel is incised, exhibits a stairstepped profile, and the valley floor gradient increases to above 12 percent. Some of the channel is in bedrock formations, but most of the segment is characterized by large boulders, apparently derived from debris avalanches and rock falls. The channel and its banks appear to be very unstable in this segment, and both recent and active coarse-grained sediment deposits are common. Waterfalls form prominent barriers to upstream migration in lower portions of this segment (Foster Wheeler Environmental Corporation 1995).

At 0.4 mile above the reservoir, Rack Creek contacts the upper edge of a highly active alluvial fan containing poorly sorted large cobbles and boulders, and the channel gradient decreases to 6 percent. Woody debris is common in this segment, functioning to trap sediment and force channel scour. Wood and boulders both play a prominent role in pool formation. In the lowest stream segment immediately upstream of the confluence with the reservoir (0.25 mile), the stream gradient decreases to 3 percent and recent sediment delivery is evident (e.g., cobble berms in floodplain). Riffles predominate in the lower segment, and wood appears to play the dominant role in inducing channel scour and pool formation. Wood is scarce, typically non-embedded and in small pieces, and lateral streambank erosion is common in this reach (Foster Wheeler Environmental Corporation 1995).

Most of the other tributary basins draining to the south side of the reservoir are very small and are comprised entirely of shallowly incised, high-gradient mountainslope channels that maintain high gradients nearly to the lake (e.g., Snowshoe Creek (08.0403). Shotgun Creek represents one exception in that the stream gradient moderates approximately 500 feet upstream of the reservoir as it flows across mountain footslopes. Also, unlike Rack Creek, streams in this category have portions of their high-gradient channels deeply incised into the mountainslope, and landslide activity and subsequent sediment transport appears much less substantial (Foster Wheeler Environmental Corporation 1995). Shotgun Creek flows typically throughout the year with the exception that subsurface flow may occur infrequently at the immediate confluence with the reservoir in especially dry years.

The landscape at the perimeter of the reservoir complex is dominated by 60-69 year old second-growth coniferous forest with small patches of mixed coniferous/deciduous forest and/or deciduous forest (mostly red alder) persisting adjacent to small tributary drainages and in areas with poor soil drainage. Several patches of both somewhat younger and older forest exists within this zone (e.g., younger in Otter and Rack creeks, older upstream of

major river deltas). Large, low gradient delta fans at the mouths of the Cedar and Rex rivers support diverse plant communities that gradually shift from zones dominated by sedges (*Carex* spp.) at lower elevation into willow thickets (*Salix* spp.) slightly higher, and eventually into the mixed coniferous/deciduous forest of the broad river flood plains of both systems. A much smaller area of sedge and willow vegetation types is present at the confluence of Bridge Creek (08.0398) and also in one small area of the Masonry Pool. Slopes rise abruptly from both the northern and southern perimeter of the reservoir basin, stream gradient in most small reservoir tributaries increases within relatively short distances of the lake (e.g., Otter, Green Point, McClellan, Echo, and Lost creeks), and the steep landscape is dominated by second-growth conifer forest with primarily 60-69 year old forest up to an approximate elevation of 2,500 feet, patchy, regenerating forest ranging from 20-70 years old at mid-slope and in some cases to ridge tops, and both youngest forest (e.g., 0-9 and 10-19 year old) and oldest (190+ years) existing as fragmented and isolated old growth patches along the ridgelines at elevations of about 4,000 feet (see Figure 2 – in Appendix C).

Major Tributary Basin – Rex River

The 14,622-acre Rex River subbasin is located generally southeast of Chester Morse Lake and includes the Rex River (8,089 acres) (08.0405), Lindsay Creek (2,471 acres) (08.0412), Pine Creek (1,027 acres) (08.0415), and Boulder Creek (3,037 acres) (08.0406) drainages. The headwaters of these drainages originate along the crest of the hydrographic divide between the Cedar River Municipal Watershed and the Green River Watershed immediately adjacent to the south. Boulder Creek enters the Rex River a relatively short distance upstream from the Rex River delta. Lindsay and Pine creeks, both glacially carved headwater minor subbasins, enter from the south in mid-reaches and from the east in upper reaches of the mainstem of the Rex River, respectively. Overall, the major subbasin exhibits a trunk/dendritic drainage pattern over a 3,200 feet vertical relief with uppermost reaches of headwater streams at an elevation near 4,800 feet. Approximately 72 percent of the major subbasin is situated within the highland snow zone and an additional 25 percent is found within the rain-on-snow zone at mid elevations associated with the valley bottom and lower valley sideslopes of the Rex mainstem above the reservoir (Foster Wheeler Environmental Corporation 1995).

Streams in the uppermost portion of the subbasin originate in a north to northeast-facing glacial cirque that is similar to the cirque formations at the headwaters of other smaller tributaries in this area and to those found in Goat and Seattle creeks, further to the east in the municipal watershed. The upper basin is characterized by a sparse network of headwater tributaries originating from mountain slopes, associated with shallow, narrow inner gorges, and stream gradients exceeding 20 percent typically. Stream channels are incising through glacial till and are therefore bounded by narrow, confined valleys. Stream bed elements are emplaced by mass wasting and tree uprooting most commonly and flows are generally shallow and ephemeral. On the cirque floor, channel gradients moderate and the channel beds are dominated by large cobbles and gravels, plane bed pocket waters, and forced-pool riffle channels. Channels have scoured to bedrock in lower reaches of stream

segments in the lower cirque basin and immediately downstream (Foster Wheeler Environmental Corporation 1995).

After exiting the cirque basin the channel is incised through a bedrock ledge creating bedrock canyon walls that exceed 50 feet commonly. The channel bed is almost entirely dominated by bedrock with infrequent pools below the base of large waterfalls. Upstream of the confluence with Pine Creek, a relatively short stream segment is less confined, exhibits more moderate gradients, and is associated with small wetlands and seeps. Base wall seeps, perched 3 to 10 feet above the ordinary high water mark, are abundant on the north bank. Further downstream, the mainstem channel is only moderately confined and has incised into coarse-grained alluvium with fine-grained soils. Step-pools are common and alluvium bed material consists of boulders and cobbles. Backwater boulder cluster pools and pools spanning the width of the channel are common and large woody debris is scarce. Immediately downstream of the confluence with Pine Creek, bedrock ledges are again present over a short stream segment and channel conditions are similar to those described above (Foster Wheeler Environmental Corporation 1995).

Between the confluence with Pine Creek and approximately 0.25 mile upstream of lake-perimeter roads (approximately mid-third of the drainage) channel conditions alternate between well developed step-pool channels and bedrock channels. Typically, valley bottom width in the step-pool reaches ranges between 1.5 to 2.0 times the active channel width, well vegetated boulder and cobble terraces are common, stream gradients range between 3 and 5 percent, and channel sinuosity is low. Boulders and large cobbles comprise the steps, which are associated with deep, channel-wide pools. Sediment fines are uncommon and those present are temporarily stored in pools between bed mobilizing events. Backwater boulder cluster pools and pools spanning the width of the channel are common. Large, woody debris is scarce, except for large jams along the channel margins (Foster Wheeler Environmental Corporation 1995). In contrast, nearly vertical bedrock walls confine the channel in bedrock scour reaches where the absence of a contiguous alluvial bed is characteristic. Bedrock channels in these stream reaches may have occurred because of the high magnitude scour events associated with flood events and because they are present in lower-gradient portions of the drainage that have not been subjected to debris torrent scour, may indicate a relatively high transport capacity (Foster Wheeler Environmental Corporation 1995).

The mainstem Rex River, from approximately the lake-perimeter road downstream to the confluence with the reservoir (Rex River delta), flows across an extensively developed floodplain situated in a broad, alluvial valley that is typically more than three times as wide as the bankfull channel width. The channel bed is composed predominately of large and small cobbles. The channel is highly sinuous, exhibits braiding in isolated reaches, and both point and lateral gravel bars are common. This low gradient portion of the drainage acts as a natural deposition zone for material exiting from the higher gradient, more tightly confined channels upstream. Relict channels are numerous and some may contain groundwater-fed pools. Large, woody debris is common, but mostly on the channel margins (Foster Wheeler Environmental Corporation 1995). The reservoir inundation zone during the late winter/early spring refill period (lake elevation of 1,563 feet) extends

upstream into the mainstem reach between the current confluence of Boulder Creek (previously nearer the reservoir) (08.0406) and Cabin Creek (08.0410). At higher reservoir elevations, the lowermost reaches of both Boulder and Cabin creeks are also inundated.

Pine Creek (08.0415) drains a small, shallow cirque basin with moderate gradient valley floor. Nearly all of the stream segments in the upper cirque exceed 10 percent. Bedrock scour and steep, stairstepped boulder-cataract channels prevail. High gradients continue until the convergence with the Rex River (Foster Wheeler Environmental Corporation 1995).

Lindsay Creek is characterized by tightly confined channels and moderate to high stream gradients throughout the system. Similar to the Rex River headwaters, Lindsay Creek drains a shallow cirque basin with moderate mountain slopes where headwater tributaries are characterized by stairstepped, boulder-cataract channel types and gradients typically exceed 20 percent. After tributaries leave the cirque walls and converge on the valley floor, the channel is less constrained, the stream gradient moderates to from 8 to 15 percent, and the segments apparently serve as sediment deposition zones. For most of the lower one third of the drainage, the channel is incised into bedrock within a tightly confined valley, bedrock outcrops are evident, and channel gradient remains approximately 8-15 percent. Coarse-grained sediment deposits and coarse, woody debris are uncommon, presumably because they are regularly transported downstream when high energy flows prevail. Waterfalls form prominent barriers to upstream migration through this reach. In the 500-foot reach above the confluence with the Rex River, the stream gradient decreases to approximately 4 to 6 percent. Large, woody debris concentrations are common on cobble and boulder berms where the channel energy is dissipated as flood flows exit the incised canyon reaches (Foster Wheeler Environmental Corporation 1995).

Evidence of channel disturbances in the Rex River major subbasin include inner gorge failures, especially in upper valley segments with steep streambanks downstream of the headwater glacial cirque. Several inner gorge failures are also evident on smaller tributaries within the headwaters and cirque floor, presumably serving as a source of periodic sediment pulses from these reaches during some storm events. Evidence (cobble deposits) of a recent (early 1990s), large debris flow that originated in the lower portion of the cirque basin is present downstream nearly to the confluence of Pine Creek. A few minor mass wasting events in the mid- to lower segments of the Rex mainstem are evident and some channel widening has occurred in reaches from near and somewhat upstream of the perimeter road to the reservoir. A debris flow originating from a forest road and some channel widening are evident in a headwall tributary to upper Lindsay Creek and numerous small inner gorge failures are also evident in mid- to lower segments of the Lindsay mainstem. The lower segments of Lindsay Creek also represent a zone of coarse sediment transport, presumably resulting from periodic re-mobilization of bed and/or bank material generate pulses of sediment from these reaches (Foster Wheeler Environmental Corporation 1995).

The Boulder Creek subbasin, the largest tributary to the Rex River, is glacially carved in volcanic and volcaniclastic geologic formations with a moderate gradient and steep valley

sidewalls. Its drainage pattern, like other drainages in the Rex River system, is trunk/dendritic with first order tributaries originating on the steep valley sidewalls. The drainage extends from an elevation of 1,620 feet near its confluence with the Rex River to the slopes of Mt. Lindsay at approximately 4,300 feet. Stream corridors throughout the subbasin, including headwater, tributary, and mainstem reaches, are generally very steep, tightly confined, and have high transport capacities. Gradient and confinement moderate only in lowermost reaches within approximately 1.25 miles of the confluence with the Rex River. Most channels in the drainage are composed of boulders and large cobbles, however, bedrock is common in localized reaches, especially throughout mid segments of the mainstem (Foster Wheeler Environmental Corporation 1995).

The Boulder Creek drainage contains evidence of the most extensive and varied channel disturbance over the last half century within the Rex River major subbasin including:

1) destabilization of a number of the headwall and valley wall tributary channels following forest road construction and subsequent timber harvest;

2) sediment deposition in some lower gradient, upstream reaches;

3) early, small scale mass wasting in an inner gorge reach within old-growth forest surrounding a upper tributary;

4) extensive landsliding in middle segments (coupled with debris flows from valley wall tributaries) causing widespread sedimentation and aggradation in downstream, lower gradient segments;

5) recurrent episodes of mass wasting events associated with forest roads, producing debris slides delivering to the east fork of the upper drainage and mainstem downstream (minimum of 7 events, including a road failure, between 1950 and 1990); road subsequently abandoned;

6) recurring episodes of mass wasting resulting from forest road construction and timber harvest associated with mid-drainage tributary streams;

7) mass wasting in inner gorges and debris flows in many tributary segments, especially in very high gradient reaches within the lower half of the drainage; and,

8) shifts in the location of lateral and medial gravel bars in low gradient stream reaches in lower segments upstream of the confluence with the Rex River (Foster Wheeler Environmental Corporation 1995).

Major Tributary Basin – Upper Cedar River

The 15,287-acre upper Cedar River subbasin contains the area from Chester Morse Lake (east of McClellan Creek (08.0418) to the confluence of the North (08.0466) and South (08.0443) forks of the Cedar River west of Meadow Mountain. This subbasin includes Bear Creek (08.0435) (1,959 acres) and Roaring Creek (08.0424) (707 acres) draining from the north, Findley Creek (08.0426) (1,277 acres), Goat Creek (08.0441) (1,336 acres), and

Seattle Creek (08.0433) (2,406 acres) draining from the south, and the upper Cedar River (7,602 acres), including several valley wall channels that drain directly to the mainstem. These drainages are situated primarily in volcanic and volcaniclastic geologic formations and their valley bottoms are overlain by glacial and alluvial deposits (Foster Wheeler Environmental Corporation 1995). Over this reach of the mainstem elevations range from 1560 feet near Chester Morse Lake to approximately 2,200 feet at the confluence of the North and South forks, with major tributaries such as Findley, Seattle, Bear, and Goat creeks, as well as many secondary tributaries, originating at nearly 4,800 feet.

The stream corridors within the upper Cedar River mainstem and its associated secondary tributaries can be grouped generally into three major types including 1) valley wall channels, 2) confined mainstem reaches, and 3) broad floodplain reaches of the mainstem. The first type, valley wall channels, are characterized by high gradient headwater tributaries along mountain slopes with steep, stairstepped and bedrock scour channels common, especially at the heads of these smaller drainage networks. Some headwater streams are deeply incised with high gradient inner gorge zones. Channel gradients in these channels typically moderates near the confluence with mainstem segments and step-pool, plane-bed, or forced-pool/riffle channels prevail. In several cases, the lowermost reaches of tributary channels transverse broad, gravel-dominated floodplain terraces of the mainstem. In the second type, the mainstem channel is variably confined from immediately downstream of the confluence of the North and South forks downstream to approximately the confluence of Seattle Creek. In upper reaches (20 percent of segment) the stream is tightly confined in a steep-sided, V-shaped valley with many evident bedrock outcrops evident. The channel is tightly confined in a canyon with boulder and bedrock banks. Downstream of the canyon reach (30 percent of segment), the channel remains moderate to tightly confined in a steep-sided, V-shaped valley, with a narrow floodplain or a colluvial fill terrace of boulder or large cobble material bordering the channel, although the channel gradient moderates to 3 to 4 percent. A relatively short distance downstream of the confluence of Viola Creek (08.0440), the valley bottom widens to twice the channel width in lower segments and has allowed limited widening of the stream channel. Boulder cataract and step-pool channels are typical of these reaches (50 percent of segment), with large boulder clasts in evidence. Large, woody debris plays a minor role controlling channel morphology unless formed into stable concentrations. The third channel type, broad floodplain, is evident in the segment of the Cedar mainstem from the confluence of Seattle Creek (08.0433) downstream to Chester Morse Lake. The valley bottom is broad, floodplain development is extensive, and the lower gradient stream reaches are acting as natural deposition zones for material being mobilized from higher gradient, more tightly confined reaches and tributaries upstream. Continuous bank erosion and bank building processes have produced substantial lateral shifting of the channel. Smooth meander bends, extensive gravel bars, and large concentrations of woody debris are characteristic throughout this channel segment. In mid- and lower reaches of this segment, low level alluvial fans are present and the channel bed is composed mostly of large and small cobbles. The channel is highly sinuous and braiding is especially evident in specific reaches. In middle reaches of the segment, split channels, recent shifts, and large accumulations of both old and new woody debris are common. Numerous relic channels are present and some may act as off-channel percolation zones (Foster Wheeler

Environmental Corporation 1995). Lower and mid-reaches of this segment (nearer the reservoir, see below) are the most consistently utilized by spawning adfluvial bull trout from Chester Morse Lake. The reservoir inundation zone during the late winter/early spring refill period (lake elevation of 1,563 feet) extends upstream into the mainstem reach approximately 0.6 mile upstream of lake delta willow zones.

Evidence of disturbance in this drainage section is present in the form of slope failures in the high gradient inner gorges of secondary tributary streams in some areas, which have resulted in delivery of substantial sediment loads to the Cedar mainstem. Large variation in mainstem channel width and location over the last 50 years have apparently been triggered by both high flow events and debris flows that have delivered coarse sediment. Sediment in many areas (e.g., mouths of Bear (08.0435) and Findley creeks (08.0426)) of the mainstem channel has been periodically re-mobilized, presumably during peak flow events. Major channel alterations (widening and avulsion) occurred in the mainstem downstream of the confluence of Roaring Creek (08.0424) between 1970 and 1978, presumably because of the third and fourth largest flow events on record (measured near confluence of Seattle Creek) in 1975 and 1977. Recent channel widening and substantial channel migration have occurred downstream of Findley and Roaring creeks, possible as a result of peak flow events during the 1990 flooding period (Foster Wheeler Environmental Corporation 1995).

The source channels of Findley Creek originate at an approximate elevation of 4,700 feet from the walls of the glacial cirque containing Findley Lake (28 acres). Although similar in many characteristics to other small subbasins that originate in glacial cirques such as are present in the North Fork and Rex basins (e.g., Lindsay Creek), the Findley Creek drainage differs because of the presence of Findley Lake and one or two other smaller alpine cirque lakes within the drainage system. These lakes may serve to attenuate flood flows during peak flow events. The channel network is characterized by high-gradient because of the vertical relief of the basin and the stream corridors are typically very steep and tightly confined. High-gradient, deeply incised inner gorge stream corridors predominate downstream of the cirque lakes (Foster Wheeler Environmental Corporation 1995). The stream drops steeply to its confluence with the mainstem Cedar River at an elevation of approximately 1600 feet. An impassable waterfall barrier is reported to occur approximately 0.2 miles upstream of the confluence and no resident salmonid species have been observed to date upstream of this barrier. In contrast to most other tributary basins to the upper Cedar mainstem, nearly 65 percent of the basin remains in uncut, native conifer forest and the upper third of the basin is virtually unroaded. An approximate 1-mi² area surrounding Findley Lake has been designated by the City as the Joe E. Monahan Findley Lake Research Area in order to protect and promote ecological research in this diverse alpine drainage basin.

Evidence of historic disturbance in the form of landslides and possibly debris flow activity is evident in some reaches of the system prior to 1958, however, all were associated with forested areas. With few exceptions, since 1958 all channel openings have become re-vegetated. Some channel width reduction of the mainstem Cedar River was observed at the confluence with Findley Creek (Foster Wheeler Environmental Corporation 1995).

Seattle Creek, as is the case for the Findley Creek (see above) and Goat Creek (see below) subbasins, is similar in many characteristics to other small subbasins that originate in glacial cirques such as are also present in the North Fork and Rex basins (e.g., Lindsay Creek). Source channels originate at an approximate elevation of 5,100 feet in a U-shaped valley where most secondary tributaries (mountain-slope channels) are shallowly incised. Channel gradient and valley confinement is moderate in mid-reaches of the drainage and the stream channel is shallowly incised. The channel in the lower 1.2-mile reach of the stream to its confluence with the mainstem Cedar River at an approximate elevation of 2,100 feet is characterized by a high gradient, deeply incised inner gorge. An impassable cascade barrier is reported to occur immediately upstream of the confluence with the mainstem Cedar River and no resident salmonid species have been observed to date upstream of this barrier. Also, a second barrier, an impassable waterfall, is located 1.2 miles upstream of the confluence. Uncut, native coniferous forest constituting about 40 percent of the subbasin area currently remains, mostly concentrated at higher elevations on the west slope of the valley. The remainder of the subbasin has been logged to streamside. Also, approximately 9 percent of the subbasin is non-forested, this area concentrated in one small tributary and comprised mostly of talus and shrub-dominated slopes.

Evidence of historic disturbance in the form of open-canopied areas in mid- and lower reaches of the creek mainstem (gradually decreased since 1958) and signs of channel widening and apparent bar formation also throughout mid-reaches is readily apparent. The presence of localized open areas was somewhat less apparent in higher gradient, downstream reaches. Improvement in these conditions was only slight through 1970. Disturbance during the 1970s was also apparent in the form of channel widening and re-mobilization, presumably the result of periods of major flow in 1975 and 1977. Some recovery of streamside vegetation has occurred, however, evidence of continued re-mobilization and transport of sediment continues to be evident in mid- and lower reaches of Seattle Creek. Evidence of recent climax snow/debris avalanche events (pre-1958) was also present in several upper headwater reaches and sediment was deposited in middle creek mainstem reaches (widened reaches). More recent events of this type have apparently not occurred. Some localized debris avalanches in inner gorge segments and several landslides associated with forest roads have also occurred in lower stream reaches within the drainage system. Disturbance, with the exception of streamside timber harvest, does not appear to be significant in other downstream reaches (Foster Wheeler Environmental Corporation 1995).

Bear Creek originates along alpine ridges at an elevation of approximately 5,200 feet on the divide between the South Fork Snoqualmie and Cedar River drainages. The upper subbasin drains non-forested alpine slopes and rock outcrops to the north where many secondary tributaries descend the south-facing ridge from the divide. Snow avalanche chutes are common on these steep, south-facing headwater slopes. Two small, high gradient streams also flow into Bear Lake in a small cirque near the headwaters. Immediately downstream of the lake, the main channel enters a deep inner gorge exhibiting many rock outcrops and where debris avalanches are common. Flow in the main channel and major tributaries is predominantly from east to west, meeting the mainstem of the Cedar River immediately upstream of the confluence with Seattle Creek at an elevation of

approximately 1,600 feet. Stream channels within the subbasin are typically very steep and tightly confined with the mainstem channel exceeding 12 percent except for reaches immediately upstream of the confluence with the Cedar River. Steep, stairstepped, boulder cataract, and bedrock channel types predominate within the subbasin and stream velocities are generally high. Rock formations composed of granodiorite and tonalite from the Snoqualmie Batholith predominate in the upper basin with undifferentiated surficial deposits (glacial outwash and till) underlying the lower reaches of the drainage (Foster Wheeler Environmental Corporation 1995). Timber harvest began in the basin during the 1940s and over 30 percent of the basin was harvested in the next two decades, however, over 50 percent of the basin, mostly in the upper portion and especially the eastern side, remains in native uncut conifer forest. A significant portion of the subbasin (>60 percent) is located in highland and snow-dominated zones and snow accumulations are substantial.

Historic disturbance in the basin exists in the form of small-scale snow/debris avalanches and mass wasting, and their effects on vegetation, in many of the upper and mid-reaches of the mainstem channel within sections of the inner gorge. Small scale inner gorge failures originating in both harvested and unharvested sections are also evident in downstream valley wall tributaries. Sediment and coarse woody debris delivered to the main channel are mostly transported to downstream reaches. Disturbance within the upper basin has been episodic and much has occurred prior to road construction and timber harvest. Disturbance is also evident in the form of several debris avalanches associated with forest road failures (Foster Wheeler Environmental Corporation 1995). Rainbow trout are present in lower reaches of Bear Creek and both rainbow and bull trout presumably have access to lower reaches from the mainstem Cedar River, however, no bull trout have been observed to date in Bear Creek. Stream size and high gradients presumably limit the utility of this stream for larger sized fish. A waterfall barrier exists 0.9 miles upstream of the confluence with the Cedar River (Foster Wheeler Environmental Corporation 1995).

Goat Creek, as is the case for the Findley Creek and Seattle Creek subbasins (see above), is similar in many characteristics to other small subbasins that originate in glacial cirques such as are present in the North Fork and Rex basins (e.g., Lindsay Creek). The entire network is considered a secondary tributary channel due to the prevailing stream size, overall high-gradient, and basin area. Stream corridors are very steep and tightly confined. Source channels originate at an approximate elevation of 5,100 feet from the walls of the glacial cirque, descend to short, lower gradient cirque floor reaches that serve to attenuate sediment transport from cirque wall source channels, and then drop again more steeply to the confluence with the Cedar River mainstem at an approximate elevation of 2,100 feet. An impassable waterfall barrier is reported to occur near the confluence and no resident salmonid species have been observed to date upstream of this barrier (Foster Wheeler Environmental Corporation 1995). The eastern fork in the Goat Creek drainage includes two small lakes, Upper and Lower Sutton Lake. Nearly 50 percent of the drainage, almost entirely in the upper two thirds of the subbasin, remains in uncut, native coniferous forest although it is not contiguous. Timber harvest has taken place adjacent to most of the cirque floor and other downstream reaches.

Evidence of historic debris flows occurring prior to 1958 (all currently re-vegetated), originating from both forested and shrub-dominated cirque headwalls is apparent within the uppermost portion of the subbasin. Sediment transported from steep source reaches has been deposited in a substantial portion of the cirque floor reaches where timber harvest has also taken place. Indications of patchy channel openings and channel widening, as well as evidence of a debris avalanche from a forest road are evident in these cirque floor reaches. Since 1978 channel width in these areas has gradually decreased and hardwood shrubs have re-established although localized open areas are still apparent and tend to suggest that some continual remobilization of sediment is taking place. Disturbance, with the exception of streamside timber harvest, does not appear to be significant in other downstream reaches (Foster Wheeler Environmental Corporation 1995).

Major Tributary Basin – North Fork Cedar River

The mainstem headwaters of the 6,388-acre North Fork Cedar River subbasin originate near the crest of the divide in the central Cascade mountains at Yakama Pass and Twilight Lake (elevation 3,575 feet). Similar to other basins described above, the North Fork subbasin exhibits a trunk/dendritic drainage pattern that includes several third-order tributary basins, most notably Tinkham Creek (08.0452) to the north, originating from Abiel Lake and Spring Creek (unnumbered)to the south, as well as other, less prominent and unnamed tributaries upstream of the confluence of the South Fork. Maximum elevation in the subbasin extends to 5,400 feet (Meadow Mountain) and the vertical relief spans approximately 3,220 feet. Northern extents of the subbasin lie on the hydrographic divide between the Cedar River and Snoqualmie River watersheds. Almost 90 percent of the subbasin lies within the highland and snow dominated zones, where snow accumulations may reach 100 inches. The remaining approximate 11 percent, most of which occupies the valley bottom and lower sideslopes of the mainstem, is situated in the rain-on-snow zone (Foster Wheeler Environmental Corporation 1995).

The North Fork Cedar River subbasin is situated primarily in volcanic geologic formations containing a wide variety of rock types, more than in other Cedar subbasins described. Tributary stream corridors are generally very steep and tightly confined valley wall and headwater channel types, with valley floor slopes exceeding 15 percent. Channel gradients decrease to 4 to 8 percent only near the confluence with the mainstem and in a few, small isolated channel reaches. Alpine glacial deposits, ranging from boulder till in the uplands and upper part of the stream network to gravel and outwash on areas where the valley floor widens, are common along the mainstem. Wider reaches contain recent stream alluvium. Within the mainstem, valley floor slopes range between 2 and 8 percent and limited widened reaches represent the only low gradient, unconfined reaches in the entire channel network. Downstream of the confluence of Spring Creek, the channel flows across bedrock for approximately 1.5 miles. The high gradient channels of both Tinkham and Spring creeks are typically bedrock controlled where erosive flows have removed even boulder-sized alluvium (Foster Wheeler Environmental Corporation 1995).

Evidence of disturbance in the North Fork Cedar River subbasin was present in the form of localized areas of channel widening and sediment deposition, as well as a few split

channels, especially in the upper one third of the mainstem more than seventy years ago. Early channel widening, small inner gorge failures, and natural channel avulsion are also evident in some reaches in the upper one third of the basin. Recent inner gorge failures and some channel widening also occurred as a result of the 1990 flood flows near the mainstem headwaters. Large channel disturbances have also occurred as a result of mass wasting events including debris torrents and debris avalanches from forest roads (Foster Wheeler Environmental Corporation 1995).

The headwaters of Tinkham Creek drain a shallow cirque basin with a high gradient valley floor, where nearly all of the stream segments in the upper cirque exceed 20 percent gradient. Bedrock scour, steep, stairstepped and boulder cataract channel types prevail. The channels converge and the valley floor gradient decreases, eventually assuming the characteristics of a lower gradient, incised cirque floor (Foster Wheeler Environmental Corporation 1995).

The configuration of the headwaters of Spring Creek is virtually the same as that of Tinkham Creek. Below the level of the cirque basin for approximately 4,000 feet the valley floor gradient steepens to over 12 percent and the channel is incised within a tightly confined valley. Steep, stairstepped channel profiles are characteristic, with bedrock scour channel types predominating. Coarse-grained sediment and wood deposits are uncommon, apparently because of prevailing high energy flows causing their regular transport through the system. Several waterfalls are present within this stream segment. Stream gradient decreases to approximately 6 to 8 percent within the lower 1,000 feet of the channel upstream of the confluence with the mainstem. Steep, stairstepped channel types predominate in this lower segment and wood is scarce within the channel margins (Foster Wheeler Environmental Corporation 1995).

Major Tributary Basin -- South Fork Cedar River

The mainstem headwaters of the 4,521-acre South Fork Cedar River subbasin originate at an elevation of 3,200 feet near Meadow Pass at the eastern extent of the municipal watershed. The subbasin also includes several second and third-order tributary basins that join the mainstem upstream from the confluence of the most notably tributary, the steep drainage of Troublesome Creek (unnumbered) to the south. Tributary stream corridors within the South Fork subbasin are generally very steep and tightly confined valley wall and headwater tributary channels. The valley floor slope exceeds 15 percent even within the two largest tributaries. Unlike the North Fork Cedar River, major tributaries in the South Fork are not bordered by bedrock cliffs, nor do bedrock beds predominate. Large boulder and boulder size materials are most common. Valley floor slopes in the mainstem corridor of the South Fork are generally moderate (2 to 8 percent), however, two noticeably widened reaches are evident and represent the only low-gradient, unconfined segments in the channel network. Extensive “bedrock sheet” reaches were absent in the South Fork channel as compared with the North Fork, although a few isolated areas within one area of the stream corridor have been scoured to bedrock, despite a low channel gradient. Large wood is rare, however, channel spanning pieces are functioning to trap sediment and initiate alluvial deposition (Foster Wheeler Environmental Corporation 1995).

Evidence of disturbance in the South Fork Cedar River subbasin is present in the form of debris flow events emanating from the old-growth forest edge reaches of Troublesome Creek and from a single forest road crossing on a tributary stream. In the mainstem downstream of Troublesome Creek, localized widening and split channels were evident in some areas, presumably occurring several decades ago in response to a combination of coarse sediment routing and riparian harvest. Renewed activity (widening) of the channel in these areas was again evident between 1970 and 1978, presumably due to the high magnitude flood events of 1975 and 1976. Channel widening was also evident in other reaches during this same time period. Two small channeled debris flows associated with forest roads occurred between 1970 and 1978 in other reaches, causing some channel widening, and small landslides were also evident in one inner gorge reach (Foster Wheeler Environmental Corporation 1995).

The four major tributary basins in the upper watershed upstream of the Chester Morse Lake subbasin including, Rex River, Upper Cedar River, North Fork Cedar River, and South Fork Cedar River are similar in several major characteristics relative to current forest cover conditions as follows:

- Old-growth forest is concentrated at the highest elevations in headwater reaches of most of these tributary basins. The largest blocks of old growth remain in the areas of Findley Creek, Tinkham Creek, Troublesome Creek, between the North and South Forks of the Cedar River, and to a lesser extent in the areas of Goat Creek and the Rex River.
- Second-growth forest in various stages of seral development predominates at mid- and lower elevations in most tributary drainages within the upper section of the watershed.
- Upper and mid-elevation basins exhibit a mosaic of forest cover predominantly in age classes less than 40 years old and in various seral stages of regeneration (e.g., Rex River, Goat Creek, South Fork Cedar, Pine Creek, Seattle Creek).
- Upper and mid-elevation basins contain a substantial portion of the most recently harvested areas (less than 20 years old) within the municipal watershed and are still in early seral stages (e.g., Bear Creek, Tinkham Creek, North Fork Cedar, South Fork Cedar).
- Lower elevation reaches of most tributary basins exhibit relatively older stands in the range of 30 to 40 years old (Lindsay Creek, Seattle Creek).
- A majority of the forest surrounding the lowest elevation tributaries and the mainstems of the Cedar and Rex rivers is in the range of 40 to 60 years old.
- Generally, forest cover regeneration and subsequent stream recovery has proceeded in most drainage systems relative to the period of time since timber harvest. As a result, those stream reaches still exhibiting evidence of most recent and recurrent disturbance regimes are in mid- to upper sections of tributary and headwater basins (e.g., Seattle Creek, Goat Creek, Pine Creek, Boulder Creek, Lindsay Creek) with associated effects also in evidence in certain downstream reaches.

Future management of the Cedar River Municipal Watershed under the HCP will not include commercial harvest of timber, the forest road system will be reduced by approximately 30 percent, and intervention in watershed forests will essentially be limited to restoration thinning in forest less than 40 years old and ecological thinning in stands from 40 to 60 years old. Management interventions of this type in forest environs will be solely with the intent of achieving improved forest health, preventing catastrophic damage (e.g., fire, disease), encouraging more rapid development of late-successional and old growth structural characteristics, and promoting more naturally functioning forest and aquatic ecosystems. Under this management regime both forest and stream conditions will continue to improve over the 50-year term of the HCP. Table 35 categorizes the distribution of forest habitat in major seral stages across the landscape of the Cedar River Municipal Watershed that will be likely to occur with the implementation of the HCP (see below).

Table 35. Cedar River watershed HCP, projected forest seral stages by major subbasins at year 2020 and 2050[1]

Forest Seral Stages for the **Cedar River Municipal Watershed (Acres)**			***Projected***	
Subbasin	**Seral-Stage**	**1997**	**2020**	**2050**
Chester Morse Subbasin	Early seral-grass/forb	340	0	0
	Early seral-open canopy	2,144	207	0
	Mid seral-closed canopy	5,591	3,915	1,595
	Mature forest	0	3,892	4,558
	Late-successional forest	0	0	1,862
	Old-growth forest	1,277	1,277	1,277
Lower Cedar River Subbasin	Early seral-grass/forb	105	0	0
	Early seral-open canopy	585	96	0
	Mid seral-closed canopy	14,861	1,937	542
	Mature forest	268	13,766	4,034
	Late-successional forest	9	21	11,244
	Old-growth forest	187	187	187
North Fork Cedar River Subbasin	Early seral-grass/forb	52	0	0
	Early seral-open canopy	1,042	47	0
	Mid seral-closed canopy	1,047	2,089	872
	Mature forest	0	0	1,264
	Late-successional forest	0	0	0
	Old-growth forest	3,762	3,762	3,762
Rex River Subbasin	Early seral-grass/forb	54	0	0
	Early seral-open canopy	4,434	0	0
	Mid seral-closed canopy	7,962	8,673	3,463

Forest Seral Stages for the **Cedar River Municipal Watershed (Acres)**			***Projected***	
Subbasin	**Seral-Stage**	**1997**	**2020**	**2050**
	Mature forest	13	3,754	8,599
	Late-successional forest	0	0	366
	Old-growth forest	1,737	1,737	1,737
South Fork Cedar River Subbasin	Early seral-grass/forb	47	0	0
	Early seral-open canopy	1,135	0	0
	Mid seral-closed canopy	1,677	2,853	1,007
	Mature forest	0	0	1,847
	Late-successional forest	0	0	0
	Old-growth forest	1,503	1,503	1,503
Taylor Creek Subbasin	Early seral-grass/forb	482	0	0
	Early seral-open canopy	303	202	0
	Mid seral-closed canopy	9,710	3,973	754
	Mature forest	0	6,319	4,101
	Late-successional forest	0	0	5,640
	Old-growth forest	364	364	364
Upper Cedar River Subbasin	Early seral-grass/forb	356	0	0
	Early seral-open canopy	2,931	168	0
	Mid seral-closed canopy	6,222	7,571	2,701
	Mature forest	0	1,751	6,370
	Late-successional forest	0	0	420
	Old-growth forest	4,557	4,557	4,557
Walsh Lake Ditch Subbasin	Early seral-grass/forb	2	0	0
	Early seral-open canopy	42	0	0
	Mid seral-closed canopy	2,110	682	42
	Mature forest	565	2,035	836
	Late-successional forest	0	0	1,839
	Old-growth forest	121	121	121
City of Seattle Land Outside Above Subbasins	Early seral-grass/forb	497	0	0
	Early seral-open canopy	1,057	444	0
	Mid seral-closed canopy	5,413	2,315	1,356
	Mature forest	227	4,301	3,326
	Late-successional forest	82	170	2,548
	Old-growth forest	380	380	380

Forest Seral Stages for the **Cedar River Municipal Watershed (Acres)**			***Projected***	
Subbasin	**Seral-Stage**	**1997**	**2020**	**2050**
Totals - Cedar River Municipal Watershed	Early seral-grass/forb	1,937	0	0
	Early seral-open canopy	13,673	1,164	0
	Mid seral-closed canopy	54,592	34,009	12,331
	Mature forest	1,074	35,819	34,933
	Late-successional forest	91	190	23,918
	Old-growth forest	13,889	13,889	13,889
	Not modeled	0	184	184
Total Forest Acres for the Cedar River Municipal Watershed		**85,477**	**85,477**	**85,477**

1 Table modified from "Resource Maps for the Final Cedar River Watershed Habitat Conservation Plan", City of Seattle, April 2000.

Figure 2 (in Appendix C) shows the projected forest seral stages by major subbasin at years 2020 and 2050 for the Cedar River Watershed HCP area.

Salmonid Populations

Only three salmonid species are known to occur in the upper Cedar River drainage upstream of the Masonry Dam. These are the pygmy whitefish (*Prosopium coulteri)*, the rainbow trout (*Oncorhynchus mykiss*), and the bull trout (*Salvelinus confluentus*), with the later listed as Threatened by the USFWS. These three species are all present in the Chester Morse Lake/Masonry Pool reservoir complex although spatial distributions and relative densities of each species vary considerably on a seasonal basis throughout the reservoir complex. Population estimates based on hydroacoustic survey data project the number of bull trout present *within the reservoir complex* to be at least 3000 adults, the number of rainbow trout to be near 8,969, and the approximate number of pygmy whitefish to approach 50,000 individuals. It is significant to note that the population estimate of 3,000 adult bull trout refers only to the reservoir complex, and does not include resident adults or juveniles/fry rearing in the Cedar and Rex rivers or other tributary streams. A disproportionate number of each of these species populations is present in Chester Morse Lake as compared with Masonry Pool, presumably because of the relative lack of substrate structural complexity, relatively limited, less productive food sources (e.g., one seasonal tributary), and seasonally fluctuating water levels in the Pool. Currently, the only other fish species known to be present in the drainage system upstream of Masonry Dam is the shorthead sculpin (*Cottus confusus).*

Pygmy whitefish, a glacial relict species and a major food item for predatory bull trout, are prevalent in the deeper and colder waters of the reservoir complex, particularly in Chester Morse Lake, but are also found in Masonry Pool, although they are substantially fewer in

number in the shallower, and presumably warmer, waters of the Pool. During a brief spawning period in late November through mid-December, large numbers of this species, many in schools, can be observed in pool and riffle habitats in the lower reaches of the Cedar and Rex rivers and in Boulder Creek (08.0406), a tributary of the Rex River. It is not known whether lake spawning is part of the life history of pygmy whitefish in this drainage although it is thought to occur in some other systems (Hallock and Mongillo 1998).

Rainbow trout are present throughout the reservoir complex and in all of its tributaries that are accessible, at least to the level of perimeter roads, above which gradient increases abruptly in most cases. Some level of rainbow spawning activity occurs in virtually all of these streams. The steep slopes adjacent to the lake present a natural passage barrier in the case of some smaller tributaries (e.g., Echo Creek, Snowshoe Creek). In addition, the lower reaches of several larger reservoir tributaries exhibit only subsurface flow on an annual basis during drier periods (e.g., Damburat, Green Point, McClellan, and Rack creeks), presenting at least a seasonal barrier to fish passage.

Upstream of the reservoir complex, the known distribution of rainbow trout extends to reaches near the headwaters of the North (upstream of Tinkham Creek) and South Forks (upstream of Troublesome Creek) of the Cedar River, and to natural barriers in the Rex River near the confluence of Pine Creek (i.e., falls and bedrock chutes). In the North Fork of the Cedar River, rainbow trout are found upstream of a natural barrier (falls). Rainbow trout are present in several tributaries of the Cedar River including Eagle Ridge, Bear, and Tinkham (lower) creeks, but not in Roaring, Findley, Seattle, Goat, or Viola creeks above natural barriers (i.e., gradient or falls) that exist at or very near their confluences with the mainstem. In the Rex River drainage, rainbow trout are present in several tributaries including Boulder, Cabin , Morse, and Lindsay creeks upstream from the Rex River mainstem to natural barriers, steep stream gradients or a falls in most cases. The known distribution of this species may be extended in some tributary drainages as additional field surveys are completed.

The adfluvial life history form of bull trout, in which spawning and juvenile rearing (2-3 years) typically take place in rivers and small streams, and fish grow to full sexual maturity in lakes, is the only one known at this time to occur in this watershed, although it is possible that fluvial and/or resident forms may exist. A substantial majority of bull trout spawning activity takes place in the mainstem of the Cedar and Rex rivers, primarily within approximately five river miles and three river miles of Chester Morse Lake, respectively. Spawning activity, at substantially lower levels, has also been observed in Boulder Creek and Cabin Creek, tributaries to the Rex River, in Rack Creek (08.0399) and Damburat Creek (08.0394) (one potential redd), tributaries of Chester Morse Lake, and to a very limited extent in the mainstem Cedar upstream of the confluence of Bear Creek (08.0435). Spawning in smaller tributaries occurs mostly in lower reaches relatively near the river or lake confluence. No spawning activity has been documented in tributaries of the Cedar River or the Masonry Pool (i.e., Lost Creek(unnumbered)). It is unknown if any lake spawning, observed in bull trout populations on an uncommon basis, occurs along the shores of Chester Morse Lake.

Low-velocity, shallow side-channels, alcove pools, and woody debris are important habitat features for newly emerged bull trout fry and juveniles in the watershed, as are cool water temperatures and adequate food, both of which depend on channel structure and the condition of riparian vegetation. Juvenile rearing occurs to some extent in most of the areas utilized for spawning, but also takes place to a significant degree in specific, small tributaries of the Cedar and Rex rivers, Eagle Ridge Creek (unnumbered) and Morse Creek (unnumbered), respectively. Substantial rearing also occurs in several ground-based channels in the Cedar River flood plain, in other small tributaries originating in wetland systems, and in wetland systems proper (e.g., headwaters of Eagle Ridge and Morse creeks), none of which are apparently utilized to any significant extent for spawning. Most of these small tributary and off-channel rearing habitats are characterized by substrates containing substantial quantities of fine sediment and organic material. Adult bull trout, for the most part, mature in the Chester Morse Lake and Masonry Pool reservoir complex.

The presence of bull trout has been documented in the mainstem of the Cedar River upstream from Chester Morse Lake, 0.7 mile into the North Fork to a natural barrier (falls) and also 0.7 mile into the South Fork to a partial seasonal barrier. With one exception, upstream of the falls on the North Fork Cedar, adfluvial bull trout within the drainage system have at least seasonal access to the same stream reaches as described above for rainbow trout, both in the lake basin and tributaries of the Cedar and Rex rivers. In contrast to the rainbow trout distribution, however, within the lake basin, bull trout (or redds) have only been observed in three tributaries to the reservoir complex (i.e., Rack Creek, Shotgun Creek, and Damburat Creek) and with the exception of Rack Creek, only single observations were recorded. Bull trout have not been found in major tributaries of the Cedar River including that portion of Bear Creek which is accessible and rainbow trout are present. Within the Rex River system, bull trout have been observed upstream in the mainstem as far as the confluence of Lindsay Creek, in Boulder Creek and Cabin Creek (spawning/rearing), and in Morse Creek and Lindsay Creek (rearing only). The known distribution of this species may be extended in some tributary drainages as additional field surveys are completed.

MAJOR CURRENT ACTIVITIES

Research and Monitoring

Spawning surveys are conducted in the Cedar and Rex rivers, their major tributaries (Boulder and Cabin creeks) and several tributaries of Chester Morse Lake (e.g., Rack Creek, Shotgun Creek) to determine seasonal timing and prevailing environmental conditions during spawning activities and to identify general trends in the number of bull trout spawning in the Chester Morse Lake system.

Periodic surveys of bull trout fry are conducted in selected reaches of the Cedar and Rex rivers and selected tributary streams (e.g., Boulder, Cabin, Eagle Ridge, and Morse creeks) to determine seasonal timing of fry emergence and prevailing environmental conditions during emergence, and to identify general trends in the number of bull trout fry present in

the tributaries of Chester Morse Lake from year to year. These techniques are experimental at present and are being investigated for possible use as indexes to monitor population trends under the HCP.

Surveys of juvenile bull trout habitat are also conducted in order to determine the distribution of potential rearing habitat and provide management prescriptions for protection and/or enhancement under the HCP.

General observation surveys are conducted periodically in the lower reaches of the Cedar and Rex rivers, their major tributaries (Boulder and Cabin creeks), and other selected tributaries in the Chester Morse Lake system (e.g., Rack Creek, Shotgun Creek) to investigate the seasonal timing and prevailing environmental conditions during pygmy whitefish spawning activities in the Chester Morse Lake tributary system.

Cedar River Watershed Habitat Conservation Plan (HCP)

A monitoring program, including several types of research projects, aimed at gaining more significant knowledge of the specific life history of bull trout within the municipal watershed so as to better protect bull trout habitat and the populations within the system through monitoring efforts and a program of adaptive management provided for in the HCP. Several aspects of environmental conditions, operational regimes, and land management related to the status of the bull trout population within the upper watershed have been identified, including overall distribution (reservoir and tributaries), spawning and rearing habitat availability and condition, effects of redd inundation, and upstream access to spawning bull trout from the adfluvial population in Chester Morse Lake (see below).

OTHER MAJOR ISSUES

BULL TROUT REDD DENSITY

Since 1992, there has been an apparent discrepancy between the number of adfluvial bull trout redds actually counted annually in the tributaries of Chester Morse Lake in the municipal watershed and the number that might be expected based on the estimate of the adult population for the Chester Morse/Masonry Pool Reservoir complex (approximately 3,000). From 1992 through 1999 the number of bull trout redds counted per year in the watershed ranged from 6 to 109. For example, by proportionally comparing the Chester Morse population with the population in Flathead Lake, Montana, between 184 and 334 redds might be expected to be present annually in the Cedar River Watershed. In fall 2000, however, stream flow conditions were very conducive for field surveys and a conservative count totaled 236 bull trout redds (plus 42 test redds), a count well within the predicted range based on the Montana data. Several circumstances, or a combination of circumstances may contribute to explaining the apparent discrepancy in at least some of the annual surveys including, but not limited to, the following:

1. Life history adaptations of the adfluvial bull trout within this system may be naturally, and even substantially, different from populations in other regions or lake systems; those locally specific adaptations to the specific flow and lake regimes within the specific system may include naturally low and/or highly variable annual spawning numbers;

2. All known spawning areas within the system may not yet be identified;

3. Environmental conditions (e.g., high flow conditions) have precluded consistent survey of all known spawning areas in successive years, or with the same survey intensity/frequency between years, increasing variability in the data;

4. The number of bull trout spawning in any given year may be highly variable due to environmental conditions; and

5. High flows between survey efforts may obliterate all definitive evidence of redds dug prior to, or even during, some flow events.

Bull Trout Stream and Lake Spawning Distribution

Radio tagging has been successfully used to track adult bull trout to previously unknown spawning areas in Oregon (Thiesfield, S., Oregon Department of Fish and Wildlife, 1997, personal communication). As provided in the HCP, the City of Seattle will design a study to tag and radio track bull trout in Chester Morse Lake tributary streams to refine the understanding of spatial and temporal habitat use patterns.

While it is unknown if bull trout spawn along the shores of Chester Morse Lake, lake spawning is known to sustain the population of at least one bull trout stock in Washington State (Middle Hidden Lake, Okanogan County) and possibly one other (First Hidden Lake, Okanogan County). As provided in the HCP, the City will tag and acoustically track adult bull trout in the Chester Morse Lake to learn if they might be spawning at selected locations in the reservoir.

Bull Trout Redd Inundation and Egg Mortality

Adfluvial bull trout construct redds and spawn every fall in the lower reaches of the Cedar and Rex rivers upstream of Chester Morse Lake. In most years, reservoir levels, and especially rising reservoir levels from mid-March extending through May, inundate some portion of these redds. The greatest risk of mortality is during the period from egg deposition through the incubation and hatching period that extends to mid-March. The risk is substantially less post-hatching and through the period of emergence. In "normal" years, reservoir fill does not occur until the lower risk period of fry emergence. Reservoir levels of two types of events outside the "normal" range of operation would include: 1) very infrequent high elevations, of concern during spring incubation, having an expected frequency of 1 in 50 years with a duration of 1 week, and 1 in 10 years with a duration of less than 1 week; and 2) infrequent high elevations, of concern during spring incubation,

having an expected frequency of 1 in 10 years with a duration of 1-2 weeks (This zone includes floods, which are short-term events.).

It is assumed (by the City of Seattle), however, that although mortality resulting from inundation has not been demonstrated in the Cedar system, that some unknown number of redds are inundated for variable periods of time, and that the change from a running-water to a lacustrine environment does kill some unknown fraction of the developing eggs, or possibly alevins, in some of the inundated redds.

The actual level of mortality caused by inundation of redds in the lower Rex and Cedar rivers is not known. It is puzzling that such a high percentage (up to 95%) of Rex River bull trout redds are placed at elevations that have been inundated annually by storage of water in Chester Morse Lake for almost 85 years. Severe mortality to eggs and alevins usually would be expected to exert a strong selective pressure against those bull trout spawning in the annually inundated stream reaches. Inundation of salmonid redds is known to cause mortality in some reservoirs (Seattle City Light 1989). In regard to the effects of redd inundation by Chester Morse Lake, one hypothesis is that the degree of impact is somewhat reduced by water upwelling through the spawning gravels in the inundated stream reaches. Upwelling in spawning gravels serves to aerate eggs and alevins and remove metabolic wastes. It is not known whether upwelling actually occurs in bull trout spawning areas in the lower Cedar or Rex rivers. The fact that regular inundation has been occurring for many decades in much of the area in which bull trout spawn, however, suggests that there has been relatively little selection exerted on bull trout to avoid these reaches. Furthermore, even if a high degree of mortality from inundation does occur, it is probable that the limiting life stage for bull trout in the watershed is not spawning or egg incubation (especially in the lower reaches of the tributaries), but juvenile rearing.

In an effort to more closely examine this potential issue, the staff from the City of Seattle will conduct a study of bull trout egg mortality that potentially results from redd inundation. Redd caps will be placed over bull trout redds in stream reaches that are upstream of, if available, and within the zone of reservoir inundation. The percentage of alevins emerging will be monitored. Alternatively, ripe adults will be captured at a weir, and eggs and sperm will be extracted. Eggs will be fertilized and then will be buried in experimental incubation boxes upstream of and within the zone of eventual redd inundation. The egg boxes will be monitored to determine embryo development.

Spawning Access From Chester Morse Lake to the Cedar River and Rex River

Chester Morse Lake pool levels under the current reservoir operation range from a normal high pool of 1,563 feet above sea level to a minimum drawdown of 1,532 feet. Under extreme emergency conditions, Chester Morse Lake can be lowered below 1,532 feet to as low as 1,502 feet using the existing emergency pumps. Access to tributary streams by fall spawning bull trout may be impeded or blocked because of the exposure of the steeply sloped faces of delta fans where the Cedar River delta (14 percent slope) and Rex River delta (17 percent slope) meet the main body of Chester Morse Lake. Exposure of several feet of the steep faces of the delta fans may present either a partial or a complete barrier to

migrating bull trout, with timing and duration of impedance varying both within and among years, if the exposed channel gradient and resultant stream conditions exceed the swimming and leaping capabilities of bull trout (City of Seattle. Cedar River Habitat Conservation Plan, in preparation).

A very conservative estimate is that the potential for exposure of the steeply sloped faces of the delta fans of the Cedar and Rex river deltas begins to occur initially as reservoir levels drop below about 1,540 feet. The degree of potential impact is relatively minor immediately below 1,540 feet, however, because water depths sufficient to allow fish passage (approximately 1-3 feet) typically remain, and because only some parts of each steeply sloped delta face could be completely exposed, if any parts are exposed at all. Although some uncertainty exists, the City of Seattle does not expect that any substantial portions of the steep-gradient stream channels on the deltas are actually exposed or that each delta face, as a whole, will not carry flow sufficient to pass fish, at 1,540 feet surface elevation. As the reservoir level drops below 1,540 feet and approaches 1,535 feet, however, the steep channel gradients are believed to extend for sufficient length to potentially impede or block bull trout migration (R2 Resource Consultants, in preparation). The question regarding the potential impedance of passage of bull trout at the face of the delta fans during occasional low drawdown events, including the timing, extent, and duration, has been raised only recently. Since Chester Morse Lake levels have not dropped below 1,540 feet since 1991 and none of the critical portions of the channel confluence or face of the delta fans has been exposed, staff biologists have not had the opportunity to directly observe the substrate structure, or flow conditions, that exist either where or when impedance of passage of bull trout is thought to be the most likely to occur (City of Seattle, Cedar River Habitat Conservation Plan).

A comparison of modeled reservoir levels projected under the IRPP (current) flow regime to projected reservoir levels under the new HCP instream flow regime was done using historical data sets for the period of record (64 plus years including the annual 13-week bull trout spawning season). Overall, the modeling analysis indicated that differences between current reservoir management and reservoir management under the HCP are small, with reservoir levels in the fall slightly lower under the HCP regime (an average weekly difference of –0.41 feet) as a result of commitments to higher summer streamflows for steelhead in the mainstem Cedar River downstream of Cedar Falls. The difference in reservoir levels was less than 1 foot (higher or lower) 78 percent of the time (City of Seattle. Cedar River Habitat Conservation Plan).

A second type of analysis of reservoir elevations, comparing actual past elevations to analytically derived elevations under the HCP, as opposed to the modeled elevations described above, gives a better picture of the likelihood of potential impacts of reservoir drawdown on bull trout during fall spawning (mid-September until mid-December). This analysis indicates that from early October through December reservoir elevations under the same environmental conditions should be nearly the same under the HCP as during the 60 year historic record, except for a few weeks in which there is a slightly higher frequency of lower elevations. As indicated by this analysis, reservoir elevations can be expected to be below 1535 feet at frequencies of 1 in 10 years or less only part of the fall spawning period,

and then only for periods of 1-3 weeks (within the “infrequent” operating zone). To place this effect in context, it should be noted that some delay of adults entering the Cedar and Rex rivers can be expected during the fall period in many years as a result of *natural* variability in both timing and volume of attraction flows that depend on the onset of heavy fall rains. Delays of several weeks during the fall migration upstream probably occur under natural conditions, although extreme reservoir drawdown could exacerbate this situation (City of Seattle. Cedar River Habitat Conservation Plan).

SAMMAMISH RIVER AND TRIBUTARIES

SAMMAMISH RIVER AND SIDEWALL TRIBUTARIES

A. PHYSICAL DESCRIPTION

The Sammamish River (08.0057) corridor is a distinct, regional landscape feature, which originates at the north end of Lake Sammamish and ends at the river mouth at the northern tip of Lake Washington. The river itself drains a watershed of about 240 square miles, of which 97 square miles are in the Lake Sammamish basin, 50 are in the Bear Creek basin, 67 are in the combined basins of Little Bear, Swamp and North creeks, and the remaining 26 comprise this subarea. The river is 13.8 miles long, as depicted in Williams (1975).

The Sammamish River Corridor may be divided into two reaches, based on topography and, to a lesser extent, land use. The upper river corridor extends from the head at river mile (R.M.) 13.8 north to R.M. 4.5 through a floodplain valley that is more than one-mile wide in places. Two salmon-bearing tributaries are located in the upper reach: Bear Creek (08.0105), at R.M. 12.2, and Little Bear Creek (08.0080) at R.M. 5.4. Land uses include open space and recreational areas at Marymoor Park, urban commercial and residential development in the City of Redmond, the Willows Run Golf Course, the Sammamish Valley Agricultural Production District (which includes large turf farms and smaller nurseries and crop farms) and urban development again in the City of Woodinville. The lower corridor extends from R.M. 4.5 to R.M. 0.0 on Lake Washington. It has a much narrower, topographically constrained drainage area, which includes the downtown cores of the cities of Bothell and Kenmore but also some open space areas, including the Wayne and Inglemoor Country Club golf courses, Bothell parkland along the Sammamish River Trail, and King County-owned parcels at the mouth of Swamp Creek and the mouth of the river. The lower reach includes two large salmon-bearing tributaries, Swamp Creek (08.0059), at R.M. 0.6, and North Creek (08.0070), at R.M. 4.35. A major King County sewer line runs underneath the Sammamish River Trail, which is adjacent to most of the river. The sewer line and the trail create potential constraints for restoration projects on their side of the river (mostly the right bank). From the standpoint of planning, the trail is also important for the recreational use it receives and the public ownership it provides.

Prior to Euro-American settlement, the Sammamish River had a complex, highly sinuous, meandering channel and abundant "swampy" areas that were filled with peat and diatomaceous earth. Prior to the lowering of Lake Washington, there was generally about an 8.4-foot elevation difference between Lake Sammamish and Lake Washington (King County, 1911). The river lost most of this elevation in its upper reach; backwater effects from Lake Washington appear to have extended beyond the confluence with Little Bear Creek (King County, 1892). This area included extensive forested wetlands, especially at the mouth of North Creek (U.S. Department of Interior, 1859). The Sammamish River was historically approximately twice as long as it is today, and overflowed its banks regularly. Its corridor was densely forested with cedar, hemlock and Douglas fir, with willows and deciduous vegetation dominating close to the river banks (Stickney, 1977).

The river corridor was heavily logged from the 1870s through the early twentieth century, by which time it had been essentially cleared of its old growth forest. Small-scale farming

was attempted in the floodplain, but farming became feasible on a much larger scale after the opening of the Chittenden Locks in 1916, which lowered Lake Washington about nine feet, effectively draining most of the sloughs and wetland habitats of much of the corridor, especially in the lower reach (Stickney, 1977; Martz, et al, 1999). Lake Sammamish was lowered by this action as well, which increased the elevation difference between the lakes to approximately twelve feet, strengthening the river current somewhat. Around this same time, farmers in the Sammamish Valley formed a drainage district, which began to straighten the upper reach of the river dramatically (King County, 1911). By the mid-1920s, the river had largely been placed in its current location, though not at its current depth (Metsker Map, 1926). The lowering of the lake, the channelization of the river and the construction of drainage ditches in the river valley eliminated much of the complexity of the floodplain, including wetlands, side-channels and many spring-fed streams that had flowed into the river from neighboring hillsides. Beginning in 1962, the Corps of Engineers systematically dredged and channelized the mainstem Sammamish River into its current channel, primarily as a flood control project to prevent flooding of adjacent farmland during high spring flows. This action deepened the river by five feet throughout the valley and hardened the river's banks throughout most of its length, dramatically decreasing its remaining connection with the floodplain and cutting off most of the smaller tributaries to the river as refugia or forage areas (Martz, et al, 1999).

B. SALMONID UTILIZATION

The following salmonid species are currently known to inhabit the Sammamish River system: chinook, coho, sockeye, kokanee, steelhead, and coastal cutthroat. The U.S. Fish and Wildlife Service has conservatively identified the river and its tributaries as potential foraging habitat for bull trout, on the assumption that they are found in the Sammamish watershed.

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

The channelization and deepening of the mainstem Sammamish River left many sidewall tributaries in hanging culverts that are impossible for fish to access, particularly during low flows. Capital projects along the river have restored access to some, but not all, of these tributaries (Lackey, 2000).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

The Sammamish River probably always had less spawning area than most Northwest rivers, since its origins were from a lake (which acts as a sediment trap) and has such a low gradient (allowing greater deposition of fines). Still, the changes in channel complexity and hydrology described elsewhere in this chapter have dramatically simplified the substrate in the river, to the detriment of salmonids. The 1999 habitat assessment found that silt and clay were the dominant substrate in 82 of 97 measured units along the river (R2

Resource Consultants, 1999). The area immediately downstream of the confluence with Little Bear Creek was the only section of the mainstem river with substrate dominated by gravel. Kokanee have been observed spawning there (R2 Resource Consultants, 1999). Erosion of the streambeds and banks of sidewall tributaries has limited the quantity and quality of their spawning substrate and has increased the amount of fine sediment reaching the river (Lackey, 2000). The plowing of land, stripping of turf and excavation and maintenance of drainage channels on the valley floor during the wet season results in a major influx of silt to the river, along with some clay and diatomaceous earth (Clayton, 2001).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

The lowering of Lake Washington, dredging and channelization have radically simplified the river and cut it off from its natural connections with the vast wetland complexes and off-channel habitats that historically characterized much of the river corridor. The dredging by the Corps in the 1960s widened the river and deepened it five feet below the previous river bottom (U.S. Army, 1997). This action removed woody debris and all natural vegetation from the riverbanks. Any recruitment of new woody debris has been largely eliminated by continued clearing of natural vegetation in riparian areas to maintain channel conveyance, and by widespread use of herbicides in the valley and along many of the river's tributaries. The hardened riverbanks, created with dredging spoils and rip-rap, have drastically reduced the capacity of the river to scour its bed and banks, a process that normally creates and maintains channel complexity and recruits sand and gravel into the channel. The reduction in bed scour has reduced the capacity of the river to intercept cool groundwater, thereby exacerbating water temperature problems (Martz, et al, 1999). A 1999 habitat assessment found river habitat to be 98.2 percent glide, 1.4 percent riffle and 0.4 percent pool. No pools were identified in the sidewall tributaries, which were described as 100 percent riffle (R2 Resource Consultants, 1999).

DEGRADATION OF RIPARIAN CONDITIONS

From Marymoor Park to Bothell, essentially all of the banks of the Sammamish River consist of dredging spoils, often with a base of rip-rap. Except where the banks have been deliberately cut back for habitat benefits or bridge crossings, they are unnaturally steep (R2 Resource Consultants, 1999). Much of this riparian area is dominated by invasive, non-native Himalayan blackberry and reed canary grass. The two species make up well over 80 percent of the riparian vegetation from Marymoor Park to the confluence with Little Bear Creek, more than half of the river's total length (R2 Resource Consultants, 1999). Reed canary grass was used for decades in the mid-twentieth century as an erosion control method along the banks of the river and its tributaries, with the encouragement of the U.S. Soil Conservation Service (Ryan, 2001). Willows tend to dominate at the beginning and end of the river, while cottonwood trees make up a significant portion of the riparian environment of parkland in Bothell, where there has also been some natural re-growth of cedar and Douglas fir. Conifers make up less than 5 percent of the total riparian area and are not dominant anywhere along the river (R2 Resource Consultants, 1999). The lack of

normal riparian characteristics contributes to loss of channel complexity, increased temperatures and poor cover, forage, refugia and LWD recruitment potential.

ALTERED HYDROLOGY/FLOW

The weir located at the outlet of Lake Sammamish exacerbates summer low flows in the Sammamish River, especially in the area directly downstream of weir structure. The weir existed prior to the Corps flood control project in the 1960s, but the Corps reinforced and upgraded it in 1962 to provide a minimum level for Lake Sammamish during summer low flows. The low flow notch in this new weir was then designed to convey a minimum of 35 cubic feet per second (cfs), which was considered an extreme low flow. After the weir was completed, flow and climate data showed that flows lower than 35 cfs have been occurring on an average frequency of every other year; flows of 21 cfs have occurred about once every 10 years. Flows lower than 35 cfs provided so little water over the weir that fish passage was largely prevented (U.S. Army, 1997). Largely for this reason, the Corps modified the weir in 1998 with a narrower, deeper notch for low flows. Though the modified weir provides improved fish passage, it slightly reduces the lowest flows in the river because the narrower notch restricts low flows out of Lake Sammamish more than the previous weir (U.S. Army, 1997). Lower flows in the river may in turn exacerbate water temperature problems (Martz, et al, 1999).

In many sidewall tributaries, peak flows have increased in duration, frequency and size while summer low flows have decreased relative to natural conditions, due to clearing and urbanization. Past development practices in steep erosive stream basins have made many of the tributaries very flashy, also generating bed scour and bank erosion (Lackey, 2000).

WATER QUALITY-INCREASED TEMPERATURE

The mainstem Sammamish River can exhibit extremely high water temperatures during the summer and early fall, when chinook and sockeye adults are migrating through it. Stress and mortality of migrating adult salmon due to high water temperatures has been documented (Matilla, 1998). The river is on the Washington Department of Ecology (WDOE) 303(d) list for violations of water temperature standards. The warmest reach of the river is upstream of its confluence with Bear Creek, where the much cooler water of the creek can lower the river's temperature by as much as 2°C (McIntosh and Faux, 2000). The reach above Bear Creek was found to be as warm as 27°C (81°F) in late July 1998 (Martz, et al, 1999). Temperatures exceeding 25°C are lethal to salmon, even when they have been acclimated to unusually high temperatures (Martz, et al, 1999). NMFS water quality criteria for juvenile rearing and migrating adult salmonids states that water temperatures that exceed 17.8°C are considered to be “Not Properly Functioning”; NMFS considers water temperatures between 14 – 15.6°C to be "At Risk" for spawning salmonids and between 14 – 17.8°C for migrating and rearing salmonids. Most adult chinook pass through the upper river after it has usually reached its peak temperatures, but elevated water temperatures are probably common through August and often early September. Adult chinook appear to hold in the slightly cooler water of the very few pools that remain in the river, waiting for water temperature regimes to change (Martz, et al, 1999). A 1998

chinook tracking study found that adult chinook took up to 30 days to travel the length of the river, with an average of 10 days. Even when warm water temperatures do not cause mortality of salmon, they may cause sub-lethal effects that impair their reproductive success (Fresh, et al, 1999). High water temperature conditions also contribute to other water quality problems, such as decreased dissolved oxygen (Boyle's Law). Temperature stress may also increase the susceptibility of salmon to fish pathogens (disease), cause an advancement in sexual maturation, and spawn timing. The degree to which juvenile salmon are affected by high water temperatures in the river is not known, but high temperatures in the summer and early fall certainly inhibit possible rearing in the mainstem of the river.

Historically, the river was probably always warmer in the summer and early fall than most Northwest rivers, since it is fed by the warm upper layers (the epilimnion) of Lake Sammamish and it flows slowly through a low-gradient valley. However, the complex and heavily forested historic channel of the river would have provided far more shade than the river receives today. The historic channel also would have had far more cool-water refuges from springs and deep pools (Martz, et al, 1999). Channelization and deepening of the river also simplified and disturbed the river's connections with its tributaries and with groundwater. This reduced the degree to which the tributaries and their confluences now serve as cool-water refugia (McIntosh and Faux, 2000).

POOR WATER QUALITY-INCREASED OTHER

Dissolved oxygen levels decrease when the river's water temperatures increase (Boyle's Law). Nutrient loads exacerbate this problem by contributing to overall productivity (e.g., algae and macrophyte growth), since decaying vegetation consumes oxygen from the water. The Sammamish River is on WDOE's 303(d) list for violations of dissolved oxygen standards, which can reach levels in the river that are harmful to salmon.

Studies of the presence and effect of pesticides and herbicides in the water column of the river are underway by King County. Diazinon and other chemicals that are believed to cause behavioral and possible reproductive problems for salmon have been found in an irrigation and drainage ditch feeding the river at levels that are a significant concern (Wilson, 2001).

BIOLOGICAL PROCESSES

Escapement goals are not set for the Sammamish River nor is any reach of the river an index area. Counts of adult salmonids, primarily for sockeye, are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- The channelization of the mainstem Sammamish River has reduced its length by approximately 50 percent;
- Changes in channel complexity and hydrology have dramatically simplified the substrate in the river;
- The lowering of Lake Washington, dredging and channelization have radically simplified the river and cut it off from its natural connections with the vast wetland complexes and off-channel habitats that historically characterized much of the river corridor;
- Current land use practices have removed and eliminated the potential for recruitment of any LWD;
- Any functioning riparian habitat along the Sammamish River is largely absent; and
- Water quality, particularly temperature, limits natural salmonid production.

E. DATA GAPS

- The areas utilized by juvenile and adult salmonids is not fully known;

SAMMAMISH RIVER TRIBUTARIES

BEAR CREEK

A. PHYSICAL DESCRIPTION

The Bear Creek drainage basin covers approximately 32,100 acres (50 square miles). The basin is geographically located in southern Snohomish County and northern King County. The Bear Creek basin is best described as being comprised of three sub-basins: Bear Creek (08.0105) (sometimes referred to as Big Bear Creek) at 14,300 acres, Cottage Lake Creek (08.0122) at 8000 acres, and Evans Creek (08.0106) at 9800 acres. Bear Creek empties into the Sammamish River in the City of Redmond on the north side of the SR 520 were it crosses the Sammamish River. Throughout the basin are more than 100 plus miles of streams, nine (9) lakes, and over 2000 acres of identified wetlands (King County, 1989). The following is a list, in decreasing order by area covered, of local jurisdictions within the basin: unincorporated King County, unincorporated Snohomish County, City of Redmond, City of Sammamish, and the City of Woodinville.

The geography of the Bear Creek basin reflects millennia of activity by water and ice. These landforms and deposits now influence the runoff processes and patterns throughout the basin. Rolling uplands of glacial till pass storm runoff downslope through the soil layer developed on them. Steep-walled hillsides are sites of ravines, deeply incised into erodible sandy material, and perennially flowing springs fed by groundwater. Widespread permeable gravel and sand fill the valleys of Evans Creek and Bear Creek, which absorb much of the water from local storm events and the inflowing tributaries (King County, 1990).

The basin landscape and hydrologic network of streams have changed markedly in the past 150 years from primarily forest to a mix of forest, grass, and impervious surfaces. The landscape of the Bear Creek basin in 1985 was a mix of forest (71 percent), grass (17 percent), wetland (9 percent), and effective impervious surfaces (3 percent) (King County, 1989). The Bear Creek Basin Plan completed in 1990 identified large portions of lower Bear, Evans, and Cottage Lake Creeks needing habitat restoration.

The Bear Creek Basin plan designated Regionally Significant Resource Areas (RSRAs) along Bear and Cottage Lake Creeks. (King County, 1990). These RSRAs exhibit high aquatic habitat diversity and abundance as measured by various stream and wetland habitat characteristics along with diversity and abundance of salmonids and a demonstrated contribution to the regional fishery resource. Other aquatic species of note in the RSRAs are extensive freshwater mussel populations, freshwater sponges, river otters, crayfish and a good representation of aquatic insects. The diversity and number of aquatic resources in the Bear Creek basin distinguished it as one of the top six natural resource basins in King County in the Waterways 2000 program. One of the unique resource areas is Cold Creek. This cold-water spring is 5 to 7 degrees Centigrade (°C) colder than the remainder of Bear Creek stream water temperatures. Evans Creek cools the summer and early fall water temperatures in the Sammamish River downstream of the confluence with Bear Creek. (King County, 2000).

B. SALMONID UTILIZATION

The Bear Creek Basin is known to have the following salmonids: chinook, sockeye, coho, kokanee, coastal cutthroat, and steelhead. The US Fish and Wildlife Service (USFWS) shows the Bear Creek basin as potential habitat for Bull Trout but none have been observed to date (Heller pers. comm). Salmonid distribution in Bear Creek can be found in Appendix A.

Chinook

Adult chinook salmon currently spawn each fall from late August through late November in approximately 4 river miles (RM) of Cottage Lake Creek, 10 RM of Bear Creek, and 1 RM of Evans Creek. Washington Department of Fish and Wildlife (WDFW) staff conducted surveys of juvenile chinook smolts migrating downstream from February to July in 1999 and again in year 2000 (Seiler, et al, 2000). The 1999 report estimated a production number of 14,525 downstream migrant chinook smolts passed the counting station on lower Bear Creek located at RM 0.9. Counts remained low until early May when they increased with a daily peak of 533 on May 24th then declined through June to very low levels by early July (Seiler et al, 2000). Smolt length averaged about 90 mm over the final six weeks of the trapping season with individuals measuring as high as 114 mm (Seiler et al, 2000). Egg to migrant survival was estimated to be 1.8 percent (Seiler et al, 2000).

Genetic studies were conducted by WDFW on adult chinook spawners from the Cottage Lake/Bear Creek Basin in the fall of 1998 and 1999 (Marshall, 2000). The genetic characteristics studied, allozyme allele frequencies, showed significant variability between years. Genetic drift, or random changes, due to small population size, and mixing of fish from different populations are two possible sources of this type of temporal variability. If small population size was the major source of annual variation, versus changes in stray rates, and then using combined years' allele frequencies would be an appropriate genetic characterization of Cottage Lake/Bear creeks chinook (Marshall, 2000). Genetic data were used subsequently for comparisons with Issaquah Hatchery chinook.

The 1998 and 1999 samples showed different levels of genetic similarity to a 1992 Issaquah Hatchery sample, and the combined years' sample compared to the hatchery sample showed non-significant differences in allele frequencies (Marshall, 2000). Similar allele frequency profiles for Cottage Lake/Bear creeks and Issaquah Hatchery populations indicate a common ancestral origin from chinook typical of south Puget Sound, and may reflect some level of gene flow between the two populations (Marshall, 2000). Knowledge of the presence and magnitude of Issaquah Hatchery produced chinook strays in Cottage Lake/Bear Creeks would allow a better assessment of gene flow. From the perspective of regional chinook salmon genetic diversity, Sammamish basin populations appear closely related, and are more closely allied with populations in South Puget Sound than those from the Snohomish basin and northwards (Marshall, 2000).

Marshall (2000) noted that similar allele frequency profiles do not rule out the possibility that Cottage Lake/Bear Creeks chinook are a relatively independent population from Issaquah Hatchery. The genetic data did not provide information about the influence of Issaquah Hatchery production on the persistence of the natural spawning population. Studying the pattern of Issaquah Hatchery chinook straying will be instructive for determining independence of the Cottage/Bear population. It would also be useful to compare other biological traits of the two populations (Marshall, 2000).

Sockeye

Adult sockeye salmon spawn each fall from late August through early November in approximately 4 river miles (RM) of Cottage Lake Creek, 14 RM of Bear Creek, and one RM of Evans Creek (Mavros et al, 1999). Sockeye were observed in October 2000 for the first time spawning about a mile north of the King/Snohomish County line in Bear Creek (Heller, 2000). Downstream migrant fry trapping was conducted by the Washington Department of Fish and Wildlife at RM 0.9 on Bear Creek in 1999 and 2000 (Seiler, et al, 2000). The 1999 report estimates a production number of 1,514,669 sockeye fry passed the downstream migrant trap (Seiler et al, 2000). The peak downstream migration time was during the middle of March with over 60,000 juvenile sockeye passed daily (Seiler et al, 2000). Fry numbers dropped dramatically near the end of March and reached zero by mid April. Egg to migrant survival was estimated to be 11 percent. (Seiler et al, 2000).

In the March 10, 1998 Federal Register, the National Marine Fisheries Service (NMFS) Biological Review Team (BRT) discussed the Bear Creek sockeye population. The BRT considered making the Bear Creek basin its own Evolutionarily Significant Unit (ESU) but deferred action on this decision. Some on the BRT felt that the current sockeye salmon population in Big Bear and Cottage Lake Creeks is a separate ESU that represents either an indigenous Lake Washington/Lake Sammamish sockeye salmon population or a native kokanee population that has naturally reestablished anadromy. The remainder of the BRT felt that the available information was insufficient to describe the population of sockeye salmon in Big Bear Creek as an ESU. This issue is particularly difficult due to the equivocal nature of historical accounts surrounding the presence and distribution of sockeye salmon within the Cedar - Sammamish Basin.

Genetically, Big Bear and Cottage Lake Creek sockeye salmon are quite distinct from other stocks of sockeye salmon in the Lake Washington/Lake Sammamish's Basin: they are genetically more similar to Okanogan River sockeye salmon than they are to any other sockeye salmon population examined. The BRT acknowledged that this genetic distinctiveness, as revealed through an analysis of allozyme data may be the result from genetic change following a recorded return of 2 adult sockeye in October 1940 after a transplant of Baker River origin sockeye in 1937, or it may be indicative of a native population of *O. nerk*a indigenous to the Cedar - Sammamish Basin (Federal Register, March 10, 1998). Based on the available data the BR determined that the Bear Creek sockeye salmon population unit did not meet the criteria necessary to be defined as an ESU.

Kokanee

Although sporadic spawner counts were conducted by King County staff in the mid to later 1990's and kokanee sized *O. nerka* were observed, by volunteers, spawning in small numbers (<100) in Bear, Cottage Lake, and Cold Creeks, relatively little is known of the status of kokanee in the Bear Creek basin (Ostergaard, 1998). In the 1930's and 1940's ten's of thousands of kokanee spawned annually in the Bear Creek basin (WDG Unpublished data). Currently, the spawn timing of kokanee in Bear Creek is much later than the only remaining NMFS recognized native kokanee stock in the Cedar - Sammamish Basin. The effects of a fry stocking program, that utilized Lake Whatcom origin kokanee between 1917 and 1969, on the native kokanee population is unknown. In addition, any interactions between stocked kokanee and sockeye salmon are unknown.

The June 16, 1950 USFWS report states "there is an important run of kokanee (in Bear Creek) from which the Washington Department of Game takes annually as many as 14 million eggs for artificial propagation (USFWS, 1950). The BRT stated the possibility that the current sockeye population in the Bear Creek basin could be a native kokanee population that has reestablished "anadromy" (Federal Register, March 10, 1998).

Coho

Adult coho salmon spawn each fall from mid-October through January throughout most of the 100+ miles of streams in the Bear Creek Basin where they have access. In a June 1950 report from the USFWS to the Washington State Department of Game is a reference that "Redmond Bear Creek now supports the most important silver salmon run of any of the streams in the (Sammamish) watershed (USFWS, 1950). The annual run is estimated to be between 10 and 15 thousand adults (USFWS, 1950). In 1976-1977, the return of adult coho to the Bear-Evans system was estimated at 5,000 fish (King County, 1989). Because more recent years the escapement estimates are for the entire Lake Washington system and not stream specific, updated estimates of coho returns to the Bear Creek system are not available (B. Graeber, formerly with Washington State Department of Fisheries, pers. comm., 1988; King County, 1989).

Bear Creek has been annually planted with hatchery produced coho fry from the Issaquah Hatchery for many years. In May of 1998, 166,000 coho fry from Issaquah Hatchery were stocked throughout the Bear Creek system. The downstream migrant trap at RM 0.9 estimated a broodyear (BY) 1997 production number of 64,102 smolts leaving the Bear Creek system (Seiler, et al, 2000). These smolts are year old fish and started downstream in early March and peaked downstream migration in early May with an estimated daily peak of 839 smolts (Seiler et al, 2000).

Winter Steelhead

Because steelhead adult spawner surveys began in 1984, only limited information is available. In the five years between 1984 and1988, counts of steelhead in the Bear Creek system ranged from 46 to 368 fish (Pfeiffer, 1988). As a part of a Lake Washington

steelhead supplementation program, steelhead fry obtained from natural spawned parents were released in 1997 and 1998. On October 15, 1997 a total of 13,464 steelhead fry were planted throughout the Bear Creek system. A similar number (13,000) were planted on September 24, 1998. Both release groups were identified with removal of the adipose fin. The 1999 downstream migrant trap estimated steelhead production at 1,772 smolts. Virtually all steelhead smolts were caught from early April through mid-June (Seiler et al, 2000)

Coastal Cutthroat

No population estimates for any life stage were available for cutthroat trout. Electroshocking surveys by WDFW in 1996 at six locations in the Bear Creek basin found cutthroat present in significant numbers and sizes ranges throughout the basin (Carr, 1996). The downstream migrant trap reported in 1999 an estimate of 3,413 cutthroat during the 141-day period of operation with no discernable date or dates of high downstream migration activity (Seiler et al, 2000).

Bull Trout

The USFWS maps Bear Creek as "Potential" Bull Trout habitat. Bull Trout have not been observed nor have there been any organized searches for them.

C. HABITAT FACTORS OF DECLINE

The habitat factors of decline discussed below are summaries from the WRIA 8 factors of decline workshops held in March 2000. These workshops concluded that loss of channel complexity, degradation of riparian areas, and increased sedimentation appear to be the principle habitat factors associated with the decline of naturally produced salmonids in the Bear Creek Basin. Altered hydrology and flows due to conversions of historic forest land cover to grass and impervious surfaces, and loss of channel connectivity, along with increased water temperatures during the summer months may also contribute to salmonid decline. Nutrient levels increase significantly during storm events, but it is unknown to what extent, if any, these events contribute to the decline of salmonids in the Bear Creek sub area. Another concern expressed at the March 2000 workshop on Factors of Decline is the poor state of the hydrologic map overlay for Bear Creek including the absence of many streams and inaccurate locations for others.

The factors of decline statements above and following in this report derive primarily from the following sources. The primary source of data in the Bear Creek basin is a basinwide monitoring program established in 1993 through a Bear Creek Basin Plan Implementation Interlocal Agreement (ILA) signed by King County, Snohomish County, and the City of Redmond. The ILA stipulates sharing in the cost of a basinwide-monitoring program. This monitoring program is called Basin Management and Evaluation Program (BMEP). Key relevant components of the BMEP program to this report are several rainfall gauges, six stream flow gauge sites, biological monitoring, and stream cross sections. The six gauge sites record stream flow every 15 minutes as well as air and stream water temperatures.

Most water quality monitoring information presented in this section is from the long-term (1978 to date) King County Metro monthly ambient water quality collection sites. There are six water quality-monitoring sites in the basin of which several overlap with the stream flow gauge sites. Other primary sources of data for this section is from the Bear Creek portion of the Habitat Assessment Reconnaissance Report are the Current and Future Conditions Analysis for the Bear Creek Basin Plan in 1989, the King County 1993-4 stream habitat assessment by Entranco, and various habitat assessment reports from development projects, and Master's theses.

FISH ACCESS AND PASSAGE BARRIERS

There are many known and an unknown number of undocumented salmonid access barriers in the Bear Creek sub area but a comprehensive basinwide examination of barriers is lacking. All known barriers affecting adult chinook and sockeye other than beaver dams have been addressed (Heller, 2000). Many documented and an unknown number of undocumented barriers exist on the smaller streams and upper reaches of the main streams in the Bear Creek basin, which affect primarily coho and cutthroat at all life stages (Heller, 2000). The passage barriers include culverts, dams, weirs, high velocity stream flows, beaver dams, and choking vegetation.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Loss of large woody debris (LWD) has resulted from the degradation of riparian areas, including the active removal of trees both instream and from the riparian area that could provide LWD recruitment and key pieces for formation of channel complexity. Most of the existing in-stream LWD is less than 24 inches in diameter (Entranco, 1994). Monitoring studies throughout the system has noted many scour sites, a low pool frequency, and a number of wide shallow areas (Entranco, 1994). Floodplain connectivity may be impacted by some moderate confinement that has been documented (Entranco, 1994). Loss of wetlands has also been documented (King County, 2000). Conversion of the floodplain and riparian areas to residential and commercial development has reduced the complexity and diversity of the Bear Creek sub area. The high density of road crossings resulting from urban development, particularly in the lower section of Bear Creek, contributes to the loss of stream channel connectivity (King County, 2000).

Data (Figure 42) collected by staff from King County and the University of Washington (Ostergaard and May, In Progress) indicated that none of the surveyed stream reaches approaches any current criteria to meet a properly functioning condition (good) or at risk (fair) criteria.

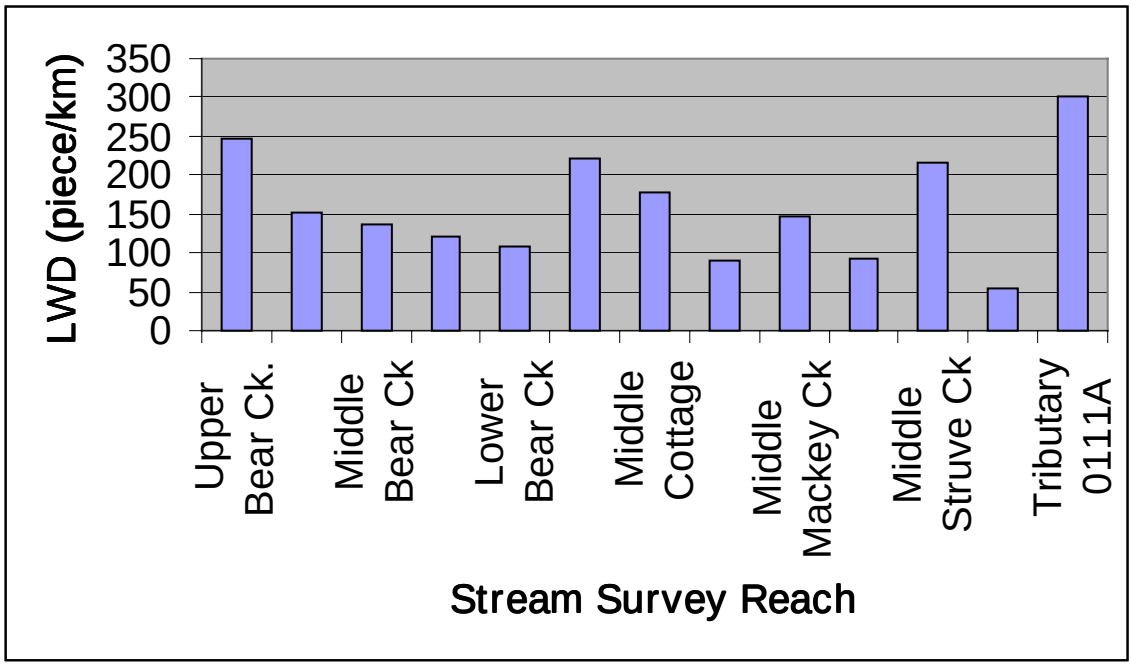


Figure 42. LWD frequency (pieces/km) in the Bear Creek basin (Source: Ostergaard and May, In Progress)

The City of Redmond conducted stream habitat assessments for streams within their local jurisdiction in calendar year 2000. Data from those assessments has not yet been made available.

DEGRADATION OF RIPARIAN CONDITIONS

In the majority of reaches in Bear Creek, the stream buffers have not been well maintained. The loss of land/forest cover in riparian areas has been extensive throughout the basin. The 1995 basin aerial photos indicate average intactness for 10-meter buffers is only 59 percent of the total stream and for 30-meter buffers the intactness is only 42 percent.

Ostergaard and May (In Progress) determined that an average of 66 percent of the basin has retained 10 meter buffers with the unnamed tributary stream 0111 having retained 90 percent of the 10 meter buffers. In the Evans Creek subbasin, 59 percent of the stream remains with 10 meter buffers, in the Cottage Lake subbasin 54 percent meets this criteria and Bear Creek upstream of the confluence with Cottage Lake remains the most protected with 78 percent of the subbasin meeting the criteria.

The invasive non-native plant Purple Loosestrife (*Lythrum salicaria*) has been documented in both the Evans Creek and Cottage Lake Creek sub basins (Heller, 2000). Increased impervious surface resulting from development has resulted in loss of stream channel complexity and has potentially altered hydrology (May, 1996 and King County, 2000).

ALTERED HYDROLOGY/FLOW

One of the most profound changes to the ecological processes in the Bear Creek Basin is that of hydrology. Horner and May (1991) found that one of the factors that has resulted from anthropogenic modifications to the landscape is the shift from a coniferous dominated forested watershed to one dominated by impervious surfaces. Under historic forested land cover conditions there was almost no run-off produced except during very large storm events or rain-on-snow events (Booth 1991).

In the Bear Creek Basin peak flow and flows of sufficient duration to move streambed sediments have increased since 1985 to date (Hartley, 2000). The annual maximum discharge flood frequency return interval has increased; particularly in the Evans Creek subbasin and peak maximum annual flows have increased 25-30 percent (Hartley, 2000). Ostergaard and May (In Progress) determined annual peak discharges increased by 30 percent in Bear Creek and 21 percent in Evans Creek over the 4 year time period from 1995 – 1998. Flow durations in excess of 50 percent of the forested 2-year flow have increased (Hartley, 2000). Peak flow discharges are larger and last longer when compared with modeled forested flow conditions. Preliminary analysis of base flows show they have declined significantly (15-30 percent) in both the Bear and Evans sub-basins (Hartley, 2000).

Another important measurement indicative of habitat degradation is forest cover. May et al (1997) determined that the threshold of degradation to occur at 30 percent or lower forest retention while Horner and May (1999) recommended that forested area remain above 60 percent to maintain natural conditions. The Wild Salmonid Policy (WDFW) recommends that 60 percent of the watershed be maintained with forest stands age 25 years or more. The overall forest retention in the Bear Creek basin as of 1995 was approximately 42 percent. It is likely that these values have decreased since the 1995 measurements but that data was not available at this time.

Loss of forest cover and increases in impervious surface are key factors to changes in hydrology. Bear Creek in 15 years (1985 to 2000) has changed from about 71 percent forest to about 57 percent forest and from about 3 percent effective impervious area (EIA) to about 13 percent (King County 1989; Hartley 2000). Booth (2000) demonstrated that in western Washington approximately 10 percent effective impervious area in a watershed typically yields demonstrable stream degradation. In general, the “evidence” has been based on the observed correlation of channel instability to the modeled hydrologic condition of peak flows (Booth, 2000). Hydrologically and biologically, there are no truly negligible amounts of clearing or watershed imperviousness. Almost every increment of cleared land, and of constructed pavement, is likely to result in some degree of resource degradation or loss (Booth, 2000). The decision of how much is “acceptable” is thus as much a social decision as a hydrologic one. A threshold of 10 percent EIA and <60 percent forest cover aged 25 years or more mark an observed transition to severely degraded stream conditions (WDFW - WSP). Not every watershed responds equally to a given level of human disturbance, but some degree of measurable resource degradation can be seen at virtually any level of urban development (Booth, 2000).

Percent impervious area (EIA) as measured in 1995 indicated that in the Bear Creek basin the EIA was generally below the threshold of degradation and ranged from 2.36 percent to 5.84 percent (Ostergaard and May, In Progress). Booth and Reinelt (1994) found that eight to ten percent was generally the threshold above which many lowland Puget Sound streams have degraded water quality. In the Bear Creek Basin, the subbasin with the lowest EIA was upstream of NE 133rd Street (2.36 percent). The Evans Creek subbasin had a high EIA (5.26 percent) and Cottage Lake was 4.86 percent EIA. The Lower Bear Creek subbasin was the highest EIA at 5.84 percent. It is likely that these EIA values have increased since the 1995 measurements but that data was not available at this time.

Road density and stream crossings in the Bear Creek basin average 2.2/km stream for the entire basin. The unnamed tributary 08.0111A has the highest number of stream crossings at 3.47/km of stream while Seidel Creek has the lowest at 0.9/km of stream. Road density is higher than three kilometers per square kilometer in the majority of reaches examined by Ostergaard and May (In Progress). Only Seidel Creek (1.67 km/sq km), Upper Evans (2.95 km/sq km) and the unnamed tributary 0111 (2.41 km/sq km) had road densities less than the threshold of three kilometers of roads per square kilometer that NMFS considers to be properly functioning.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Turbidity readings show that state water quality standards are exceeded (5 percent of ambient readings and 17 percent of storm readings) when measured at the mouths of Bear Creek and Evans Creek (King County Metro, 2000). It is possible that substrate embeddedness from excessive fines occurs, but this aspect needs additional assessment (King County, 2000).

POOR WATER QUALITY-INCREASED TEMPERATURE

Except at the Cold Creek gauge, stream water temperatures at six continuously monitored sites between 1995 and 2000 inclusive in Bear Creek exceeded 64°F during the summer months of July through early September, and fall below 60°F by October (King County, 2000). Isolated instances of high water temperatures on Evans Creek have been recorded above 64° F during the time period of 1978 to 1998 (King County, 2000).

King County (1990) noted the following water quality problems in the Bear Creek basin: (1) high levels of fecal coliforms; (2) high water temperatures; (3) turbidity and sediment problems from the unnamed tributary 0111A; and industrial spills from commercial properties along NE Union Hill Road and Evans Creek.

During 1994, staff from King County conducted a Level 1 survey for unnamed tributary 08.0111D (King County 1994) and found the stream has been degraded by stormwater flows. Generated from upstream developments and the Sahalee Golf and Country Club.

POOR WATER QUALITY- OTHER

Measured values for most nutrients that have been recorded show significant increases during storm events. The Bear Creek basin is on the Washington Department of Ecology 303d list for exceeding State water quality standards of fecal coliforms and mercury (King County Metro, 2000). Cottage Lake has been determined to be eutrophic (King County, 1996).

Macroinvertebrates have been sampled in fifteen reaches of this subbasin with eight of those reaches having been sampled for at least two years. Seven of the most recent samples obtained from the fifteen sites had scores in the low quality range (below 27), eight of the sites received moderate scores and none received high quality scores. Ostergaard and May (In Progress) found that riparian buffer retention appear to be slightly correlated with macroinvertebrate (B-IBI) score for both the 10 and 30 meter buffers in the Bear Creek basin.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- The Bear Creek basin is generally much less impacted when compared to most of the other urbanized basins in WRIA 8;
- There are several known barriers to adult salmonid fish passage in the Bear Creek subbasin;
- Increased impervious surface resulting from development has resulted in loss of stream channel complexity and has potentially altered hydrology;
- Annual peak discharges increased by 30 percent in Bear Creek and 21 percent in Evans Creek over the 4 year time period from 1995 – 1998;
- Flow durations in excess of 50 percent of the forested 2-year flow have increased;
- Peak flow discharges are larger and last longer when compared with modeled forested flow conditions;
- A preliminary analysis of base flows show they have declined significantly (15-30 percent) in both the Bear and Evans sub-basins;
- Cold Creek is a cold-water spring that is 5 to 7 degrees °C colder than the remainder of Bear Creek stream water temperatures and as such serves as a thermal refuge;
- Bear Creek in 15 years (1985 to 2000) has changed from about 71 percent forest to about 57 percent forest and from about 3 percent effective impervious area (EIA) to about 13 percent; and
- Stream water temperatures at six continuously monitored sites between 1995 and 2000 inclusive in Bear Creek exceeded 64°F during the summer months of July through early September, and fall below 60°F by October.

E. DATA GAPS

- Long term sampling of the habitat quality of the Bear Creek basin streams may be necessary to detect trends over time;
- No information was available during the course of this report to assess either the historic or existing extent or condition of off-channel habitat in the Bear Creek subbasin;
- The extent to which plant and animal non-native species are impacting salmonid survival is not fully understood. A comprehensive assessment of non-native species needs to be initiated, completed and action plan developed;
- A baseline habitat inventory is lacking in this subbasin; and
- The extent of actual usage by anadromous and resident salmonids is not known.

LITTLE BEAR CREEK

A. PHYSICAL DESCRIPTION

Little Bear Creek (08.0080), encompassing a drainage area of approximately 15 square miles (mi^2), has its origins in Snohomish County, flows southward into King County and empties into the Sammamish River. Little Bear Creek begins in a gently sloping upper basin and descends through a narrow valley that gradually broadens into a floodplain of up to several kilometers in width. Approximately 80 percent of Little Bear Creek of the area of the drainage basin is contained within Snohomish County.

The topography was shaped during the Vashon period of the Fraser glaciation between 14,000 and 18,000 years ago. As glaciers receded, they left behind an undulating landscape of till, recessional outwash, and pro-glacial lacustrine and outwash sediments. Lakes and wetlands formed in poorly drained depressions scattered throughout the sub-basin providing areas for surface water storage and groundwater recharge.

Little Bear Creek originates about 1.5 miles north of the town of Clearview, at an elevation of 310 feet and flows approximately 7.7 miles southward into the Sammamish River with an overall gradient of about 0.8 percent. Anadromous salmon and trout access almost all of this system, though there are some significant passage barriers to adults during periods of low stream water flows, and to juveniles during high flows. Most of the basin is situated outside of urban growth boundaries in rurally zoned land. As a result, the basin is still forested (approximately 40 percent), with a present total impervious area of about 37 percent (Simmonds and Purser, Snohomish County unpublished data). Little Bear Creek is currently the least developed of the three main north tributaries to the Sammamish River, and has the least degraded salmon habitat.

B. SALMONID UTILIZATION

The following salmonid species are known to inhabit Little Bear Creek; chinook (*O. tshawytscha*), sockeye (*O. nerka*), kokanee (*O. nerka*), and coho (*O. kisutch*) salmon and coastal cutthroat (*O. clarki clarki*) trout (Williams et al. 1975). Steelhead/rainbow trout (*O. mykiss*) are presumed to use the sub-area.

In 1998 and 1999, volunteer salmon watchers observed adult sockeye at RM 0.2 and 5.9 (King County 2001). In 1998, one chinook was observed at RM 0.2 (King County 2001). In 2000, volunteer observers also sighted adult coho salmon. Also in 1999, King County habitat surveyors observed one chinook redd just south of the King/Snohomish County line (King County, in preparation). They also observed juvenile coho and cutthroat throughout the entire mainstem (King County, in preparation).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

In Little Bear Creek, 88 potential fish passage barriers (culverts, dams, fishways) were assessed using WSDOT's Level A protocols (Adopt-a-Stream, unpublished data). Only 8 of these culverts were fully passable to fish during winter and spring flow conditions (1999). Fully 62 percent of these water crossing structures were deemed impassable because of slope, culvert size or drop, and water velocity-other culverts were questionable.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

The delivery and routing of sediments to stream channels in urbanizing drainages is characterized by asynchronous pulses of sediment originating from basin-wide soil disturbing activities and also from streambank erosion (Trimble 1997). Sediment is also routed to streams by way of the increased drainage network of roads, ditches, outfalls, and surface flow. Where stream discharge increases, streambank erosion is expected, and lower stream segments in Little Bear Creek exhibit a high level of bank disturbance and scouring (KCDNR, in prep.) However, where hydromodifications restrict channel adjustment and LWD is scarce, streambed incision and suspension of bedload to depths critical to incubating salmonids is more frequent. May et al. (1997) reported that lower Little Bear Creek stream segments were entrenched within the floodplain and bed scour exceeded 20 cm (in 1995-1996), a critical depth for coho salmon redds.

An increase in fine sediment delivery and transport through the channel network can lead to riffle embeddedness and pool filling, both of which have been documented in Little Bear Creek (KCDNR, in prep.) Furthermore, in urbanizing Puget lowland streams, the total suspended solids in storm flows is significantly greater in basins with higher impervious area (May et al. 1997). The direct and indirect effects of excess fine sediment include riffle embeddedness, intrusion into redds, pool filling, turbidity, and gill abrasion.

Fine sediment intrusion or coarsening of the streambed also can affect the macroinvertebrate community (Wydzga 1997), and indirectly, trophic support of fish (Sloane-Richey et al. 1981). Morley (2000) sampled macroinvertebrates at 10 locations in Little Bear Creek in 1997 and 1998. She found B-IBI variability was strongly related to local land cover changes (urban to vegetated condition) observed among sampling sites.

No data was located during the course of this investigation that quantified fines in spawning gravels or provided insight into a sediment budget for this subarea.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

In Little Bear Creek, channel complexity and connectivity with the floodplain and adjacent stream reaches are reduced due to road crossings/culverts, streambank hydromodification, abrupt land-use changes, channel incision and instability, and historical and on-going clearing and development in riparian areas. Changes in land-use practices (forest harvest, rural development, and suburbanization) over time have limited in-stream large wood recruitment that contributes to channel complexity. Additionally, with less wood, scour is exacerbated and channel beds are less stable and become riffle dominated. These factors may impact spawning success. In-stream habitat complexity, as characterized by LWD, channel form (bankfull width:depth ratio) and pool area, are significantly degraded.

The highest frequency of LWD (236 pieces/km, at least 2 m long and 15 cm diameter) is observed in the uppermost sub-basin (KCDNR, in prep.), which also was dry during low flows in 1999. All other stream segments did not meet published thresholds of natural LWD occurrence (e.g., 150-460 pieces/km, Peterson et al. 1992). Furthermore, the number of “key” LWD pieces (>0.5 m diameter); those that control bedform, channel migration, and habitat formation, was very low, even where riparian conditions were mature (KCDNR, in prep.).

Channel survey data indicate Little Bear Creek bankfull width to depth ratios rarely exceed 10.0 (KCDNR, in prep.), a threshold of “at risk” functional condition (NMFS 1996). Stable streambanks are the dominant condition in 8 of 13 segments. Streambank armoring and full scour were the dominant conditions in only 2 stream segments (KCDNR, in prep.). Therefore streambank stability may presently limit widespread channel adjustment and degradation even with altered hydrological and sediment regimes (see below).

Stream riffle, pool, and LWD metrics in 1999 were combined into a Habitat Quality Index (HQI- KCDNR, in prep.) score for each stream segment in Little Bear Creek. Approximately ½ of all stream segments scored better than the low habitat quality category, although only three segments contained 40 percent or better pool area coverage, and no stream segment met pool frequency “properly functioning” conditions (NMFS 1996). Spawning habitat, as indicated by riffle area, was less than 40 percent in all but one stream segment. Pool frequency did not meet suggested “properly functioning condition” (30/km) in any stream segments (KCDNR, in prep.). Pool frequency was related to LWD frequency, but did not correspond with riparian conditions (KCDNR, in prep.)

DEGRADATION OF RIPARIAN CONDITIONS

Clearing and development in the riparian corridors has reduced the extent of riparian forests and changed land cover from predominantly coniferous and mixed forests to deciduous forest, and, in turn, from forest to impervious surfaces. Only 7 of 12 stream segments contained at least 50 percent forested riparian area (KCDNR, in prep.), and total riparian forest cover (within 300-ft. of stream and wetlands) was estimated to be 45 percent (Simmonds and Purser, unpublished data). This cover is presently dominated by deciduous species. Only one stream reach contained notable coniferous riparian forest cover (12 percent cover, KCDNR, in prep.). These changes in riparian conditions, along with stream wood removal (May et al. 1997) have led to a reduced amount of available wood that could function as LWD and fish habitat (KCDNR, in prep.).

Stream canopy cover, which contributes to stream temperature regulation and nutrient input, among other functions, was usually low (0-25 percent) at the creek mouth and along State route 9. Otherwise the majority of 8 stream segments (out of 13) had greater than 50 percent canopy coverage (KCDNR, in prep.). Road crossing frequency in riparian areas ranged from 0.2-3.5/km, but tended to decrease in an upstream direction

The degradation of riparian conditions has likely contributed to the need for streambank armoring to protect denuded, eroding streambanks. However, armoring has occurred in 5 of 13 stream segments, and significantly so in only two segments. Streambank scour is very prevalent in downstream segments, while the 5 upstream segments exhibited stable streambanks (KCDNR, in prep.).

ALTERED HYDROLOGY/FLOW

Information on the change in hydrology within Little Bear Creek attributable to land use changes is lacking. However, basin land cover characteristics and stream surveys indicate deleterious effects of hydrologic change (from sub-surface dominated flow paths to surface water) on instream habitat conditions throughout the sub area. These include basin-wide conditions of 40 percent forest cover (Simmonds and Purser, unpublished data) (31.7-37.1 percent by stream segment, KCDNR, in prep.), road density up to 5.9 km/km2, and road crossing frequency up to 3.5 crossings/km (KCDNR, in prep.). Additionally, the undocumented loss of wetlands, loss of floodplain area, water withdrawal and high levels of impervious surfaces basin-wide (37 percent) and within 300-foot stream buffers (30 percent, Simmonds and Purser, unpublished data) contribute to altered hydrologic regimes. Additionally, many tributaries and mainstem creek segments dry up in summer without adequate base flow storage in floodplain and wetland areas upstream. In 1999, the mainstem was mostly dry north of 180th St SE (Segments 14 and 15, KCDNR, in prep.).

WATER QUALITY-INCREASED OTHER

Little Bear Creek is designated Class AA waterbody, and has been monitored by METRO (1989, 1990, 1991) in King County and by Snohomish County at two locations since 1993. Fecal coliform bacteria levels have routinely exceeded standards throughout the watershed

during the period of record, and nitrate levels are among the highest in Snohomish County (Thornburgh and Williams 2000). Dissolved oxygen has not met standards 8 percent of the time. Concentrations of metals and chemicals, including copper, lead, zinc; nickel and chromium were present in sediments collected from the mouth of Little Bear Creek. Biological sampling in 1997 and 1999 in lower Little Bear Creek found fair conditions in comparison with Swamp and North creeks (Thornburgh and Williams 2000). WDOE has determined Little Bear Creek does not support designated uses, and contains three 303(d) listed stream segments for fecal coliform (1998 303(d) list, WDOE). It is unknown at this time what direct, indirect and cumulative effects these water quality conditions have upon the survival of salmonids in Little Bear Creek.

Additionally, in 2000, the King County Small Streams Toxicity/Pesticide study was conducted to assess the presence of pesticides and other toxicants in Little Bear Creek. Little Bear Creek was sampled early and late during a spring storm, several weeks later in the spring when it wasn't raining and again during a storm in the early fall.

Some of the 2000 data have been reported and the preliminary results indicate a variety of pesticides are present in Little Bear Creek during storm and non-storm events. Toxicity to *C. dubia, S. capricornutum,* and *L. minor* was observed early and late during storms and during non-storm conditions (King County unpublished data).

Observed toxicity to test species represents violations of the State water quality standards (State of Washington 1997).

WATER QUALITY-INCREASED TEMPERATURE

Recent investigations have recorded temperatures in excess of 16º C only once since Snohomish County began ambient monitoring in 1992 (Thornburgh and Williams 2000). However, single day volunteer sampling in1999 at 18 sites (University of Washington, Center for Urban Water Resources, unpublished data) found 8 excursions of 16° C. Although, ambient monitoring over the last decade has not documented widespread high temperatures in the sub area, high temperatures in the basin are expected to result from riparian clearing, direct runoff from impervious surfaces, decreased groundwater recharge/discharge, and low flows.

D. KEY FINDINGS AND IDENTIFIED HABITAT- LIMITING FACTORS

- 88 potential fish passage barriers have been assessed and only 8 of these culverts were fully passable to fish during winter and spring flow conditions. 62 percent of these water crossing structures were deemed impassable because of slope, culvert size or drop, and water velocity-other culverts were questionable;
- B-IBI variability in Little Bear Creek was strongly related to local land cover changes (urban to vegetated condition) observed among sampling sites;
- LWD is generally lacking throughout the subarea;

- Only 7 of 12 stream segments contained at least 50 percent forested riparian area, and total riparian forest cover (within 300 feet of stream and wetlands) was estimated to be 45 percent; and
- Preliminary results from a study to observe toxicity and assess the presence of pesticides and other toxicants to test species indicates violations of the State water quality standards.

E. DATA GAPS

- No data was located during the course of this investigation that quantified fines in spawning gravels or provided insight into a sediment budget for this subarea;
- Information on the change in hydrology within Little Bear Creek attributable to land use changes is lacking; and
- It is unknown what the direct, indirect and cumulative effects water quality conditions have upon the survival of salmonids in Little Bear Creek.

NORTH CREEK

A. PHYSICAL DESCRIPTION

North Creek (08.0070) has its headwaters in Snohomish County and flows southward into King County, where it empties into the Sammamish River. The origins of North Creek are in a gently sloping plateau (approximately 160 meter elevation) and descends through a valley that gradually broadens into a floodplain on the Sammamish River valley floor.

The topography was shaped during the Vashon period of the Fraser glaciation between 14,000 and 18,000 years ago. As glaciers receded, they left behind an undulating landscape of till, recessional outwash, and pro-glacial lacustrine and outwash sediments. Lakes and wetlands formed in poorly drained depressions scattered throughout the area providing areas for surface water storage and groundwater recharge. Most soils in the watershed are generally a gravelly sandy type loam (Alderwood, Everett, and Norma soils). The climate and rainfall patterns exhibited are typical of Puget Sound lowland streams. Approximately 75 percent of annual precipitation falls as rain in winter. Snowfall is negligible.

North Creek originates in highly urbanized south Everett in the Everett Mall area and flows southward through Mill Creek and Bothell. The 75 km^2 North Creek subarea is approximately 16 kilometers long and 5 kilometers wide. It contains approximately 70 kilometers of stream, most of which are within the anadromous zone. Major lakes within the subarea include Silver Lake (102 surface acres), Ruggs Lake (11.5 surface acres) and Thomas Lake (7.2 surface acres) (Wolcott 1973). This rapidly urbanizing subarea contains approximately 49 percent impervious surface area (including lakes) (Simmonds and Purser, unpublished data) and over 98 percent of the area is inside the county Urban Growth Boundary.

B. SALMONID UTILIZATION

North Creek supports runs of chinook (*O. tshawytscha*), sockeye (*O. nerka*), kokanee (*O. nerka*) and coho (*O. kisutch*) salmon; steelhead (*O. mykiss*) and coastal cutthroat (*O. clarki clarki*) trout (Williams et al. 1975). In North Creek, Silver Lake is used heavily for recreational fishing of rainbow and cutthroat trout, kokanee and non-native non-salmonids.

Coho salmon counts in North Creek near 164th St SE have ranged from 247 fish/mile in 1976 to 18 fish/mile in 1990. A similar decline was observed in Silver Creek/Tambark Creek (SCSWM 1994b). In 1998 and 1999, Volunteer Salmon Watchers observed 55 and 73 coho salmon, respectively (King County 2001).

In 1999, one chinook redd was observed during stream habitat survey work (King County, in preparation). However, in 1998 and 1999, volunteer Salmon Watchers observed 11 and 22 chinook, respectively (King County 2001). In 2000, five chinook were observed in North Creek (Roger Kelley, Snohomish County, pers. comm.) Salmon Watchers also confirmed the presence of sockeye, kokanee, and cutthroat trout in North Creek (King County 2001).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Adopt-A-Stream Foundation (unpublished data) has identified several fish passage barriers in North Creek. Many culverts in North Creek have also been assessed by Snohomish County and found to be undersized and poorly installed (SCSWM 1994b). The locations of the problem culverts suggest they may be of greater risk to coho, cutthroat and potentially native char, although some fish passage problems on main-stem channels may also exist, especially during low flow conditions prior to adult spawning by chinook salmon.

In addition, high stream water temperatures and low dissolved oxygen levels may be significant enough in some locations to potentially create seasonal migration barriers, although these environmental barriers are more difficult to track. Alterations to the hydrologic and sediment regimes exacerbate existing problems and create additional barriers. All access barriers fragment habitat and potentially disrupt migratory behavior.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

The delivery and routing of sediments to stream channels in urbanizing drainages is characterized by asynchronous pulses of sediment originating from basin-wide soil disturbing activities and also from streambank erosion (Trimble 1997). Sediment is also routed to streams by way of the increased drainage network of roads, ditches, outfalls, and surface flow. Where stream discharge increases, stream channels will tend to over-widen,

and surveyed segments in North Creek exhibit a high level of bank disturbance and scouring (King County, in preparation) However, where hydromodifications restrict channel adjustment and LWD is scarce, streambed incision and scour to depths critical to incubating salmonids can occur (May et al. 1997). In some stream segments in North Creek, the channel has downcut to compact till (F. Leonetti, Snohomish County, pers. obs.).

An increase in fine sediment delivery and transport through the channel network can lead to riffle embeddedness and pool filling, both of which have been documented in North Creek (King County, in preparation). Furthermore, in urbanizing Puget lowland streams, the total suspended solids in storm flows is significantly greater in basins with higher impervious area (May et al. 1997). The direct and indirect effects of excess fine sediment include riffle embeddedness, intrusion into redds, pool filling, turbidity, and gill abrasion. Fine sediment intrusion into streambeds also affects the macroinvertebrate community (Wydzga 1997), and indirectly, trophic support of fish (Sloane-Richey et al. 1981).

No information about sediment contamination or sediment budgets for and reach of stream in this subarea was located during the course of this investigation.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

In North Creek, channel complexity and connectivity with the floodplain and adjacent stream reaches has been reduced due to road crossings/culverts, streambank hydromodification, channel incision and instability, and historical and on-going clearing and development in riparian areas. Changes in land-use practices have limited in-stream LWD recruitment that would have contributed to stream channel complexity. Additionally, with less LWD, scour is exacerbated and channel beds are less stable and become riffle dominated. In-stream habitat complexity, as characterized by LWD, channel form (bankfull width-to-depth ratio) and pool area, are significantly degraded (King County, in preparation). These factors may impact spawning and rearing success, as well as migration and holding.

The highest frequency of LWD (at least 2 m long and 15 cm diameter) was 256 pieces/km, observed in upper North Creek in McCollum Park (King County, in preparation). However, much of this LWD was part of a restoration project. In North Creek, four stream segments contained LWD that met NMFS criteria (NMFS 1996) for minimum size (0.6 x 15 m) of “key” pieces, but the frequency of these pieces was low and could not be considered properly functioning for LWD frequency. Degraded riparian conditions in these reaches, and the lack of LWD recruitment potential warrant a “not properly functioning” designation (NMFS, 1996).

Channel survey data show North Creek bankfull width to depth ratios usually are less than 10, which is indicative of “properly functioning” condition (NMFS 1996). Where bankfull width to depth ratio does exceed 12, there is a preponderance of streambank armoring, which has likely been the result of scour and streambank erosion. Armoring acts to fix

bankfull width to depth ratios, and the channel migration zone within the floodplain becomes constrained or non-existent.

Stream riffle, pool, and LWD metrics in 1999 were combined into a Habitat Quality Index (HQI) (King County, in preparation) score for each stream segment in North Creek. Six stream segments scored in the lowest HQI score category and 7 segments scored better than the medium-low habitat quality category (four categories total) (King County, in preparation). Current land use practices will generally preclude any long-term LWD recruitment.

DEGRADATION OF RIPARIAN CONDITIONS

Clearing and development in the riparian corridors has reduced the extent of riparian forests and changed land cover from predominantly mature coniferous and mixed forests to a young deciduous forest, and, in turn, from forest to impervious surface land cover. Six of 13 stream segments in North Creek contained at least 50 percent forested riparian area adjacent to the stream channel (King County, in preparation). However, total riparian forest cover (within 300 feet of streams and wetlands) is estimated to be less than 30 percent (Simmonds and Purser, unpublished data). Furthermore, only one of thirteen stream reaches contained notable coniferous riparian forest cover (57 percent cover in McCollum Park) (King County, in preparation). These changes in riparian conditions have led to a reduced amount of available wood that could function as LWD. Stream canopy cover, which contributes to stream temperature regulation and nutrient input, among other functions, was usually low (0-25 percent) in more developed stream reaches and higher (26-76 percent) in less developed areas along North Creek (King County, in preparation).

Additionally, the degradation of riparian conditions has likely contributed to the need for streambank armoring to protect denuded, eroding streambanks. Channel armoring (>5 percent of stream segment) occurs in 7 of 13 stream segments, and only three stream segments were stable over 80 percent of their length, which would indicate “properly functioning” conditions for streambank stability in those segments (King County, in preparation).

ALTERED HYDROLOGY/FLOW

Alterations to the hydrologic regime in North Creek have been documented from gauging station data and modeling efforts (SCSWM 1994b; CH2Mhill 1997). It is estimated that the current 2-year flood discharge exceeds the historical 100-year discharge for North Creek (SCSWM 1994b), and since the mid-1970s, peak flows for the 100-year flood have increased by 50 percent. Furthermore, many tributaries and mainstem creek segments dry up in summer without adequate base flow storage in floodplain and wetland areas (SCSWM 1994b).

Basin land cover alterations are the root causes of hydrologic change in these subareas. These include basin-wide conditions of only 23 percent forest land cover, road density up to 9.8 km/km2, and road crossing frequency up to 2 crossings/km (King County, in

preparation). Additionally, the loss of wetlands, loss of floodplain area, water withdrawal and high levels of impervious surfaces (49 percent, Simmonds and Purser, unpublished data) contribute to the altered hydrologic regimes.

WATER QUALITY-INCREASED TEMPERATURE

North Creek is designated Class AA waterbody by the WDOE. Snohomish County has monitored North Creek at multiple locations since 1992. In North Creek, temperature has exceeded 16º C twenty-six percent of the time and 18º C four percent of the time (Thornburgh and Williams 2000). High stream temperatures in the basin result from riparian clearing, direct runoff from impervious surfaces, decreased groundwater recharge/discharge, and low flows. These values not only exceed State designated standards, but also are in excess of required temperatures for successful salmonid rearing.

WATER QUALITY- OTHER

North Creek is designated Class AA waterbody by the WDOE. Water quality in North Creek has been monitored by Snohomish County at multiple locations since 1992. Dissolved oxygen in North Creek has not met standards 19 percent of the time. Fecal coliform bacteria levels routinely exceeded water quality standards throughout the watershed during the period of record (Thornburgh and Williams 2000). Concentrations of metals, including copper, lead, zinc, and chromium, are some of the highest in Snohomish County (Thornburgh and Williams 2000). Furthermore, biological sampling in 1997 and 1999 in lower North Creek found few long-lived and “clinger” invertebrate species (Thornburgh and Williams 2000). WDOE has determined North Creek does not support its designated uses. North Creek contains 303(d) listed stream segments for violations that exceed water quality standards for dissolved oxygen and fecal coliform. It is unknown at this time what direct, indirect and cumulative effects these water quality conditions have upon the survival of salmonids in North Creek.

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek. Counts of adult salmonids, primarily coho are made in index reaches annually but counts for adult chinook and sockeye are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Stream channel complexity and connectivity with the floodplain and adjacent stream reaches has been reduced;
- LWD is lacking;
- High levels of impervious surfaces (49 percent) are present in this subarea;
- The current 2-year flood discharge exceeds the historical 100-year discharge for and since the mid-1970s, peak flows for the 100-year flood have increased by 50 percent;
- Many tributaries and mainstem creek segments dry up in summer;

- Stream water temperature has exceeded 16º C twenty-six percent of the time and 18º C four percent of the time in North Creek;
- Dissolved oxygen in North Creek has not met standards 19 percent of the time; and
- Biological sampling in 1997 and 1999 in lower North Creek found few long-lived and "clinger" invertebrate species which is indicative of poor water quality.

E. DATA GAPS

- No information was located during the course of this investigation about sediment budgets for any portion of the North Creek subarea;
- It is unknown at this time what direct, indirect and cumulative effects the poor water quality conditions of North Creek have upon the survival of salmonids in North Creek; and
- A comprehensive fish barrier assessment is missing.

SWAMP CREEK

A. PHYSICAL DESCRIPTION

Swamp Creek (08.0059) has its origins in Snohomish County and flows southward into King County, before it empties into the Sammamish River at RM 0.6. Swamp Creek begins in a gently sloping plateau (approximately 160 meters elevation) and descends through a narrow valley that gradually broadens into a floodplain on the Sammamish River valley floor.

The topography was shaped during the Vashon period of the Fraser glaciation between 14,000 and 18,000 years ago. As glaciers receded, they left behind an undulating landscape of till, recessional outwash, and pro-glacial lacustrine and outwash sediments. Lakes and wetlands formed in poorly drained depressions scattered throughout the area providing areas for surface water storage and groundwater recharge. Most soils in the subarea are generally a gravelly sandy type loam (Alderwood, Everett, and Norma soils). The climate and rainfall patterns exhibited are typical of Puget Sound lowland streams. Approximately 75 percent of annual precipitation falls as rain in winter. Snowfall is negligible.

The Swamp Creek sub-basin, approximately 18 kilometers long and 3 kilometers wide, encompasses 64 square kilometers (km^2). Stream channel gradient ranges from 1 to 6 percent (May et al. 1997). It contains Scriber Lake (3.4 surface acres), Martha Lake (59.3 surface acres), Lake Stickney (25.7 surface acres) (Wolcott 1973) and 59 kilometers of stream channels, most of which are within the anadromous zone. It drains portions of Lynnwood, Everett, Brier, Bothell, Mountlake Terrace, Kenmore and unincorporated Snohomish County. The entire sub-basin resides within the Urban Growth Boundaries of southern Snohomish and northern King counties. It is estimated that approximately 52

percent of the Swamp Creek drainage land is impervious (Simmonds and Purser, Snohomish County Surface Water Management, unpublished data).

B. SALMONID UTILIZATION

Swamp Creek supports runs of chinook (*O. tshawytscha*), sockeye (*O. nerka*), kokanee (*O. nerka*), and coho (*O. kisutch*) salmon; steelhead (*O. mykiss*) and coastal cutthroat (*O. clarki clarki*) trout (Williams et al. 1975).

In 1999 and 2000, coho, sockeye, and kokanee adults and redds were observed south of the King/Snohomish County line (Wesley Sprague, King County, pers. comm.). Volunteer Salmon Watch observers did not observe any spawning adults in 1998 and 1999 in Swamp Creek in Snohomish County (King County 2001). Spawning surveys for chinook and sockeye are sporadic and more consistent for coho.

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Adopt-A-Stream Foundation (in progress) is conducting fish passage barrier assessments in Swamp Creek. Numerous culverts in Swamp Creek have also been assessed by Snohomish County and found to be undersized and poorly installed (SCSWM 1994a). The locations of the problem culverts suggest they may be of greater risk to coho, cutthroat and potentially native char, although some fish passage problems on main-stem channels may also effect chinook. Culverts under I-405 and I-5 likely impede passage under certain flow conditions. Where Martha Creek crosses under I-405, there is a complete blockage (Craig Young, pers. comm.).

In addition, high stream water temperature and low dissolved oxygen levels are significant enough in some locations to potentially create seasonal migration barriers, although these environmental barriers are more difficult to track. Alterations to the hydrologic and sediment regimes exacerbate existing problems and create additional barriers. All access barriers fragment habitat and potentially disrupt migratory behavior.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

The delivery and routing of sediments to stream channels in urbanizing drainages is characterized by asynchronous pulses of sediment originating from basin-wide soil disturbing activities and also from streambank erosion (Trimble 1997). Sediment is also routed to streams by way of the increased drainage network of roads, ditches, outfalls, and surface flow. Where stream discharge increases, stream channels will tend to over-widen, and the majority of surveyed segments in Swamp Creek exhibit a high level of bank disturbance and scouring (King County, in preparation). However, where hydromodifications restrict channel adjustment and LWD is scarce, streambed incision and scour to depths critical to incubating salmonids have occurred in Swamp Creek (May et al.

1997). In some stream segments in Swamp Creek, the channel has downcut to compact till (F. Leonetti, pers. obs.).

An increase in fine sediment delivery and transport through the channel network can lead to riffle embeddedness and pool filling, both of which have been documented in Swamp Creek (King County, in preparation). Furthermore, in urbanizing Puget lowland streams, the total suspended solids in storm flows is significantly greater in basins with higher impervious area (May et al. 1997). The direct and indirect effects of excess fine sediment include riffle embeddedness, intrusion into redds, pool filling, turbidity, and gill abrasion. Fine sediment intrusion into streambeds also affects the macroinvertebrate community (Wydzga 1997), and indirectly, trophic support of fish (Sloane-Richey et al. 1981).

No information about sediment contamination or sediment budgets for and reach of stream in this subarea was located during the course of this investigation.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

In Swamp Creek, channel complexity and connectivity with the floodplain and adjacent stream reaches are reduced due to road crossings/culverts, streambank hydromodification, channel incision and instability, and historical and on-going clearing and development in riparian areas. Changes in land-use practices have limited in-stream large wood recruitment that contributes to channel complexity. Additionally, with less wood, scour is exacerbated and channel beds are less stable and have become riffle dominated in many segments (King County, in preparation). In-stream habitat complexity, as characterized by LWD, channel form (bankfull width to depth ratio) and pool area, are significantly degraded (King County, in preparation). These factors may impact spawning and rearing success, as well as migration and holding.

The highest frequency of LWD (at least 2 m long and 15 cm diameter) was 121 pieces/km, observed in lower Swamp Creek (near Kenmore. King County, in preparation). No Swamp Creek stream segment met published thresholds of natural LWD occurrence (e.g., 150-460 pieces/km, Peterson et al. 1992). Channel survey data indicate Swamp Creek bankfull width to depth ratios usually exceed 12 (King County, in preparation). NMFS (1996) indicates “properly functioning condition” for bankfull width to depth ratio should be 10 or less. Given that streambank armoring is a common occurrence in Swamp Creek (present in 8 of 13 total stream reaches, King County, in preparation), bankfull width to depth ratios are fixed in many locations and the channel migration zone within the floodplain is dramatically constrained or non-existent.

Stream riffle, pool, and LWD metrics in 1999 were combined into a Habitat Quality Index (HQI, King County, in preparation) score for each stream segment in Swamp Creek. Only 3 of 13 stream segments (pooled streams) scored better than the medium-low habitat quality category (4 categories). 6 of the 13 stream segments scored in the lowest habitat quality category.

DEGRADATION OF RIPARIAN CONDITION

Clearing and development in the riparian corridors has reduced the extent of riparian forests and changed land cover from predominantly mature coniferous and mixed forests to young deciduous forest, and, in turn, from forest to impervious surface land cover. Ten of 13 stream segments in Swamp Creek contained at least 50 percent forested riparian area adjacent to the creek (King County, in preparation). However, Simmonds and Purser (unpublished data), determined total riparian forest cover is less than 30 percent within 300 feet of streams and wetlands. Furthermore, only two stream segments contained notable coniferous riparian forest cover (13 and 46 percent cover) that could contribute high quality LWD (King County, in preparation), but not enough to establish properly functioning conditions. These changes in riparian conditions have led to a reduced amount of available wood that could function as LWD (King County, in preparation).

Stream canopy cover, which contributes to stream temperature regulation and nutrient input, among other functions, was usually low (0-25 percent) in more developed stream reaches and higher (26-76 percent) in less developed areas Swamp Creek (King County, in preparation).

Additionally, the degradation of riparian conditions has likely contributed to the need for streambank armoring to protect denuded, eroding streambanks. Channel armoring occurs in 8 of 13 stream segments, and only 3 of 13 stream segments were more than 70 percent stable, and were otherwise dominated by either streambank armoring or erosion (King County , in preparation).

ALTERED HYDROLOGY/FLOW

Alterations to the hydrologic regime in Swamp Creek have been documented from gauging station data and research efforts (SCSWM 1994a; Moscrip and Montgomery 1997). It is estimated that the current 2-year flood discharge exceeds the historical 100-year discharge in Swamp Creek (SCSWM 1994a). Additionally, Moscrip and Montgomery (1997) demonstrated that the frequency of flood flows increased during the period of hydrologic record from 1964 -1990. This coincided with urbanization over the same period of record, which was strongly correlated with spawner abundance (all anadromous species). In other Puget lowland streams (e.g., May Creek) without significant urbanization, spawner abundance remained unchanged over the same period of record (Moscrip and Montgomery 1997). Furthermore, many tributaries and mainstem creek segments in Swamp Creek dry up in summer without adequate base flow storage in floodplain and wetland areas (SCSWM 1994a).

Basin land cover alterations are the root causes of hydrologic change in Swamp Creek. These include basin-wide conditions of only 19 percent forested cover, road density up to 9.2 km/km2, and road crossing frequency up to 7 crossings/km (King County, in preparation). Additionally, the loss of wetlands, loss of floodplain area, water withdrawal and high levels of impervious surfaces (>50 percent, Simmonds and Purser, unpublished data) contribute to the altered hydrologic regimes.

The effects have been peak flows of greater intensity and duration, lower summer flows, increased flashiness, over-widening of the stream channel, bank erosion, and scour of the streambed. This, in turn, has led to the washout of LWD, reduction in pool frequency and pool habitat quality, scour of salmon redds, and degradation of the aquatic macroinvertebrate communities (May et al. 1997).

WATER QUALITY-INCREASED TEMPERATURE

Swamp Creek is designated Class AA waterbody by WDOE. Snohomish County has monitored Swamp Creek at multiple locations since 1992. In Swamp Creek, investigations have recorded temperatures in excess of 16º C, 34 percent of the time and 18º C, 4 percent of the time (Thornburgh and Williams 2000). High stream temperatures in the basin result from riparian clearing, direct runoff from impervious surfaces, decreased groundwater recharge/discharge, and low flows. These values not only exceed State designated standards, but also are in excess of required temperatures for successful salmonid rearing.

WATER QUALITY-INCREASED OTHER

Swamp Creek is designated Class AA waterbody by WDOE. Snohomish County has monitored water quality in Swamp Creek at multiple locations since 1992. In Swamp Creek, at the King/Snohomish County line, dissolved oxygen has not met standards 18 percent of the time, although standards have been met since 1995. In Swamp Creek, fecal coliform bacteria levels have routinely exceeded standards throughout the watershed during the period of record (Thornburgh and Williams 2000). Concentrations of metals, including copper, lead, zinc, and chromium are some of the highest in Snohomish County (Thornburgh and Williams 2000). Furthermore, biological sampling in 1997 and 1999 in lower Swamp Creek found few long-lived and “clinger” invertebrate species (Thornburgh and Williams 2000). DOE has determined Swamp Creek does not support their designated uses. Swamp Creek contains 303d listed stream segments for dissolved oxygen and fecal coliform. It is unknown at this time what direct, indirect and cumulative effects these water quality conditions have upon the survival of salmonids in Swamp Creek.

Additionally, in 2000, the King County Small Streams Toxicity/Pesticide study was conducted to assess the presence of pesticides and other toxicants in Swamp Creek. Swamp Creek was sampled early and late during a spring storm, several weeks later in the spring when it wasn't raining and again during a storm in the early fall.

Some of the 2000 data have been reported and the preliminary results indicate a variety of pesticides are present in Swamp Creek during storm and non-storm events. Toxicity to *C. dubia, S. capricornutum,* and *L. minor* was observed early and late during storms and during non-storm conditions (King County unpublished data).

Observed toxicity to test species represents violations of the State water quality standards (State of Washington 1997). Measured levels of diazinon in Swamp Creek approached

levels that NMFS (Scholz et al. 2000) reported as having an adverse effect on chinook salmon's predator avoidance response and homing ability.

D. KEY FINDINGS AND IDENTIFIED HABITAT- LIMITING FACTORS

- It is estimated that approximately 52 percent of the Swamp Creek drainage land is an impervious surface;
- In-stream habitat complexity, as characterized by LWD, channel form and pool area, are significantly degraded;
- The total riparian forest cover is less than 30 percent within 300 feet of streams and wetlands;
- It is estimated that the current 2-year flood discharge exceeds the historical 100-year discharge in Swamp Creek. Additionally, the frequency of flood flows increased during the period of hydrologic record from 1964 –1990;
- In Swamp Creek, investigations have recorded temperatures in excess of 16º C 34 percent of the time and 18º C 4 percent of the time;
- Concentrations of metals in Swamp Creek streamwater, including copper, lead, zinc, and chromium are some of the highest in Snohomish County; and
- Measured levels of diazinon in Swamp Creek approached levels that NMFS reported as having an adverse effect on chinook salmon's predator avoidance response and homing ability.

E. DATA GAPS

- A comprehensive fish barrier assessment has not been conducted but one is currently being completed; and
- No information about sediment contamination or sediment budgets for and reach of stream in this subarea was located during the course of this investigation.

LAKE SAMMAMISH

LAKE SAMMAMISH

A. PHYSICAL DESCRIPTION

Lake Sammamish is located approximately 16 kilometers east of Seattle and is situated within the northern end of the 223 km^2 Sammamish Watershed. The lake provides a wide range of recreational and natural resource opportunities. The majority of the shoreline is privately owned; with a few major public parks that are located on the lakeshore, including King County's Marymoor Park at the north end of the lake, and the City of Redmond's Idylwood Park on the northwest end of the lake. Sammamish State Park, the most heavily used park in the State Park system, is located at the south end of the lake. The lake is designated as a "resource of statewide significance" under Washington's Shoreline Management Act, and provides migratory and rearing habitat for many salmonid species and wildlife, as well as supporting a variety of introduced warm water fish. Water quality plays a key role in protecting the lake's recreational uses, its ecological health and scenic beauty.

Lake Sammamish is approximately 13 kilometers long and 2 kilometers wide with a surface area of 19.8 km^2, a maximum depth of 32 meters and a mean depth of 17.7 meters. The major tributary to the lake is Issaquah Creek (08.0178), which enters at the south end and contributes approximately 70 percent of the surface flow (and phosphorus load) (Entranco et al. 1996). Tibbetts Creek (08.0169) to the south, and Pine Lake Creek (08.0152) to the east, contribute about 6 percent and 3 percent of the flow, respectively (Entranco et al. 1996). Surface water discharge from Lake Sammamish is through the Sammamish River (08.0057) at the north end of the lake, where a flow control weir at Marymoor Park controls the discharge (see discussion in Sammamish River chapter).

B. SALMONID UTILIZATION

Although Lake Sammamish serves as a migration route for juvenile salmon migrating from their natal tributaries and adult salmon returning to their natal tributaries to spawn, little is known about how these fish actually utilize the lake. Summer/fall chinook salmon returning to the Issaquah Creek State Fish Hatchery and naturally spawning fish returning to Issaquah Creek and other tributary streams must pass through the lake. Coho salmon spawn in tributaries (i.e., George Davis, Zacuse, Ebright, Pine Lake, Kanim, Laughing Jacobs, Mary Springs, Issaquah, Tibbetts and Lewis Creeks) to the lake, and sockeye and kokanee utilize Lake Sammamish for rearing. Historically, a stock of early timing kokanee salmon returned to spawn in Issaquah Creek during August and currently later kokanee runs spawn in various tributaries that flow into the lake (Ostergaard et al. 1995, Ostergaard 1996, Ostergaard 1998a, Ostergaard 1998b, and Ostergaard 1998c, R2 Resources 2000). Coastal cutthroat trout also reside in the basin.

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Fish access and passage barriers have been identified as a possible factor of decline, however, there is limited data to determine the extent to which this is a problem. There is a concern that the weir located at the outlet of the lake (at Marymoor Park) may impede access and migration of salmonids. In addition, a culvert in Lewis Creek under Interstate 90 is a migration barrier to the upper portion of this drainage.

DEGRADATION OF RIPARIAN CONDITIONS

There has been a general loss of natural riparian habitat along the Lake Sammamish shoreline. Shoreline development and associated bank armoring has likely been the cause of the significant loss of riparian vegetation along much of the lake's shoreline. Very little native vegetation remains along the lake's shoreline, which currently consists primarily of landscaped suburban lawns (Kahler et al. 2000). It is possible that lack of native plant communities along the shoreline may be causing a decline or shift in available food resources. However, a complete understanding of in-lake habitat is currently unknown. Docks and bulkheads are suspected to contribute to an overall decline in both the quality and quantity of available shoreline habitat and also likely contribute to alteration of the aquatic community structure. However, it is currently unknown to what degree docks and bulkheads impact survival of juvenile chinook salmon or other salmonids in Lake Sammamish.

PREDATION

Alteration of the type and abundance of salmonid predators in Lake Sammamish have been identified as a probable factor of decline. Change in plant and animal species composition (e.g., increases in predators and invasive species of both fish and aquatic plants) and habitat quality and quantity associated with alteration and loss of littoral habitat may contribute to shifts in fish predation dynamics. The extent to which shifts in predation impact salmonid survival and the successful reproduction of fish or other aquatic organisms, however, is not clearly understood.

It is suspected that loss and alteration of littoral habitat may have resulted in an overall change in species composition (e.g., increase in predators, increase in invasive species of both fish and aquatic plants) and predation dynamics. Currently, however, there are few data available to quantify the extent to which this is a problem.

ALTERED SPECIES COMPOSITION AND INTER-SPECIES DYNAMICS

As previously indicated above, the structure and dynamics of the Lake Sammamish food web are currently not well understood. It is suspected however, that the combination of introduced species and altered habitat in the lake have significantly altered the historical species composition, which in turn has likely impacted salmonids and other aquatic life.

POOR WATER QUALITY

After approximately a ten-year period of increasing in-lake total phosphorus levels, recent monitoring data has shown a decline in total phosphorus. Alkalinity and pH levels have increased over this period (King County 2000). The direct impact of these changes on salmonid survival and reproduction is unknown. It is likely, however, that impacts to juvenile fish would be indirect, including changes such as nutrient levels, phyto- and zooplankton abundance and composition, and resulting changes to the food web structure.

Temperature and summer stratification are key elements that drive many chemical and biological interactions within the Lake Sammamish ecosystem. Lake Sammamish is monomictic (stratifies once a year) with thermal stratification usually beginning in late May and lasting until mid November. During this stratified period, the mean epilimnetic (upper layer) temperature is 16° C, while the hypolimnion is approximately 10° C. Between these 2 layers is the metalimnion (middle layer), where temperature is not isothermal (same temperature throughout the water column) but is generally cooler than epilimnetic waters (i.e., less 16° C), and warmer than hypolimnetic waters (i.e., greater than 10° C). The thermocline, or depth at which the greatest temperature gradient can be found, is within the metalimnion. Average maximum temperatures of ~20° C in the epilimnion and ~10° C in the hypolimnion, occur in early August. Stratification typically breaks down in mid-November when epilimnetic water has sufficiently cooled to decrease the temperature (density) gradient between the three layers. During the un-stratified or isothermal period, mid-November through late May, whole lake temperatures range from ~6° C to 10° C, with minimum temperatures occurring in February, and the maximum, at the onset of stratification, in May. As the surface waters warm, the depth of the epilimnion increases. Dissolved oxygen content in the hypolimnion decreases in late summer and early fall (King County 1995, Isaac et al. 1966). Due to lack of sufficient oxygen in the hypolimnion, and the relatively warm temperature of the epilimnion, many salmonids prefer the cooler, oxygenated waters of the metalimnion. However, the process described above serves to decrease the overall depth of the metalimnion over the course of the summer and early fall, and is suspected to decrease habitat available for salmonids and other aquatic species. The extent of the impact of this ‘habitat constriction’ however, is unknown.

In addition to nutrient enrichment, there is also a concern that contaminants (e.g., pesticides, metals) are being discharged into the lake from non-point sources (e.g., non-point runoff, stormwater). Recent work by NMFS (Scholz et al. 2000) suggests low-level short-term exposure to diazinon, a commonly used pesticide, may have an adverse impact on the olfactory process in salmon (EPA has recently initiated an eventual "phase out" of residential home use of diazinon). While this may limit future discharges of diazinon into Lake Sammamish, other commonly available pesticides may still have significant impacts to aquatic life. The lake is surrounded primarily by suburban homes with large landscaped yards. As such, the opportunity for diazinon and other commonly used pesticides to enter the lake is significant. However, at this point the extent to which pesticides or other contaminants impact salmon or other aquatic organisms in the lake is unknown. King

County recently initiated collection of water quality data for low level pesticides and metals. These data, combined with additional biological data being collected will provide information to better evaluate the extent to which contaminants may adversely impact aquatic organisms in the lake.

POOR SEDIMENT QUALITY

In general, sediment quality in Lake Sammamish is relatively good, particularly compared to Lakes Washington and Union. However, select areas contain elevated concentrations of sediment-associated contaminants (King County - unpublished data, Lester and Wilson 2000). The effect of these contaminants on salmonids and/or other aquatic organisms is currently unknown. It is likely, however, that any impacts would be indirect and a result off contaminant transfer and/or biomagnification through the food web. A preliminary sediment evaluation in 1995 indicated that concentrations of 6 sediment-associated contaminants (i.e., carbazole, di-n-butylphthalate, bis(2-ethylhexyl)phthalate, nickel, indeno(1,2,3-c,d,)pyrene and dibenzo(a,h)anthracene) exceeded the draft Washington State freshwater guidelines for sediment quality standards (King County unpublished data). In 1999, a comprehensive sediment evaluation was conducted by King County as part of the Sammamish Washington Assessment and Modeling Project (SWAMP) which included physical and chemical analysis, toxicity testing and an evaluation of benthic community structure (Lester and Wilson 2000). These data are currently being analyzed, however preliminary results suggest that while sediment quality is relatively good; there are a few areas of concern (e.g., Sunset Pumpstation).

ALTERED MACROPHYTE DENSITY AND DIVERSITY

Changes in the overall density and diversity of macrophytes in Lake Sammamish have been identified as a possible factor of decline. Eurasian water milfoil (*Myriophyllum. spicatum*), a non-native invasive macrophyte, has replaced native aquatic vegetation in many areas of the lake. Excessive macrophyte growth can impede wave action and decrease sediment movement, and as a result serves to trap fine material that may have otherwise been carried to deeper depths. Excessive growth may also decrease available littoral habitat for some aquatic organisms. As macrophyte density increases, species composition of some organisms may change. While macrophytes provide habitat for some organisms such as macroinvertebrates, they may also serve to provide a refuge for predators while displacing other organisms. Extensive monotypic patches of Eurasian water milfoil also locally degrade water quality by reducing dissolved oxygen levels below minimum requirements for salmonids (Frodge et al. 1995). The invasive nature of Eurasian water milfoil has likely decreased the overall diversity of macrophytes throughout the lake. The potential impacts of this condition on the survival and reproduction of salmon and/or other aquatic organisms is unknown.

BIOLOGICAL PROCESSES

Escapement goals are not set for Lake Sammamish and no estimates of resident (i.e.: kokanee) utilization are available.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Alteration of the type and abundance of salmonid predators in Lake Sammamish have been identified as a probable factor of decline;
- Select areas of the Lake Sammamish contain elevated concentrations of sediment-associated contaminants;
- Eurasian water milfoil locally degrades water quality by reducing dissolved oxygen levels below minimum requirements for salmonids. The invasive nature of Eurasian water milfoil has likely decreased the overall diversity of macrophytes throughout Lake Sammamish.

E. DATA GAPS

- Little is known about how these juvenile and adult salmonids actually utilize the lake;
- A complete understanding of in-lake habitat is currently unknown;
- It is currently unknown to what degree docks and bulkheads impact survival of juvenile chinook salmon or other salmonids in Lake Sammamish;
- There is limited data to determine the extent to which the weir at Marymoor Park is a problem;
- The extent to which shifts in predation impact salmonid survival and the successful reproduction of fish or other aquatic organisms, however, is not clearly understood;
- It is suspected that the loss and alteration of littoral habitat may have resulted in an overall change in species composition (e.g., increase in predators, increase in invasive species of both fish and aquatic plants) and predation dynamics. Currently, however, there are few data available to quantify the extent to which this is a problem;
- The direct impact of these changes of in-lake phosphorus levels on salmonid survival and reproduction is unknown;
- The water quality processes described above illustrates a decrease to the overall depth of the metalimnion over the course of the summer and early fall, and is suspected to decrease habitat available for salmonids and other aquatic species. The extent of the impact of this 'habitat constriction' however, is unknown;
- At this time, the extent to which pesticides or other contaminants impact salmon or other aquatic organisms in the lake is unknown; and
- The effect of sediment contaminants on salmonids and/or other aquatic organisms in Lake Sammamish is currently unknown.

LAKE SAMMAMISH TRIBUTARIES

EAST LAKE SAMMAMISH TRIBUTARIES

A. PHYSICAL DESCRIPTION

Much of the information contained in this chapter is somewhat dated and it should be noted that the growth in this subbasin has been substantial since the information was gathered.

The East Lake Sammamish Tributaries encompass approximately 16 square miles and contains six main streams (Laughing Jacobs (08.0166), Many Springs (08.0164A), Pine Lake (08.0152), Ebright (08.0149), Zaccuse (08.0145A), and George Davis (08.0144) along with two small lakes (Beaver and Pine) and 40 inventoried wetlands (9 of which are rated unique or outstanding) (King County 1994). Six sub-basins have been identified as part of the East Lake Sammamish basin.. These sub-basins are Laughing Jacobs, Pine Lake, Monohan, Panhandle, Inglewood, and Thompson. There is a total of 27 miles of streams, of which only 4 miles are accessible to anadromous fish. These streams are currently inaccessible to salmonids due to erosion, dredging and culvert blockages along the East Lake Sammamish Parkway, as well as natural stream channel gradient. Historically, there were 8 to 10 more miles accessible to anadromous fish (King County 1990). Most streams are short and steep, running through incised ravines. The urbanization of the basin has resulted in a variety of hydrologic and physical changes within the stream channels. Increases in peak flows and duration of high flows has resulted in expanding channel size, increased bank erosion, and increases in sediment disrupting the aquatic habitat (King County 1990; King County 1994).

B. SALMONID UTILIZATION

Chinook salmon have been seen in small numbers in the Thompson and Laughing Jacobs sub basins (King County 1997 and King County unpublished data). Coho, sockeye, kokanee, cutthroat trout and rainbow trout utilize the Laughing Jacobs, Pine Lake and Thompson sub basins. Coho salmon, cutthroat and rainbow trout are found in the Monohan and Inglewood sub basins. No salmonids are found in the Panhandle sub basin as a railroad line, the East Lake Sammamish Parkway and steep slopes restrict access (King County 1994).

C. HABITAT FACTORS OF DECLINE

PANHANDLE SUBBASIN

GENERAL

The Panhandle subbasin includes thirteen small streams numbered from north to south as 08.0143, 08.0143B, 08.0143C, 08.0143D, 08.0143E, 08.0143F, 08.0143G, 08.0143M, 08.0143H, 08.0143I, 08.0143J, 08.0143K, and 08.0143L. Several of these identified

drainages are perennial and all flow at least half the year. All originate from springs and seeps on the steep western slope.

Aquatic habitat in these drainages is minimal and no fish have been observed in any of these thirteen streams.

FISH ACCESS AND PASSAGE BARRIERS

All of these streams cross under East Lake Sammamish Parkway thru highway cross-culverts that clog from upstream derived sediments (King County 1994). This is symptomatic of uphill development impacts and results from fundamental alterations in the natural hydrologic regime.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

As a result of upland development, runoff no longer infiltrates into subsurface aquifers but is collected by the storm-drain system, runs off cleared and compacted ground, and into the stream course. This flow then further erodes from the top of the western facing slope, often forming a new channel and transporting substantial amounts of sediment that is derived from the new channel, into downstream reaches. The amount of increased sediment transported has not been quantified.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was located during the course of this investigation for the Panhandle Subbasin streams. However, King County (1994) indicated that aquatic habitats in the Panhandle drainages were “minimal”.

DEGRADATION OF RIPARIAN CONDITIONS

No quantifiable information was located during the course of this investigation for the Panhandle Subbasin streams

ALTERED HYDROLOGY / FLOW

Surface water problems are distributed unequally across the subarea. Because of the limited tributary areas in the Panhandle subbasin, King County did not model flows using any methodology in their 1994 basin plan. No quantifiable information was located during the course of this investigation for the Panhandle Subbasin streams.

WATER QUALITY

No quantifiable information was located during the course of this investigation for the Panhandle Subbasin streams.

INGLEWOOD SUBBASIN

GENERAL

The Inglewood Subbasin includes George Davis Creek (08.0144), which is also referred to locally as Inglewood Creek or Eden Creek. The creek has its origins from Wetland 26, east of 228th Avenue NE and north of SE 24th Street.

FISH ACCESS AND PASSAGE BARRIERS

A culvert under a private residence (~RM 0.2) was identified as a fish passage barrier and sediment accumulation in the lower reaches may limit usable habitat and be a partial barrier under specific flow conditions (King County 1994).

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Flooding problems were noted in the 1980s and early 1990s due to increased sediment buildup at the cross-culverts at East Lake Sammamish Parkway and the Burlington Northern Railroad tracks. The sediment source was the ravine upstream of RM 0.2.

During field surveys in 1987, King County staff noted severe landslides in the unnamed stream 08.0145 from RM 0.40 - 0 .55.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was located during the course of this investigation for the Panhandle Subbasin streams.

DEGRADATION OF RIPARIAN CONDITIONS

In 1989 land cover was approximately 7 percent impervious surface and 65 percent forest. It is predicted to be 24 percent impervious surface and 69 percent grass at full grow out (King County 1994).

ALTERED HYDROLOGY / FLOW

Changes in land cover are predicted to result in significant increases in stream flows. The average flow increase is greater than 200 percent for most of the stream system downstream of 228th Avenue NE. A subcatchment (I3) was predicted to experience the greatest flow increase of any subcatchment modeled in the East Lake Sammamish basin area with an increase of over 400 percent. This equates to an increase average of the 2-year through 100-year return period flows from 7.5 cfs to 38.3 cfs at Subcatchment I3.

WATER QUALITY

Identified water quality concerns in this subbasin include increased nutrient and bacterial levels in George Davis Creek during storm events. Stormwater samples from commercial levels were demonstrated to contain high levels of bacteria, suspended solids and heavy metals that enter tributary 08.0144D during periods of heavy rainfall.

THOMPSON SUBBASIN

GENERAL

The Thompson Subbasin is approximately three square miles in size and includes Ebright Creek (08.0149) along with two small tributaries. The creek has its origins from four wetlands, which lie near the western edge of the plateau.

FISH ACCESS AND PASSAGE BARRIERS

Coho, sockeye and kokanee salmon utilize the creek although a small dam at RM 0.45 blocks fish migration to upstream reaches. Upstream of the dam coastal cutthroat trout are present (King County 1994).

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

King County (1994) identified bed and bank erosion in the upper and middle reaches of Ebright Creek as a problem. This erosion in turn resulted in sedimentation of the lower stream reaches, which adversely impacts successful salmonid spawning. Additionally, the increased sediment loading has caused occasional roadway flooding due to filling of the culverts with these sediments.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was located during the course of this investigation for the Thompson Subbasin streams.

DEGRADATION OF RIPARIAN CONDITIONS

Land use in 1989 for the subbasin indicates that it was dominated by single family rural residences in the north and east of Wetland 17 and at the mouth of Ebright Creek. Some forest use occurs in the eastern and southeastern portions of the subbasin but no quantifiable information was located during the course of this investigation.

ALTERED HYDROLOGY / FLOW

Changes in land cover are predicted, without mitigation, to result in significant increases in stream flows. The average flow increase is expected to increase 100 to 150 percent (20 to 40 cfs).

WATER QUALITY

No major water quality problems have been identified in this subbasin although elevated turbidity and nutrient levels have been recorded (King County 1994).

PINE LAKE SUBBASIN

GENERAL

The Pine Lake Subbasin is approximately 1,175 acres in size and includes Pine Lake (86 acres), Pine Lake Creek (08.0152) and Kanin Creek (08.0153). The creek has its origins from Pine Lake and wetlands headwaters.

FISH ACCESS AND PASSAGE BARRIERS

There are no known barriers to fish passage in Pine Lake Creek.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

King County (1994) identified bed and bank erosion in Pine Lake Creek as a problem.

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was located during the course of this investigation for the Pine Lake Creek Subbasin.

DEGRADATION OF RIPARIAN CONDITIONS

Land use was approximately 50 percent forested in 1994 (King County 1994) but future land use is projected to be urban densities. No quantifiable information on riparian buffer zones was located during the course of this investigation for the Pine Lake Creek Subbasin.

ALTERED HYDROLOGY / FLOW

As of 1994, flooding problems in this basin were considered minor.

WATER QUALITY

Water quality problems identified in this subbasin include historically high phosphorus concentrations in Pine Lake. This problem may have been alleviated with the diversion of a wetland inflow from Pine Lake into Pine Lake Creek in 1988. Subsequent improvements in winter phosphorus levels and the elimination with spring algal blooms in Pine Lake suggest that the diversion project resulted in improved lake water quality (King County 1994).

MONOHON SUBBASIN

GENERAL

The Monohon Subbasin includes a number of short drainages with small tributary streams into Lake Sammamish. These streams include Zaccuse Creek (08.0145A), 08.0145B, 08.0145A (sometimes referred to as North Monohon Creek), 08.0162A, 08.0163, Many Springs Creek (08.0164A), and 08.0164B (sometimes referred to as South Monohon Creek).

FISH ACCESS AND PASSAGE BARRIERS

While a comprehensive fish passage barrier assessment has not been initiated, the presence of impassable culverts in conjunction with the shortness of these streams and the steep gradients encountered limit fish access to approximately 2000 feet in the aggregate (King County 1994).

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

Zaccuse and Many Springs creeks are the two largest tributaries in this subbasin and suffer from the greatest amount of streambank and streambed erosion and thus downstream sedimentation. King County (1994) noted that Many Springs Creek has seen "catastrophic" stream channel incision.

During field surveys in 1987 King County staff noted particularly severe erosion at RM 0.40 in 08.0164A 08.0164B and in 08.0145A (King County 1987).

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was located during the course of this investigation for the Monohon Subbasin.

DEGRADATION OF RIPARIAN CONDITIONS

In 1994, land use patterns included relatively dense single family residences located on both the top and bottom of the western slope (King County 1994). Additional single family

residences are found throughout the basin except on the steepest and most landslide prone slopes (Kerwin, pers obs).

ALTERED HYDROLOGY / FLOW

No quantifiable information was obtained during the course of this investigation that indicated changes to stream hydrology. However, severe stream channel incision in Many Springs Creek is indicative of changes from historic flows.

Wetland filling can adversely stream flows in a number of ways including effecting base flows because of diminished ability to recharge aquifers. Illegal wetland filling was noted as a problem in 1987 (king County 1987).

WATER QUALITY

The only water quality problems identified were from Many Springs Creek where high suspended sediment loads were present (King County 1994).

LAUGHING JACOBS SUBBASIN

GENERAL

The Laughing Jacobs Creek Subbasin includes two lakes (Beaver and Laughing Jacobs (7.4 surface acres), the later being drained by Laughing Jacobs Creek (08.0166). Beaver Lake is actually three connected lakes with a total surface area of 81.6 acres. The subbasin also includes five smaller streams (08.0166A – D and 08.0167).

FISH ACCESS AND PASSAGE BARRIERS

A natural fish passage barrier was identified at approximately RM 0.5.

INCREASED SEDIMENTATION AND ALTERED SEDIMENT TRANSPORT PROCESSES

King County (1994) described channel erosion as minor. Laughing Jacobs Creek, downstream of the lip of the plateau, is underlain by bedrock so as a result, erosion is less than expected. However, runoff from developed areas has resulted in the delivery of significant amounts of sediments to the stream channel. The transport of these sediments into downstream stream channels has aggraded the channel and caused some localized flooding along East Lake Sammamish Parkway (King County 1994).

LOSS OF CHANNEL COMPLEXITY / CONNECTIVITY

No quantifiable information was obtained during the course of this investigation that indicated a loss of channel complexity/connectivity. However, the lower stream channel of Laughing Jacobs Creek has been relocated from its historic location.

DEGRADATION OF RIPARIAN CONDITIONS

In 1989, approximately 63 percent of the subbasin as forested and 37 in primarily infrastructure and single family residences. At full grow out, 89 percent of the subbasin is expected to be developed at urban densities (King County 1994).

ALTERED HYDROLOGY / FLOW

King County (1994) indicated that at full grow out, flows in the streams of this subbasin would increase between 40 and 250 percent.

WATER QUALITY

Beaver Lake Number 1 and 2 are on the WDOE 303d list for exceeding total phosphorus criteria. Laughing Jacobs Creek also appears on the 303d list but for exceeding fecal coliform water quality criteria.

BIOLOGICAL PROCESSES

Escapement goals are not set for these creeks nor is any reach of these creeks an index area. Counts of adult salmonids are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT - LIMITING FACTORS

- Most of the upper stream systems exhibit significant problems with embeddedness due to channelization, erosion and higher peak flows;
- The East Lake Sammamish Tributaries lack LWD and extensive off-channel habitat;
- Less than 80 percent of the banks measured are stable;
- Pool frequency is low and the quality is poor with many of the pools being very shallow in depth; and
- The amount of impervious surface was expected to increase to 20-25 percent of the basin;

E. DATA GAPS

- Water quality data is generally lacking; and
- Salmonid utilization is not fully known.

ISSAQUAH CREEK

A. PHYSICAL DESCRIPTION

The Issaquah Creek Basin encompasses approximately 61 square miles of King County. The basin's headwaters flow from the steep slopes of Cougar, Squak, Tiger and Taylor Mountains, before entering into Lake Sammamish. Elevations range from more than 3,000 feet at the peak of Tiger Mountain to near sea level at the mouth of Issaquah Creek. The basin includes Issaquah Creek (08.0178) and its tributaries Holder (Issaquah Creek continues as Holder Creek), Carey (08.0218), Fifteenmile (08.0207) and McDonald Creeks (08.0212)) and the North (08.0181) and East (08.0183) Forks of Issaquah Creek as well as Tibbetts Creek (08.0169). Although Tibbetts Creek is not a tributary to Issaquah Creek, it shares a common floodplain with the mainstem of Issaquah Creek during large flood events.

The middle and upper Issaquah Creek Basin is identified as a Regionally Significant Resource Area because of its exceptional fisheries habitat and undeveloped character that protects natural watershed structure and function (King County 1994a). The upper Issaquah Creek Basin streams, Carey and Holder Creeks, provide particularly excellent habitats for salmonids. The high quality habitat and abundant populations of salmon distinguish the Issaquah Creek Basin as one of the three most significant basins in urbanizing King County (King County 1996a).

Land use in the basin includes commercial forests, parks, quarry and mining, residential, commercial, and agriculture. Data from 1995 indicates that more than 75 percent of the basin was forested, with the remainder in wetlands, pastures, urban (less than 10 percent), and cleared areas (King County 1996a). Currently, 30 percent of the basin is zoned commercial forest production, 12 percent is within the urban growth boundary, and the remaining in rural zoning (58 percent). Over 40 percent of the land is in public ownership (Washington Department of Natural Resources, Washington State Parks, King County Parks, City of Issaquah Parks) (King County 1996a). Population increases in the basin and resultant pressure to develop rural lands are expected to continue. The population of the Issaquah Creek Basin is projected to increase by 18 percent between the year 2000 and 2020 (Puget Sound Regional Council 1999).

B. SALMONID UTILIZATION

The streams, wetlands, and forests provide habitat for a variety of fish and wildlife species, including eight species of salmonids, six of which are anadromous (King County 1996a). This includes chinook and a stock of kokanee that has been petitioned to be listed as Endangered under the Endangered Species Act. The Issaquah Creek Hatchery, at RM 3.0 currently produces chinook, coho, and Lake Washington steelhead. All fish not needed for production are allowed to spawn in the natural habitat of Issaquah Creek (King County 1991). Chinook have been observed spawning as far upstream as 11 miles upstream in Holder Creek (T. Miller and D. Kirkpatrick pers. comm). Recent changes in operational

procedures at the hatchery have allowed additional chinook to spawn upstream of the hatchery. Beginning in 2000, the chinook and coho juveniles leaving the hatchery were mass marked in an effort to distinguish returning hatchery adults from naturally produced fish.

An investigation for char (bull trout and/or Dolly Varden) needs to be completed throughout the watershed, especially in the upper watershed above 1,000 feet and in cool water. Preliminary surveys were scheduled for summer 2000. The findings of this three to five year investigation will determine the likelihood of needing future studies to determine char strategies in the basin.

An early run timing kokanee stock was historically present in Issaquah Creek. Currently, this stock is extremely depressed with less than 4 adult spawners observed in the last three years (King County 1996b and unpublished King County/WDFW 1998-2000). A unique concern about the decline of this population is that these fish return to spawn in the late summer, immediately in advance of returning adult chinook. The adult chinook may then spawn in the same reaches and through sediment movement either superimpose their redds over the kokanee and/or cause the suffocation of kokanee eggs by moving fines from the chinook redds over the kokanee redds (Pfeifer, 1982; Downen pers. comm. 2001).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

An incomplete inventory identified 8 culverts (King County 1991). Some of the problem culverts have been fixed. Removal of the identified problem culverts will open less than one additional mile of accessible habitat. A complete assessment of culverts in the basin is needed to determine if additional barriers exist.

The Issaquah State Fish Hatchery weir (rack) is a complete barrier to anadromous and resident fish migration during the time period it is in place. The upper gravity hatchery intake does not meet current standards for fish passage and is an additional barrier.

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Particularly during storm events, there are high levels of sediment transport originating from steep forested areas. A sediment budget has determined that the origin of these sediments to be 50 percent landslides in steep forested areas; 20 percent channel bank erosion; 11 percent logging/gravel roads; 6 percent urban development (Nelson 1999). In Tibbets Creek, turbidity readings are very high during storm events. Tibbets Creek exhibits high levels of sediment transport off of coal mine tailings and rock quarries. Spawning substrate embeddedness is high in lower Issaquah Creek, Tibbetts Creek, and North Fork Issaquah Creek. The middle and upper sections of Issaquah Creek provide excellent spawning substrate (King County 1991). The lack of suitable substrate in the lower stream reaches reduces the natural productive salmonid capacity. A sediment study

estimated that 6-10 percent of the banks throughout the Issaquah system are disturbed (Nelson 1999).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

Few stream channel areas exist with quality off-channel habitat, backwater, and refugia habitat. Existing refugia has been identified mostly in middle Issaquah Creek, Carey Creek, and Holder Creek. Pool frequency throughout the lower basin is below guidance standards with very few deep pools. Lower Issaquah Creek has good quality pools, but are not very frequent. Good pool frequency and quality exists in Holder and Carey Creeks. Floodplain connectivity is poor throughout the basin (King County 1991). The loss of channel complexity as expressed through off-channel rearing refugia is believed to limit natural production of salmonid species that depend on this type of habitat during their juvenile rearing.

DEGRADATION OF RIPARIAN CONDITIONS

LWD is greatly lacking throughout the Issaquah Creek system except in lower Carey Creek and Holder Creek. Riparian areas lack cover as well. The riparian area is highly disturbed in lower portions of the basin, through downtown Issaquah. Logging in past 50 years has contributed to the fact that most of the corridor is deciduous and lacking in conifer species (King County 1991).

ALTERED HYDROLOGY/FLOW

There are two identified dams in basin, which may have an impact on the hydrologic regime. The dams are located at natural barriers, but other ecological processes may be impaired as a result of the dams (King County 1996a). Changes in peak flow are estimated to be 7 percent greater than if entire basin was forested. Baseflow is affected by groundwater withdrawal wells in the lower Issaquah Creek. Because of the mountainous terrain and steep stream gradients, stream flow within the basin is quickly influenced by storm events. Approximately 75 percent of basin remains forested which assists in maintaining base flow rates (King County 1994b). However, no information as to forest age or composition was available.

WATER QUALITY-INCREASED OTHER

Nutrient loading levels and chemical contamination state water quality standards are often exceeded during storm events. Fish kills have occurred in past annd leachate from landfill facilities (e.g.: the Cedar Hills Landfill) has been suspected as the cause. Additionally, the unknown pollution events in the North Fork (2 events in 1990) have also resulted in fish kills (King County 1991). The impacts to food resources and availability are unknown, but there may be implications for food web interactions and potential impacts to juvenile rearing. There is also a high risk of potential contamination from spills from the I-90 highway or any of the other many roads that cross the creek or parallel the creek.

WATER QUALITY-INCREASED TEMPERATURE

A portion of Issaquah Creek near the Issaquah State Fish Hatchery has been documented to exceed state water quality Class A standards for temperature. The temperature in this area is only high in the summer and confined to the lower reaches of Issaquah Creek. Most of the system is recorded to be below 57ºF (King County 1996a).

BIOLOGICAL PROCESSES

Escapement goals are set for Issaquah Creek upstream of the Issaquah State Fish Hatchery. Those goals are 500 adult chinook and 2000 coho. Historically, only limited numbers of adult salmonids were allowed upstream and in some instances salmonids were not passed upstream. Current operational protocols allow for fish passage although some delays are encountered and there is some likely deterioration of fish health (WDFW 1996). Counts of adult salmonids are made annually.

D. KEY FINDINGS AND IDENTIFIED HABITAT – LIMITING FACTORS

- Two barriers to anadromous and resident fish migration occur at the Issaquah State Fish Hatchery;
- An incomplete inventory identified 8 culverts as complete or partial fish migration barriers. However, the removal of the identified problem culverts will open less than one additional mile of accessible habitat;
- The lack of suitable substrate in the lower stream reaches reduces the natural productive salmonid capacity;
- The loss of channel complexity as expressed through off-channel rearing refugia is believed to limit natural production of some salmonid species;
- LWD is greatly lacking; and
- Concerns about detrimental species interactions have been expressed.

E. DATA GAPS

- The utilization of this subarea by native char is unknown;
- A complete assessment of culverts in the basin is needed to determine if additional barriers exist;
- A basin wide comprehensive habitat assessment is lacking;
- No information as to forest age or composition was available; and
- The full utilization of the subarea by salmonids is not known.

LEWIS CREEK

A. PHYSICAL DESCRIPTION

The Lewis Creek Basin drains a 1,209-acre area originating from the north slopes of Cougar Mountain. Lewis Creek (08.0162) flows northeasterly approximately 1.5 miles before it empties into the southern end of Lake Sammamish (City of Bellevue GIS, 2000). The dominant land uses in the watershed are single family residential and rural residential (City of Bellevue GIS, 2000). Lewis Creek has numerous branched tributaries, forming a highly dendritic hydrologic pattern. Lewis Creek and its main tributaries are high gradient and active streams with high sediment transport capacities (Dames and Moore, 1994). The slopes of Lewis Creek range from less than 1 percent to over ten percent, with tributary gradients of up to 26 percent (City of Bellevue GIS, 2000). The mainstem Lewis Creek originates in a low gradient area above the Eastgate region of Bellevue (a bench on the northeast side of Cougar Mountain). The creek then flows through a steep, wooded ravine before entering another low gradient reach downstream of Interstate 90 prior to draining into the southern end of Lake Sammamish. According to U.S. Department of Agriculture, Natural Resource and Conservation Service (NRCS), formerly the Soil Conservation Service Soil Service, (1973) four soil types are predominant in the basin: Alderwood (gravelly sandy loam), Alderwood and Kitsap soils, Beausite (gravelly sandy loam) and mixed alluvial land. A multispectral analysis conducted in 2000 shows the basin has approximately 28 percent impervious surfaces (City of Bellevue, 2000).

B. SALMONID UTILIZATION

Numerous studies on salmonid use and habitat have been conducted on Lewis Creek (The Watershed Company, 1988; The Watershed Company, 1989; Leonoff, 1988; URS Corp., 1987; Young, et al, 1995; Ostergaard, 1998; Vanderhoof et al, April, 2000; Vanderhoof, 2000). Salmonid use in Lewis Creek can be segregated into two distinct reaches, one reach is downstream of a culvert at Interstate 90 that is a total fish migration barrier at river mile 0.75, the other reach is above the migratory barrier. Upstream of Interstate 90, only resident coastal cutthroat trout have been observed. In the lower reach, Washington Department of Fish and Wildlife (WDFW) staff have observed adult kokanee, sockeye, coho and cutthroat trout during a recent habitat and barrier assessment (Cierebiej-Kanzler, 2000). Over the previous seven years, King County staff and volunteer salmon watchers have also observed adult coho, sockeye, kokanee, and chinook in Lewis Creek (Young, et al, 1995, Ostergaard, 1996; Ostergaard, 1998; Vanderhoof et al, April, 2000; Vanderhoof, draft 2000). The Watershed Company conducted a study on fish habitat and population assessment in 1992. They noted adult and juvenile coastal cutthroat trout and adult steelhead trout, kokanee, and coho, as well as lampreys and sculpins (The Watershed Company, 1992). Steelhead use may be limited as the report was based on a single adult observed midway up the lower reach to Interstate 90 on March 19,1990 (The Watershed Company, 1992). Chinook utilization may also be limited as there was only one reported sighting of two adult chinook (Ostergaard 1996) in 1995 as part of the kokanee surveys.

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Washington Department of Fish and Wildlife staff recently completed a fish barrier evaluation and habitat assessment for Lewis Creek (Cierebiej-Kanzler, 2000). They used the WDFW Salmonid Screening, Habitat Enhancement, and Restoration (SSHEAR) methodology for the assessment. WDFW staff identified four partial or complete barriers in the mainstem, at river miles 0.49, 0.75, 2.56, and 2.76 (Cierebiej-Kanzler, 2000). The lower two barriers were ranked the most significant with priority index ratings of 32.19 and 36.16. The upper watershed barriers on the main channel and three tributaries barriers all had priority index ratings less than nine (Cierebiej-Kanzler, 2000).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Lewis Creek is a naturally steep, erosive basin as evidenced by the delta formation in Lake Sammamish (Dames and Moore, 1994). According to Dames and Moore (1994), "Distribution of the soils vary greatly within a short distance and drainage and permeability vary. Runoff is rapid, and the erosion hazard is severe to very severe." (Dames and Moore, 1994, p. 15). The report also notes that the tributaries in the lower and upper watershed are unstable and many show active downcutting and mass wasting. The middle reach, through the ravine, is characterized by bedrock and boulder substrates, indicating high velocity and subsequent sediment transport (Cierebiej-Kanzler, 2000).

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

In the stream reach between Interstate 90 downstream to the creek mouth at Lake Sammamish, numerous studies have documented a loss of channel complexity and connectivity caused by bank hardening and residential encroachment (Cierebiej-Kanzler, 2000; Boehm, 1999; Dames and Moore, Inc.1994; The Watershed Company, 1992). These reports also note that the upper reach above Lakemont Boulevard is channelized with occasional bank armoring. No quantifiable information on stream channel loss was available but in some reaches it is considered severe.

DEGRADATION OF RIPARIAN CONDITIONS

Downstream of the Interstate 90 crossing, residential encroachment and the presence of a Himalayan blackberry understory characterize the riparian corridor (Dames and Moore, Inc. 1994). However, despite encroachment by residential landscaping, riparian canopy is relatively good, approximately 75 percent shading by a mixed stand of deciduous and coniferous trees (Cierebiej-Kanzler, 2000; The Watershed Company, 1992).

The Lewis Creek ravine in the middle reach of the watershed, upstream of Interstate 90, is characterized by second growth coniferous forest with steep sideslopes (The Watershed

Company, 1992). This area has 65-70 percent canopy cover from primarily coniferous trees (Cierebiej-Kanzler, 2000).

The upper watershed, above Lakemont Boulevard is best characterized by residential encroachment, often with residential landscaping to the stream edge (Cierebiej-Kanzler, 2000). Canopy cover is significantly diminished, ranging from 20-70 percent cover (Cierebiej-Kanzler, 2000).

ALTERED HYDROLOGY/FLOW

Hard data on the change in hydrology within Lewis Creek attributable to land use changes is lacking. However, basin land cover characteristics (i.e.: an impervious surface area of 28 percent) and stream surveys indicate deleterious effects of hydrologic change (from sub-surface dominated flow paths to surface water) on instream habitat conditions throughout the sub area.

Horner and May (1991) found that one of the factors that has resulted from anthropogenic modifications to the landscape is the shift from a coniferous dominated forested watershed to one dominated by impervious surfaces. Under historic forested land cover conditions there was almost no run-off produced except during very large storm events or rain-on-snow events (Booth 1991).

Another important measurement indicative of habitat degradation is forest cover. May et al (1997) determined that the threshold of degradation to occur at 30 percent or lower forest retention while Horner and May (1999) recommended that forested area remain above 60 percent to maintain natural conditions. The Wild Salmonid Policy (WDFW) recommends that 60 percent of the watershed be maintained with forest stands age 25 years or more. The precise overall forest retention in the Lewis Creek basin is unknown but is believed to be below the threshold values described above.

WATER QUALITY– INCREASED TEMPERATURE

A monitoring program for evaluating the Lakemont Development found stream temperatures exceeding 16° C during base flows in 1993 and 1994 (Herrera, 1995).

POOR WATER QUALITY– INCREASED OTHER

Water samples have exceeded Washington State water quality criteria during storm events for turbidity, copper, zinc, and fecal coliform (Herrera, 1995). The turbidity exceedances occurred during 1991-92, the primary construction period for the Lakemont development, but have not been noted in later sampling. Base samples have exceeded state water quality criteria for lead, zinc, and fecal coliform bacteria, although the stream has not been placed on the State 303(d) list of impaired water bodies (Herera, 1995).

BIOLOGICAL PROCESSES

Escapement goals are not set for this creek nor is any reach of the creek an index area. Counts of adult salmonids, are typically conducted by local jurisdiction staff. Benthic Index of Biotic Integrity in the lower reach, below Interstate 90 were 24, signifying moderately impaired biological processes.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Adult coho, sockeye, kokanee, steelhead, and chinook along with juvenile coastal cutthroat trout as well as lampreys and sculpins have been found in Lewis Creek;
- At least six (6) partially or totally impassable barriers to salmonids have been identified in this subarea;
- There has been a loss of channel complexity and connectivity caused by bank hardening;
- Residential encroachment likely limits natural production of salmonids;
- The impervious surface area of the Lewis Creek subarea is 28 percent; and
- Water quality base samples have exceeded state water quality criteria for lead, zinc, and fecal coliform bacteria.

E. DATA GAPS

- No quantifiable information on stream channel loss was available.

WEST LAKE SAMMAMISH TRIBUTARIES

A. PHYSICAL DESCRIPTION

The West Lake Sammamish sub-area encompasses over 4,000 acres and thirteen small streams (Bellevue GIS, 2000). These streams include Idylwood, Wilkins, Phantom, Vasa, unnamed tributary 08.0161, unnamed tributary 08.0160, and other small unnamed and unnumbered streams (Williams et al. 1975, Bellevue GIS, 2000). Lewis Creek is located in this area, but is discussed separately due to unique characteristics in that watershed. There are more than 8 miles of streams in the West Lake Sammamish Tributaries subarea, of which less than one mile is accessible to anadromous fish due to steep gradients, culvert blockages and altered channel structure (Bellevue Utilities, 2000; Morgenroth, pers com 2000). Most streams are short and steep, flowing through incised channels easterly into Lake Sammamish (Morgenroth, pers com 2000).

B. SALMON UTILIZATION

Little historical information is available on salmonid utilization in this sub-area. In Phantom Creek (08.1054) and Vasa Creek (08.0156) the reaches between Lake Sammamish and the steep hillsides were noted in 1975 as possible coho spawning and rearing areas (Williams, et al 1975). Vasa Creek is identified in two King County publications as possibly having historic runs of native early-run kokanee (Ostergaard et al, 1995; R2 Resource Consultants, 2000). Juvenile coho have been captured in Vasa Creek and late timing kokanee were observed in 1998 (King Co unpublished data). Cutthroat trout have been documented in Vasa Creek in the reach between Interstate 90 and Lake Sammamish (Swarts, pers com 4/27/99, Morgenroth pers com 2000). Juvenile salmonids, believed to be resident cutthroat trout, were observed during stream reconnaissance in the unnamed tributaries 08.0161, 08.0160, and the unidentified tributary between 08.0160 and 08.0161 (Morgenroth pers com 2000).

C. HABITAT FACTORS OF DECLINE

FISH ACCESS AND PASSAGE BARRIERS

Known barriers exist between Lake Sammamish and natural high gradient ravines in Idlywood (also referred to as Ardmore Creek), Wilkins, Phantom, unnamed tributaries 08.0160, and 08.0161. Vasa Creek was blocked to anadromous migration by West Lake Sammamish Parkway until 1999 when the culvert was replaced to facilitate fish passage.

ALTERED HYDROLOGY/FLOW

Most of the ravines in the northern portion of this subarea now carry any surface water and storm water runoff down the slope in pipes (Morgenroth, pers com 2000). Many of the open channels upstream of West Lake Sammamish Parkway have been enclosed in pipes downstream from West Lake Sammamish Parkway to Lake Sammamish (Bellevue Utilities, 2000). There are indications that perhaps some of these dry ravines may have carried perennial flowing water in the past (Morgenroth 2000). City of Bellevue staff found abandoned pipes and cisterns that appear to be remnants of old water systems; this suggests that early settlers or later residents may have drawn water from streams that have since ceased to exist (Morgenroth, pers com 2000).

INCREASED SEDIMENTATION/ALTERED SEDIMENT TRANSPORT PROCESSES

Portions or all of these creeks flow generally easterly through naturally steep, high gradient, erosive channels before the gradient lessens and the creeks flow into Lake Sammamish. This is evidenced by the delta formation in Lake Sammamish at the mouths of many of these creeks (Kerwin pers. observ.). Local residents report that runoff is rapid, and the erosion hazard is severe to very severe.

The substrate within these creeks consists of pebble and cobble sized particles with localized sand depositions. Gravel deposits are very local and spawning opportunities are typically few. These features are typical of flow alterations caused by unretained or underretained stormwater flows. Significant portions of this area were developed prior to detention and water quality regulations currently in place.

With the conversion of the historic forested uplands into low density residences increases in water fluctuation and sedimentation have occurred. Siltation, caused by construction activities, increases of impervious surfaces and associated peak flood flows have resulted in local high flow concerns that further degrade salmonid habitats.

LOSS OF CHANNEL COMPLEXITY/CONNECTIVITY

It appears that several of these creeks have been relocated along property boundary lines. The lower reaches of Idlywood Creek flow through a park where it appears to have been channelized. Vasa Creek flows between properties just downstream of West Lake Sammamish Parkway. Several of the unnumbered and numbered tributaries flow along property lines in the reaches areas where they cross Lake Sammamish Parkway. There is also occasional bank armoring in the vicinity of culverts and small bridges. No quantifiable information on stream channel loss was available but in some reaches it is considered severe.

DEGRADATION OF RIPARIAN CONDITIONS

Because riparian communities along these creeks are composed primarily of young trees, shrubs, exotic species and ornamental plantings none of the stream system is considered to have good bank stability. Inside the ravines many of the streams support stands of maturing deciduous and mixed coniferous and deciduous trees that are considered to be in fair condition, and will attain good condition if left undisturbed and allowed to mature.

Similar to bank stability, shade is considered to be in good condition only where there are dense stands of medium or large sized coniferous or deciduous trees.

The upper watersheds, above West Lake Sammamish Parkway are best characterized by residential encroachment, often with residential landscaping to the stream edge.

ALTERED HYDROLOGY/FLOW

Information on the change in hydrology within these streams attributable to land use changes is lacking.

WATER QUALITY– INCREASED TEMPERATURE

No information on stream water temperatures was located during the course of this investigation.

POOR WATER QUALITY– INCREASED OTHER

No information on water quality was located during the course of this investigation.

BIOLOGICAL PROCESSES

Escapement goals are not set for these creeks nor is any reach of the creek an index area. Counts of adult salmonids, are sporadic.

D. KEY FINDINGS AND IDENTIFIED HABITAT-LIMITING FACTORS

- Usage by anadromous and resident salmonids is generally confined to the lower stream reaches;.
- There has been a generalized loss of channel complexity and connectivity caused by bank hardening and channelization;
- Residential encroachment likely limits natural production of salmonids in the lower reaches;

E. DATA GAPS

- Information on the change in hydrology within these creeks attributable to land use changes is lacking;
- Water quality information is lacking; and
- No quantifiable information on stream channel loss was available.

CHANGE in the HYDROLOGIC REGIME

SCREENING LEVEL ANALYSIS OF 3RD ORDER AND HIGHER WRIA-8 STREAMS FOR CHANGE IN HYDROLOGIC REGIME-

Summary

The WRIA-8 Technical Committee's "Draft Reconnaissance Assessment-Habitat Factors that Contribute to the Decline of Salmonids" identified altered hydrology or flow to be a probable factor of decline for salmonids in most streams in the WRIA. In most cases, this alteration is related to changes in land cover, including the clearing of forests and the creation of impervious surfaces, which combine to increase storm flows and reduce base flows. In many cases, stream hydrology or flows have also been altered by water and wastewater management practices, as discussed further below.

A screening level analysis of flow changes associated with land cover alterations, water, and wastewater management throughout the Cedar-Lake-Washington basin has been performed using existing data in combination with relationships derived from hydrologic modeling. The screening level analysis attempts to provide a watershed-wide perspective on stream flow regime by looking at three flow-change parameters, showing how flow regime change is geographically distributed throughout the watershed, and apportioning the cause of flow change among water and land management activities. The term “screening level analysis” is used because of several simplifying assumptions adopted in the derivation and interpretation of the flow-change parameters and in recognition of the inadequacy of three numbers to describe the complexity of flow regime changes and their resultant ecosystem consequences. Additionally, the scope of this screening study was limited and did not include explicit correlation of hydrologic results with available salmonid usage or habitat quality data. Nor did it attempt to directly use historical stream flow data to corroborate results. These are steps that would be extremely useful for follow-up studies.

The screening level analysis provides an initial reconnaissance of altered hydrology and flow regimes throughout the WRIA-8 watershed. It is intended to:

1) help guide and support early actions to improve habitat conditions in WRIA-8 in response to the ESA, and
2) provide the basis for geographic and thematic focus using detailed analysis and comprehensive study of flow regime and flow management within WRIA-8 to support the long-term conservation and recovery program.

This screening level analysis and approach can provide a template for examination of altered hydrology and flow assessments in other WRIAs. Based upon the initial results of the screening level analysis, more detailed and targeted investigations of flow regime related to other watershed processes should be considered. For each river or stream reach, the scope of follow-up studies should be informed by knowledge of ecosystem conditions including fish populations, sediment transport, floodplain processes, water quality, physical

habitat, and other biologic parameters to the extent that these factors are significant for the particular waterbody under consideration.

Methods

The purpose of the analysis was to generally characterize the degree to which flow regime has changed from pristine to current conditions in 3rd and higher order WRIA-8 streams as a result of human activities. In general, watershed stream flow records are not of sufficient length, nor do they fall into distinct, homogeneous, pre- and post-disturbance samples that would allow a direct determination of the level of flow regime change. However, several years experience with matching watershed model simulations to measured stream flow has shown that significant changes in flow regime can be substantially predicted from changes in land cover associated with urbanization (Dinicola, 1990, KC, 1991, KC, 1993). Additionally, it is assumed that the mass balance principle can be utilized to estimate residual flow regime changes not attributable directly to land cover change- for example, changes associated with water withdrawals, irrigation, waters supply export and import, or sewering.

Three flow-change parameters were derived and applied for the screening study: a storm peak/duration change index, a storm volume change index, and a summer-fall, base flow index. These parameters were chosen because of their relationship to salmonid health and ecosystem function and the ability to readily estimate them from existing databases of land cover, surficial geology, water, and wastewater management. Peak flow magnitude and duration directly affect redd integrity and egg-to-fry survival. Storm volumes are related to periods of prolonged elevated stream velocity and potential chronic stress on fish. Both peak flow and storm volume changes are also often correlated with water quality problems. Summer and fall base flow reductions directly affect habitat access and quality.

Screening parameters were estimated from LANDSAT-derived land cover (Hill, Botsford, and Booth, 2000) surficial geology maps, and ancillary data related to water and wastewater management within a stream drainage basins (Martin, 2001). As such, the screening level analysis does not reflect additional drivers of flow regime such as retention-detention ponds, recharge and peak damping effects of lakes and wetlands, seasonal lagging of stream response to pumping, or hydraulic discontinuity of streams with pumping within a topographic drainage basin.

Peak Flow/Duration-Change Index

This index utilizes the ratio of current 2-year peak discharge to forested 10-year peak discharge (Q2/QF10). A study of 2nd, 3rd, and 4th order sub-basin streams in the East Lake Sammamish, Hylebos, and Issaquah Creek basins demonstrated that when this ratio exceeds a value of 1.0 that stream channels tend to become unstable and habitat is degraded. The relationship was shown to be useful over a wide range of stream basin conditions in the Puget Lowland, however, streams dominated by upstream lake storage were shown to be outliers to some degree. (Booth and Jackson, 1997) The ratio can be viewed as a general indicator increases in magnitude, frequency, and duration of peak

flows that erode channels and transport sediment. However, the exception noted for with lake-dominated systems is likely also to apply to sloughs and other highly backwatered stream reaches that are hydraulically less sensitive to increased inflow peaks and durations from upstream tributary subbasins

For this screening study, four soil-cover complexes were investigated as potential predictors of the Q2/QF10 ratio. These included percent basin converted to effective impervious, percent basin converted to grass on till soils, percent basin converted to grass on outwash soils, percent basin covered by lakes and open water wetlands. Peak flow and soil-cover data from the Lower Cedar River Current and Future Conditions Report for fourteen subbasins were used to look at correlation of the index to potential predictors. Multiple linear regression using this limited data set showed that percent effective impervious area was the only significant (non-zero coefficient at 95% confidence level) predictor of the four. A second round analysis resulted in the following relationship for the Peak Flow/Duration-Change Index (PFDI):

$PFDI = 74370\ EIA^{3.5}$, $R^2 = 0.979$……. (Equation 1)

in which PFDI represents the percentage change in Q2/QF10 ratio and EIA is the fraction of tributary basin that is covered by effective impervious area. EIA was computed from a power relationship with TIA, total impervious area. TIA was determined from the LANDSAT classes via a calibration process to aerial photographs (Hill, Botsford, and Booth, 2000). It should be noted that although the other soil-cover predictors were not significant at the 95% level, this does not in any sense prove that they have no effect on peak flows or the PFDI. More likely the results indicate that cross-correlation of grass with EIA or insufficient sampling in the case of the lake and open water wetland data.

Table 36. Flow change and instability risk description

Percent EIA	PFDI	RELATIVE FLOW CHANGE AND INSTABILITY RISK DESCRIPTION	COMMENT
0-5%	0-5%	LOW	Does not include potential mitigating effect of installed detention ponds, bypasses, other drainage structures, or buffering effect of lakes
6-10%	6-25%	MODERATE	
11-15%	26-100%	HIGH	
>15%	>100%	EXTREME	

The peak flow change index does not account for natural and artificial storages that partially blunt the effect of peak increases. Examples of storage in the basin include large and small lakes and retention-detention (R/D) ponds. The attenuating effect of these storages is directly related to the ratio of their live storage volume to the amount of contributing impervious area. R/D ponds have been built to varying and generally increasingly strict standards that have enlarged this ratio over the last few decades. However, even under the most optimistic scenarios, R/D ponds often perform sub-

optimally and can not be designed to fully eliminate peak flow and other stormwater effects. Assessment of the partial and spatially highly variable effect of R/D ponds on peak increases is beyond the scope of this screening level analysis.

Storm Volume Change Index:

Storm volume is assumed to be the total amount of rainfall that appears in streams immediately or within a day or two of after a storm event. In the HSPF conceptual model (Donigian, Bicknell, and Imhoff. 1994), stream flow is made up of three components, active groundwater discharge, shallow subsurface flow that is also called interflow, and surface runoff. During and after storms, stream flow above base levels will depend upon the soil-cover composition of the drainage basin because each soil-cover type produces a different mix of surface, interflow, and groundwater. Virtually all surface runoff contributes to elevated storm flows because surface runoff enters waterways during storms or within minutes or hours following the cessation of rainfall. Interflow rises during a storm event, but may take days to subside. Groundwater flow to streams occurs over an extended period of days and weeks and generally causes very moderate increases in flow. A storm volume change index (SVCI) is proposed that accounts for the differing contributions of surface, interflow, and groundwater discharge to elevated stream flows during and following storm events.

Relationship to GIS-database information:

The proposed storm volume index is based on average annual volumes of surface runoff, interflow, and groundwater flow for seven soil-cover types that can be determined by GIS analysis of LANDSAT-derived land cover within a sub-basin. The calculation of the index includes potency factors for each runoff component in recognition of their varying contribution to elevated storm volumes. For simplicity, the potency factors are assumed to be 3, 2, and 1 for surface, interflow, and groundwater. In a few urban sub-basins that have combined sewer systems or older, separate, sanitary systems that allow the influx of storm water, sanitary sewer inflow and infiltration (I&I) has been observed to actually drain away and reduce storm flows in streams. I&I is assumed to have a potency factor of 2 because it can be made up of both rapidly responding surface drainage and slower responding, perched groundwater.

The following relationship is based on the product of these potency factors and the average annual runoff in inches for each soil-cover type as predicted by HSPF with regional parameters and SeaTac rainfall. Since the index is scaled to forest conditions, the acknowledged variability of rainfall over the watershed should have a negligible effect on the use of the index as a screen tool for subbasins in different rainfall zones.

SVCI = {[93*(EIA+OW)+25*TF+35*TG+18*OF+23*OG+19*SAT-2*I&I]/[25*(TF+TG)+18*(OF+OG)+93*OW+19*SAT+23*EIA]-1.0}*100%…….(Equation 2)

In which %SVCI is the average storm volume index change, TF, TG, OF, OG, SAT, OW, and EIA are fractions of the sub-basin in till-forest, till-grass, outwash-forest, outwash-grass, wetland soil, and open water and I&I is the total volume of inflow and infiltration into sewers in the basin expressed as inches over the basin area.. This equation returns a value of 0% for a pristine, forested basin regardless of its surficial geologic composition.

Examples of results for basins with different cover compositions and a 70%-30%, till-outwash composition are shown in Table 37 below.

Table 37. Relative flow volume change results for basins with different cover compositions

CASE	PERCENT EIA	PERCENT FOREST	PERCENT GRASS	SVCI	RELATIVE FLOW VOLUME CHANGE[a]
Forest	1	85	14	8%	LOW
Forest/Ag/ Rural	3	65	32	21%	LOW
Forest/Ag/Suburb	5	50	45	32%	MEDIUM
Mixed Suburban/Open	12	38	50	55%	HIGH
Urban/Suburban	25	20	0	97%	EXTREME

[a] 0%-25%=LOW, 26%-50%=MEDIUM, 51%-75%=HIGH, >75%=EXTREME

Base Flow Change

Base flow change is assumed to result from two causes, altered (reduced) recharge and water extraction, consumptive use, and export. The component of base flow change associated with altered recharge rates is caused by soil compaction and reduced infiltrability associated with developed land that has been cleared, graded, covered with impervious surfaces or re-vegetated. Estimate of this component is made from HSPF model runs for typical soil-cover classes. A second component of base flow change is based on estimates of pumping, export, import, and consumptive use associated with water and wastewater management. The second component of base flow change is estimated from a sub-basin by sub-basin study of water monthly extraction, consumption, and export including effects of sub-basin water losses to sanitary sewers.

For screening analysis purposes, water that is pumped within a sub-basin is assumed to be 100% hydraulically connected to stream flow at the sub-basin outlet. Additionally, the effect of pumping on flow is assumed to occur without any seasonal lag over the July through October period during which base flow reductions are estimated.

The base flow change relationship is given by:

BFC = 100*{1. – [.51*TF+.43*TG+.82*OF+1.07*OG+.63*(SAT+OW)-QOUT/DA]/[.51*(TF+TG)+.82(OF+OG)+.67*EIA+.63*(SAT+OW)]}…… (Equation 3)

in which BFC is the change in summer-fall base flow as a percentage, TF,TG, OF, OG, SAT, OW, and EIA are the areas of till-forest, till-grass, outwash-forest, outwash-grass, wetlands, open water, and effective impervious in square miles, QOUT, is the July-October mean net sub-basin water consumption (Martin, 2001 and Hartley, 2000) and DA is the basin drainage area in square miles. In this expression, the coefficients represent the average July through October groundwater flow to streams in cfs that are produced by one square mile of each of the soil-cover types.

Results

General

Detailed numerical results are summarized in Tables 3-7 of Appendix F These results are also summarized graphically in Figures 2 – 5 (see Appendix F). Note that Figure 2 (see Appendix F) depicts EIA for each individual sub-basin area whether it is a headwaters sub-basin or receives drainage from an upstream sub-basin. In Figures 3-5 (see Appendix F), results are generally depicted at point locations on rivers or streams. In the minority of cases where points are not located on streams, the color-coded symbol does not represent a specific stream location, but the total runoff of the sub-basin within which the symbol is located. One example of this would be East Lake Sammamish sub-basin. The several streams that drain this sub-basin were not analyzed separately in this screening study, so one symbol within the sub-basin is used to generically characterize all East Lake Sammamish streams.

Land Cover

Table 3 (please see Appendix F for Tables 3-7) shows the basic land cover composition estimated from 1998 LANDSAT analysis (CUWRM, 2000) of the Cedar-Lake Washington watershed sub-basins. Sub-basins are generally listed from upstream to downstream beginning with the Cedar River basin, followed by the Sammamish River basin, and finally the direct drainages to Lake Washington and the Ship Canal. Entries surrounded by bold lines reflect the cumulative area and characteristics of the preceding group of entries. The "Stream Scale" column defines the order or size of the outlet stream. In this column the entry "Multiple Drainages" signifies that the data reflect the drainage area for a group of adjacent streams that are generally 3rd order or smaller in size.

Peak Flow

Table 4 (please see Appendix F) shows estimated changes in peak flow at various locations within the watershed. As shown, increases in peak flow range widely from 1% up to factor of 10 or higher for the most urbanized, western sub-basins. Peak flow increases are low (less than 5%) at all Cedar River locations because overall impervious area within the watershed is relatively low. Additionally, although it is not accounted for in the screening method for peak flows, flood control by Masonry Dam on the Cedar actually reduces peaks below their natural level for a wide range of flood events. Along the Sammamish River, moderate increases in peaks are estimated to range from 28% to 124% based on increasing

impervious area in the drainage basin from the weir to the mouth. Actual increases are likely to be smaller because of the buffering effect of Lake Sammamish.

Among the 4th order (major creeks) streams locations, increases range from 2% for Issaquah Creek at mid-basin, to 9% for Issaquah at the mouth, to 61% for Big Bear Creek at the mouth.

Increases in peaks among 28 third-order creek locations range widely. As expected the most rural, forested tributaries such as Walsh, Lower Rock, Peterson, Upper Issaquah, and Fifteenmile experienced minor increases. Among these, Walsh Lake Diversion, is somewhat unique in that is an artificial channel constructed in the 1920s that has evolved some good fish habitat (King County, 1993) over the years. Streams with urbanized basins such as North, Swamp, McAleer, and Thornton are estimated to have extremely large increases. As noted earlier, highly back-watered, lower reaches, like those in the Kelsey-Mercer Slough system may be somewhat exceptional among the highly urbanized systems for two reasons. First, the backwater and storage effect in the slough would tend to damp increases in peak flow generated by upstream impervious area suggesting a somewhat lower value for the PFDI than estimated directly from impervious area. Second, the consequences of increased peak flows (for example increased velocities, channel erosion, and sediment transport) are likely to be much less in such reaches. On the other hand, more free-flowing upstream reaches in such systems would be more typically affected with resultant transport of eroded sediments and other pollutants to downstream reaches. Streams such as East Fork Issaquah, McDonald, Tibbetts, and Upper Bear Creeks are estimated to have smaller increases between 11% and 50%, while Cottage Lake, Coal, Little Bear, and North Fork Issaquah range from 50%-200% increases in peaks.

Storm Volume

Results for winter storm (Table 5 in Appendix F) volume generally parallel those for peak flow increase however, the range of predicted increases is not as extreme. Also, storm volume results are not generally affected by basin storage. Storm volume increases are generally low along the Cedar (less then 25%) and moderate to extreme along the Sammamish (28%-48%). Among the major, 4th order creeks, increases are low in Issaquah Creek at mid-basin (20%), moderate near the mouth Issaquah (28%) and high at the mouth of Big Bear (50%). Increases in storm volumes in 3rd order creeks range from 12% to 89% generally depending on impervious percentage and other land cover changes. One exception to this rule is in basins with large amounts of sewer inflow and infiltration (I&I). These basins are estimated to have increases in storm runoff volume partially offset by leakage of surface and shallow ground water into the wastewater collection system. For example, this bypass effect explains why Thornton Creek is estimated to have extreme peak flow increases but relatively less extreme storm volume increases. Because I&I data were not available for the Marine Drainages at the time of this study, storm volume change was not calculated. Based on results in adjacent sub-basins, storm volume increases are likely to be variable within the multiple, smaller creek basins included in the Marine Drainages sub-basin.

Reduction in Summer Base Flow

Summer base flow reductions are estimated from land cover change, water extraction data and use calculations, and sewer inflow and infiltration (I&I) information applicable to the drainage basin for each stream location. All water production, use, and I&I, estimates are based on data from 1994. Results are shown in Table 6 (in Appendix F). Along the Cedar, above the Landsburg diversion, average July through October base flow is actually augmented compared to natural conditions. This results from Seattle operations at Masonry Dam. There is little effect of land cover change (<2%) and virtually none from I&I. Below Landsburg at 209th street, the situation reverses and base flows are reduced by 47%. This is mostly due to Seattle water diversion with a minor effect of water extraction from the Lower Rock Creek tributary. At the mouth, total loss is also approximately 47% of natural flow of which 42% results from Seattle operations, 2% is recharge loss from land cover change, and 3% is associated with other water management activities including pumping by the city of Renton. The minor relative effect of urbanization on lower Cedar River base flow reductions may appear surprising at first given relatively high levels of urbanization present in the lowest part of the basin- for example, 21-22% EIA in lower mainstem and north and south urban sub-basins. However, on the river basin scale that determines base flows near the mouth, total EIA is only 6%. This accounts for the relatively minor effect of urbanization on base flow in the river.

In contrast, the Sammamish River has lost 14% summer base flow at the weir, primarily (8.5% of 14%) from water management/use and secondarily (4.5% of 14%) from loss of recharge associated with land cover change in lower Issaquah and on the east and west sides of the lake. At 136th street, downstream of Big Bear Creek, but upstream of Little Bear Creek, the loss increases to 29% mainly because of additional water extraction/use in Evans, lower Bear Creek, and the upper river valley. Between this location and the mouth, the impact of water management in Little Bear, North, and Swamp Creeks actually augments summer base flows. This is due to the importation of water to these areas from outside the watershed. However, increased urbanization also cuts off more recharge. The net effect is a drop in base flow loss from 29% at mid-valley to 21% near the mouth.

Along Issaquah Creek, summer base flows are relatively unimpacted (7% reduction) at mid-basin, but significantly impacted at the mouth (24%). This is mainly due to North Fork and Issaquah valley water withdrawals and use. Similarly, summer base flows at the mouth of Big Bear Creek are affected by water withdrawals from Evans Creek and lower Bear Creek basins. These result in a 39% reduction that is approximately 2/3 from water management and 1/3 from recharge loss.

Among the 3rd order streams, estimated base flow reductions range from –9% to greater than 100%. Although the vast majority of streams locations (23 of 28) show net losses of summer base flow, the major Sammamish tributaries (Swamp at the mouth, North at the mouth), Cottage Lake Creek, and Lyons Creek appear to have minor net augmentation of base flow. Developed areas in these basins are generally supplied by the city of Seattle system that diverts water from the Tolt and Cedar rivers. Augmentation of base flow arises from water system leakage and irrigation in excess of potential evapo-transpiration. They

are also areas with relatively tight wastewater collection systems that exhibit low losses from summer I&I.

At the opposite end of the spectrum, the analysis estimates full depletion of North Fork Issaquah Creek as a result of groundwater extraction. The estimate of base flow reduction greater than 100% is not physically reasonable and results from assumptions and approximations employed in this study. Notable among these is the assumption that water pumped from within a sub-basin during the summer-fall period is assumed to be in 100% hydraulic continuity and to affect the creek at the sub-basin outlet during the same period. While this may not be totally accurate, North Fork Issaquah Creek has in fact dried up occasionally in recent years. Base flow loss in excess of 100% also occurs in the Cedar Main Urban sub-basin because of groundwater pumping in this area by the City of Renton for municipal water supply. However, this sub-basin does not comprise the drainage basin of a single creek, but rather multiple drainages and a reach of the mainstem Cedar River itself. Therefore, unlike North Fork Issaquah Creek, base flow depletion for a single stream is not necessarily indicated by the very high percentage of estimated based flow loss in this sub-basin.

Lower Rock Creek is similar to North Fork Issaquah with regard to impact from water withdrawals. It has very low urbanization and EIA, but high base flow loss (57%). East Lake Sammamish tributaries and Evans Creek also have high base flow reductions (57% and 74%) with moderate EIA (15% and 13%). Water is both pumped from and imported to these areas. In the case of Evans Creek, water is both imported to and exported from the sub-basin. However, in net, imported water does not overcome the losses to stream flow associated with exports and relatively high consumptive use within the sub-basins for residential and commercial irrigation.

East Fork Issaquah and Upper Bear Creek appear to be moderately impacted by water withdrawals and export (24% and 21% base flow reductions) of water from their respective sub-basins.

Generally, aside from Lower Rock Creek, forested, rural, sub-basins with low EIA tend to have minimal base flow impact (Peterson Creek, Upper Issaquah (Carey and Holder), Fifteenmile, and McDonald creeks.). Low base flow impacts also occur in Upper North Creek and Juanita Creeks. Like Swamp and other Sammamish tributary sub-basins, they receive enough imported water to exhibit low base flow impacts with relatively high urbanization.

The remaining creeks generally receive imported water and exhibit base flow reductions in proportion to their level of land development reflecting loss of recharge as well as some summer I&I losses. These range from 5% to 25% for Walsh Lake Ditch, May, Tibbetts, Upper Swamp, Forbes Creeks, and McAleer; 26%-50% for Coal, Kelsey above Richards Ck, and Mercer Slough at mouth (includes Kelsey Ck, Richards Ck, and Lake Bellevue Tributary subbasins), to 83% for Thornton Creek which is impacted by both high levels of EIA and relatively high summer I&I.

At the time of this report, managed water data (pumping, I&I, irrigation, etc.) were not available for the "Marine Drainages" sub-basin; therefore base flow change was not estimated. Based on results in adjacent sub-basins, base flow losses may be vary from low to extreme within the multiple, creek basins included in the Marine Drainages sub-basin.

Table 7 (see Appendix F) summarizes results for all three flow parameters and groups results as "low", "medium", "high", and "extreme" changes depending on relative degree of change.

DISCUSSION

Watershed Wide

Watershed wide, approximately 31% of July-October natural flow is lost to consumptive use and diversion to Puget Sound via the wastewater system. Groundwater recharge reductions account for another 10% loss to stream base flow within the watershed, but probably do not reduce summer-fall discharge to the Sound because stream runoff is collected in Lake Washington and outflow is controlled at the Locks. Similarly, increases in storm peaks and winter storm volumes in watershed streams also probably have minimal impact on the flow regime of the ship canal. The primary impact on Ship Canal flow regime is associated with losses due to consumptive water use and bypass of wastewater to the Sound with the latter component dominating at the watershed scale.

Rivers

Based on the screening analysis, flow regime in both major rivers has changed significantly from natural conditions. In the Cedar River, flows between Cedar Falls and Landsburg have increased during the summer-fall base flow period as a result of water management operations. The water diversion at Landsburg shifts the impact suddenly from augmented summer base flow to substantially reduced summer base flow under average conditions. Given the existing flood control operations that significantly alter winter flow conditions, these changes suggest that the Cedar River flow regime is substantially different from natural conditions to which fish adapted.

On the Sammamish River, results of the screening analysis suggest moderate to high impacts for increases in peak flows and storm volumes. However, these evaluations are based solely on land cover change within the drainage basin and do not account for storage effects of the lake. Consequently, the increases in storm volumes and peaks projected for the river are uncertain and likely to be biased to the high side. This is especially true for peak flows. A more refined analysis technique would have to be employed to elucidate changes to winter flow regime on the river. Summer base flow changes, on the other hand, are evaluated over a season and are much less affected by the lake's storage. Based on the results of the screening analysis, the Sammamish River has lost a moderate amount of base flow (14%) at the weir. The effect is compounded in the reach between the weir and the Little Bear confluence (29%), mainly due to groundwater withdrawals from Bear-Evans and the upper Sammamish valley. Downstream of Little Bear Creek, it appears that the

loss to the river is somewhat diminished (21%) by augmented tributary base flows in Swamp and North Creeks where imported water is used for summer irrigation. Most of the water loss between the weir and Little Bear Creek (~16 cfs drop) previously came to the river directly as cool groundwater or groundwater-fed tributary flow that is cooler than the water coming from the lake.

Major Creeks

Issaquah Creek near SE 141st drains roughly the upper 40% of the entire Issaquah Creek basin. Apparently, its flow condition is similar to streams in the adjacent Seattle Watershed which were not evaluated in this study. It is estimated to have low impact based on all three screening parameters. The upper Issaquah drainage area is largely forested, undeveloped, and unsewered. Additionally, the water survey did not reveal removal of significant amounts water extraction by pumping or surface diversion in the sub-basin. In contrast, Issaquah Creek near the mouth is moderately impacted according to all three screening parameters. The lower portion of the creek exhibits a measure of full complex of effects associated with urbanization. Big Bear Creek is similar to Issaquah Creek near the mouth, but to a greater degree. It is ranked as having high impacts for all three screening parameters.

3rd Order Streams

Of twenty-eight third order streams evaluated, only four appear to be close to their natural state with regard to the three flow screening parameters. These include Upper Issaquah (Holder and Carey) and Fifteenmile in Issaquah Creek basin and Walsh Lake Ditch and Peterson Creek in the lower Cedar River basin. These sub-basins are all predominantly forested with minimal water extraction. From the perspective of preserving natural flow regime as an element of highly functioning fish habitat, these streams should be considered as a high priority.

Lower Rock Creek is the only stream rated minimally impacted in two categories (peak flow and winter storm volume) and extremely impacted in a third category (summer base flow). The screening lends support to previous analyses of Lower Rock Creek that focus on low flow depletion as the single factor limiting an otherwise high quality habitat in a largely undeveloped, forested sub-basin.

Streams with multiple, moderate impacts include East Fork Issaquah, McDonald, Tibbetts, and Upper Bear Creeks. Cottage Lake Creek should also be grouped with these because the “extreme” increase in peak flow that is estimated ignores the potential damping effect of Cottage Lake itself. Storm volume and base flow changes in Cottage Lake Creek are estimated to be medium and low.

May Creek stands out as a creek that is intermediate between moderately impacted rural and intensely impacted, highly urbanized creeks. It is ranked “high” for peak flow, “medium” for storm volume, and “low” for base flows. The remaining streams generally exhibit multiple “high” or “extreme” rankings with the most severely impacted creeks generally occurring on the western, more urbanized side of Lake Washington.

Recommendations

General

More detailed and targeted follow-up studies of flow regime should be pursued in the watershed. For each river or stream reach, the scope of follow-up studies should be informed by knowledge of ecosystem status related to fish populations, sediment transport, floodplain processes, water quality, physical habitat, and other biological data to the extent that these factors are significant for the particular waterbody under consideration. Further, information gained from this study and follow-up flow regime studies should be used in an integrated manner with other ecosystem information to guide flow mitigation or flow management strategies aimed at furthering a coordinated, watershed-wide, salmonid conservation and recovery program.

Specific Recommendations:

1. Coordinate follow-up studies with the U.S. COE.

The screening analysis indicates that there are watershed-wide hydrologic impacts that likely constraint management of the Hiram Chittenden locks for both fish migration and salinity control. Follow-up studies, coordination, and cooperation should be pursued with the Corps of Engineers related to these issues.

2. Conduct Level-1[6] flow studies of the Cedar River.

This screening level analysis demonstrates some of the basic ways in which the Cedar River flow regime has been altered from natural conditions. Given the river's prominence as a highly significant salmonid habitat and plans to open the upper river to salmonids under the Seattle HCP, additional flow studies should be conducted in coordination with and complementary to work being planned by the Cedar River Instream Flow Commission. These studies should: 1) determine natural, baseline, flow regime using a wide range of ecologically meaningful flow parameters and their inter-annual variability at key river locations above and below Landsburg diversion, 2) compare current flow regime to natural conditions at key locations, 3) integrate and apply knowledge of flow regime conditions with knowledge of other ecosystem factors as described above under the General Recommendation.

3. Conduct targeted, follow-up studies of the relationship among surface flow, groundwater flow, water temperature and physical habitat on the Sammamish River.

Studies and resultant actions should target restoration of natural habitat functions of the river with emphasis on reduced mortality and increased productivity of naturally spawning

[6] Please see the appendix "WRIA-8 STREAM FLOW ASSESSMENT STRATEGY" for a definition of flow analysis levels and methods.

salmon. Apply watershed and river models to establish natural, baseline hydrologic, hydraulic, and temperature conditions and to assess efficacy of alternative management actions to restore functional river conditions.

4. Conduct Level-2 and Level-3 flow assessment to 2nd , 3rd , and 4th Order Streams.

A refined analysis should utilize hydrologic models calibrated with available precipitation and stream flow data. Models should represent water and wastewater management actions as well as effects of stormwater facilities and other sub-basin storages.

The WRIA Technical and Staff committees should identify creeks to receive Level 2 or Level 3 analysis based on their importance for salmonids, the degree to which their basins have not yet been built out, and the funds available to conduct such analyses.

Combine results of flow analyses with other ecosystem data to develop stream-specific flow protection and/or restoration goals as described under the General Recommendation.

5. Judiciously apply the results of the screening analysis in recommendations to be developed for the Near-Term Salmon Action Agenda and reports to other committees and organizations with an interest in Cedar-Lake Washington watershed hydrologic conditions.

This could include placing special emphasis on protecting the hydrology of streams that currently have had minimal impact from land cover change, water withdrawal, and sewering such as Upper Issaquah Creek (including Carey and Holder sub-basins), Peterson Creek and Walsh Lake Ditch. It could also include identifying Lower Rock Creek for potential water management actions to help restore natural flows, since it is the only creek in the watershed with minimal impacts to peak flows and storm volumes but extreme impacts to base flows, due to water withdrawal. Other tributary systems experiencing low flow problems, such as North Fork Issaquah, Issaquah Creek, Bear Creek and the Sammamish River may also be identified for corrective water management actions. These actions may include but are not limited to investigation and correction of illegal water withdrawals, accelerated programs of conservation and/or re-use, and promotion of storage of winter stormwater runoff for summer use or release to streams.

LAND USE IN THE LAKE WASHINGTON BASIN

LAND USE

OVERVIEW

Because of the nearly identical land uses and issues faced between WRIAs 8 and 9, the following information is largely adapted from the "*Duwamish/Green River Habitat Limiting Factors and Reconnaissance Assessment Report"* (Kerwin and Nelson 2001).

An understanding of the landscape as influenced by human activities is essential to providing a full picture of Cedar - Sammamish Watershed WRIA. Land use activities from forestry to agriculture to urbanization have shaped the landscape of WRIA 8 for the past 175 years. This chapter discusses how human land use activities can influence watershed processes and salmon habitat, provides information about the historical and current land uses in the watershed, and notes the regulations and policies that have helped shape and continue to shape the land use and land cover found in WRIA 8.

During the past 20 years, a significant amount of research has been done in the Pacific Northwest and the Puget Sound area regarding the impacts on streams and wetlands by various land use practices. Human activities such as forestry, agriculture, urbanization, and mining can drastically disrupt aquatic ecosystems by altering watershed ecological processes either directly or indirectly. Disruptions can include degradation or destruction of in-stream habitat through clearing of riparian vegetation, channelization and bank armoring, barriers to salmonids by dams or other water diversions, increased peak runoff rates and volume of surface water runoff, and removal of wood and reduction of wood recruitment. All of these activities in turn impact hydrology, water quality, riparian functions, and other factors of decline.

WRIA 8 was one of the first areas of Puget Sound extensively settled by European immigrants in the late 18th century**.** As the Native American populations declined, the settlers began to occupy the vacated lands. The settlers employed various methods and policies to gain economic benefit from the land. The 19th Century and the early 20th Century brought land clearing for agriculture, commercial forestry, channelization for navigational purposes, diversion of major tributaries to reduce flooding, and filling of tidelands for development. Numerous federal, state, and local policies allowed and even encouraged these activities to occur.

During the middle of the 20th century, economic development fostered the construction of dikes and levees to reduce flooding, road building and transportation infrastructure construction, and industrial, commercial, and residential development. Again, federal, state, and local policies encouraged this type of development. During the last 30 years of the 20th century, government agencies and the public began to support environmental protection measures and growth management. The federal government passed environmental legislation to protect undeveloped land, wetlands, shorelines, and endangered species habitat. State and local government began to embrace policies to manage development growth, protect shorelines, protect undeveloped land, protect wetlands, and protect

farmlands. The effectiveness of these policies varies due to a variety of constraints including overlapping and conflicting regulatory goals.

Today, the estuary of the Cedar - Sammamish basin has been shifted from its historic estuary (the Green/Duwamish River estuary) to Salmon Bay. The land area of WRIA 8 is a 692 square mile area. A total of 55.1 percent of lands within the WRIA are within the Urban Growth Area (UGA) with 81.4 percent of the land area in Snohomish County and 50.2 percent of the lands in King County inside the urban growth boundary (Rauscher pers comm.). Today, the land in the Upper Cedar River Sub-watershed is almost exclusively managed for late seral stage forest. The middle and lower Cedar River reaches are initially primarily farmland and a mix of urban and rural residential getting more urban as it gets closer to Lake Washington. Other major tributaries (e.g.: Issaquah, Bear creeks) exhibit similar characteristics. For other, smaller and shorter tributary streams they generally exhibit a more urban characteristic the closer they are to urban centers around Lakes Washington and Sammamish. The Salmon Bay Estuary is dominated by commercial and industrial land use practices. Nearly all of the Nearshore Subarea is also urban residential.

Population has increased dramatically since the beginning of the 19th century. In the early 20th century, the region experienced a dramatic increase in population predominantly in the urban areas such as Seattle and the other watershed cities. As the Puget Sound population centers continued to expand through the 1970s, 1980s, and 1990s, WRIA 8 has experienced increasing urbanization throughout its UGA. In 1990, population in WRIA 8 was estimated at 996,341 (EPA unpublished data). This represents an increase of 21 percent over the 1980 population estimate of 823,990.

KEY FINDINGS

- Effects of land use on habitat range from the elimination of habitat to degradation of habitat quality to mitigation or restoration for environmental damages under existing regulations.
- Historically, local, state, and federal policies have greatly influenced the amount and type of land use that has occurred in WRIA 8:

    - For the first 120 years of settlement, economic development was the predominant policy driver of growth and development.
    - For the last 30 years, development has occurred under an increasing number of environmental protection policies and growth management policies.
    - Specific actions were taken over many years to enable and/or assist in economic growth and develop natural resource extraction industries (e.g.: forestry, mining, etc.).
    - Many policies have been established in the last 30 years that require sound planning and development at both the regional and local level.
    - Meeting multiple objectives for the Growth Management Act, the Endangered Species Act, and other complex regulations creates a challenging, overlapping framework for regulations and protections.

- The fifteen years from 1901 to 1916 saw the most dramatic hydrologic change in the WRIA. During this time period, a dam was constructed that blocked fish access to the upper Cedar River, the Cedar River was diverted from the Black River into Lake Washington, and the Hiram Chittenden Locks were completed.
- Growth management is having a significant influence on directing growth to the Urban Growth Area (UGA) and reducing sprawl. However, as population increases, there continues to be a corresponding increase in the amount of developed land:
- Population growth has been a driving factor for the rapid development rates in the watershed:
    - ¬ Before 1996, the majority of jurisdictions in WRIA 8 were experiencing a 1.6 percent per year or higher population growth rate.
    - ¬ During the 1990s every 1 percent increase in population growth corresponded with a 2 percent or higher increase in developed land.

- Ordinances designed to protect salmonid bearing streams through riparian buffer protection vary throughout the basin.

DATA GAPS

Land use information currently available presents certain challenges. The information is not currently organized by watershed boundaries. Although a great deal has been written regarding land use and its effect on salmonids, there has not yet been a close look at local regulations and the subsequent effects on salmonid habitat. Below are the identified land use data gaps:

- Information on King County land development and demographic compiled by the boundaries of the Water Resource Inventory Areas, sub-watersheds, and basins.
- An inventory of permitting, inspection frequencies, and regulatory processes (SEPA and Shoreline review, permit review, sensitive area review, ordinance and regulatory review) throughout the WRIA. Assess the biological implications of various land use activities, regulations, and policies.
- Inventory impervious surface areas (location and amount), road densities, and forest cover retention at a sub-watershed or smaller scale.

EFFECTS OF LAND USE ACTIVITIES

Over the past 20 years, a significant amount of research has been done in the Pacific Northwest and the Puget Sound area regarding the impacts on streams and wetlands by various land use practices. Human activities such as forestry, agriculture, urbanization, and mining can drastically disrupt aquatic ecosystems by altering watershed ecological processes either directly or indirectly. Disruptions can include degradation or destruction of in-stream habitat through clearing of riparian vegetation, channelization and bank armoring, barriers to salmonids by dams or other water diversions, increased peak runoff rates and volume of surface water runoff, and removal of wood and reduction of wood

recruitment. All of these activities in turn impact hydrology, water quality, riparian functions, and other factors of decline.

Below, in Table 38, is an overview and summary of potential impacts to the natural aquatic system due to human uses. Each of the individual chapters conducted for the WRIA 8 Habitat Limiting Factors Report discusses these impacts in more detail.

Table 38. Overview of possible impacts of human land use to natural aquatic systems (adapted from Tri-County Urban Issues Study, R2 Resource Consultants, 1999).

Land Use and Human Activities	Potential Result and Impact of Salmon Habitat
Channelization and confinement of stream channels for urban and rural land uses	Reduced channel complexity; increased velocities; loss of pools for holding and rearing; loss of spawning gravel habitat; loss of side channels; loss of wood recruitment; loss of connectivity with flood plain and riparian zone ***(reduced quality and quantity of habitat)***
Loss of riparian vegetation due to urbanization, mining, forestry, agriculture, etc.	Reduced overhanging vegetation and shade cover; increased solar radiation; elevated water temperatures; loss of LWD recruitment; reduced terrestrial insect influx; reduced leaf litter influx; alteration of energy cycle ***(reduced quality and quantity of habitat)***
Loss of forested areas due to urbanization, mining, forestry, agriculture, etc.	Reduced effective watershed area; altered runoff cycle with altered timing and magnitude of flows; increased erosion; changed channel morphology ***(reduced quality and quantity of habitat)***
Loss of wetlands due to urbanization, mining, forestry, agriculture, etc.	Altered runoff cycle with altered timing and magnitude of flows; reduced base flows; changed channel morphology and loss of connectivity with floodplain ***(reduced quality and quantity of habitat)***
Creation of impervious surfaces	Altered runoff cycle with altered timing and magnitude of flows; changed channel morphology; degraded water quality increased stormwater runoff ***(reduced quality and quantity of habitat)***
Water allocation	Altered flow regime; altered instream habitat availability ***(reduced quality and quantity of habitat)***
Waste water treatment effluent	Degraded water quality related to sewage effluent; altered water temperatures; reduced dissolved oxygen concentrations; released contaminants ***(reduced quality and quantity of habitat)***
Industrial effluent	Degraded water quality; released contaminants and toxins ***(reduced quality and quantity of habitat)***
Culverts, pipes, ditches	Obstructed upstream passage; reduced downstream movement of wood and gravel; stranded fish in ditches ***(reduced quality and quantity of habitat)***
Loss of estuarine and nearshore habitats; port development	Loss of important freshwater to saltwater transition habitats, including cover and food production for smolts; loss of staging and holding habitats for adult salmon; degraded water quality ***(reduced quality and quantity of habitat)***
Bulkhead and dock construction	Increased habitat for predators (e.g., bass); altered nearshore currents and gravel movement; loss of eelgrass habitat ***(increased interaction with predators; reduced quality and quantity of habitat)***
Erosion and sedimentation	Increased turbidity and inputs of fine sediment during construction and prior to revegetation ***(reduced quality and quantity of habitat)***
Water related recreational activities	Increased potential direct contact with ESA-listed salmon; degraded water quality (e.g., fuel spills) ***(reduced quality and quantity of habitat)***
Fertilizer and pesticide use*	Degraded water quality and increased toxicity; biological degradation ***(reduced quality and quantity of habitat)***
Dams*	Loss of upstream habitat due to obstructed upstream passage; altered timing and magnitude of flows; reduced base flows; changed channel morphology; reduced downstream movement of wood and gravel; and loss of connectivity with floodplain. ***(reduced quality and quantity of habitat)***
**** Information taken from "An Ecosystem Approach to Salmonid Conservation" (Spence et. al., 1996)***	

With over 400 reports and studies looking at impacts of land use on habitat, a thorough review of all the literature covering human impacts on natural systems is beyond the scope of this chapter. Initial studies on effects of urbanization on the aquatic system in the Northwest focused on the impacts of urbanization on peak-flow increases. In 1975, Hollis synthesized separate studies to show how the dual factors of percent impervious surfaces and percent of a watershed in storm sewers increased the peak discharges of floods. Then in 1979, Klein published the first study correlating development and aquatic-system conditions in which he reported a rapid decline in biotic diversity where watershed imperviousness exceeded 10 percent (Booth, 2000).

Subsequent studies and models on the subject done throughout the 1980s and 1990s built upon this initial research. Results of research done to date have several overall implications: (1) "Imperviousness," although an imperfect measure of human influence, is clearly associated with stream-system decline. A range of stream conditions, however, can be associated with any given level of imperviousness; (2) "Thresholds of effect," identified in some of the earlier literature (e.g., Klein, 1979; Booth and Reinelt, 1993 referenced in R2, 2000) exist largely as a function of measurement precision, not necessarily as intrinsic characteristics of the system being measured. Crude evaluation tools require that large changes accrue before they can be detected, but lower levels of development may still have consequences that can be revealed by other, more sensitive methods. In particular, biological indicators demonstrate a continuum of effects resulting from human disturbance; and (3) Hydrology is not the sole determinant of stream conditions, but its effects are ubiquitous in urban systems (Booth, 2000).

One of the most comprehensive of the recent studies on impacts of urbanization on aquatic systems was conducted by Chris May et al. The resulting report, titled "*Quality Indices for Urbanization Effects in Puget Sound Lowland Streams*," was published in 1997 for the Department of Ecology. The study collected and analyzed data from 22 Puget Sound lowland streams representing a range of development intensity from predominantly rural watersheds to watersheds that were 99 percent urban. The researchers measured stream habitat conditions, water quality, sediment composition, sediment contamination, fish populations, and benthic organisms at each study site and compared them to watershed conditions. The results demonstrated that the measured parameters had the most consistent negative responses to urbanization and typically include:

- Changes in hydrology;
- Changes in riparian corridor;
- Changes in physical habitat; and
- Water quality (R2, 2000).

The frequency, volume, and quality of large woody debris also decreased significantly as basin development increased. In general, fine sediment in spawning gravels generally increased as urbanization increased while intra-gravel dissolved oxygen decreased. The study further found that as the level of basin development increased above 5 percent total impervious area, results indicated an initial decline in biological integrity as well as physical habitat conditions necessary to support natural biological diversity and complexity

(May et al., 1997). One interesting finding of the May et al. report was that the density of the road network could be used, similarly to total impervious area, as an indicator of impacts to stream conditions. This is primarily because of the drainage system associated with most roads (R2, 2000).

Less information is available regarding the impacts of urbanization on Puget Sound salmon habitat in nearshore environments, estuaries, large rivers, and lakes. In general, changes in hydrology, pollutants, and physical habitat structure in these environments may cause ecological impacts that are comparable to the findings from freshwater research (R2, 2000). Study results have indicated that in the Duwamish and Puyallup estuaries, contaminant exposure in juvenile chinook was likely from the consumption of benthic and epibenthic organisms, which inhabit the contaminated estuarine sediments in these basins (Arkoosh 1991, 1998). Some studies have suggested that suppressed immune systems in young salmon from chemical contamination could make the fish more susceptible to disease as they move further into the marine environment (Arkoosh 1991, 1998).

Below is an unprioritized list of resources with more information on the impacts of urbanization on aquatic systems.

- Forest Cover, Impervious Surface Area, and the Mitigation of Urbanization Impacts in King County. (D. Booth, Center for Urban Water Resources Management, University of Washington, September 2000) discusses impacts from urbanization on hydrology of aquatic systems.
- Tri-County Urban Issues Study (R2 Consulting, 2000) reviews and consolidates existing information related to impacts of urbanization on natural aquatic systems, summarizes current management activities to mitigate these impacts, and presents guidance in selecting salmon recovery options in urban and urbanizing areas. The ESA Urban Issues Document Library and Database contains over 400 documents including documents from federal, tribal, state, and local agencies, as well as scientific articles that were published in peer-reviewed journals.
- An Ecosystem Approach to Salmonid Conservation (Spence et al., December 1996) provides a technical basis for implementation of an ecosystem approach to habitat conservation planning. Chapter 6 discusses effects of human activities on watershed processes, salmonids, and their habitats.
- Quality Indices for Urbanization Effects in Puget Sound Lowland Streams (May et al., June 1997) reports on a study of instream habitat, riparian conditions, water quality, and biological attributes of 22 streams to determine the relationships between urbanization and stream quality.
- Factors Affecting Chinook Populations (Parametrix, June 2000) is a “snapshot” of what is currently known about how development in the City of Seattle has affected chinook salmon.

HISTORIC POLICY CONTEXT AND LAND USE EVENTS

WRIA 8 was one of the first areas of Puget Sound extensively settled by immigrants**.** Today, of the historic estuary of Lake Washington and the Cedar River has been "re-plumbed" from the historic Green/Duwamish River estuary to Salmon Bay. Lake Union and Lake Washington, once separated by a natural ridge are connected and both drain through the Locks into the greater Puget Sound estuary through Salmon Bay.

OVERVIEW AND CHRONOLOGY OF WATERSHED LAND USE CHANGES

The WRIA 8 land use history began thousands of years ago when indigenous people first moved into the WRIA 8 (Cedar - Sammamish Watershed) following the retreat of the last ice flows. However, a great preponderance of the major land use changes has occurred in the last 150 years since settlers moved into the area. Table 39 shows a chronology of the events and policies affecting WRIA 8 beginning in 1790 and ending in 2000. The scope of this chronology does not include tribal history prior to 1790.

Table 39. Chronology of policies and events in the Lake Washington Basin 1790's – .

Date	Policies and Events	Notes
1790s	First settlers move into the Puget Sound area	
1840s	Native populations in the WRIA decreased to one tenth of 1790 population levels	Settlers move into unoccupied lands
1850	Oregon Donation Land Act	Granted land to settlers if they homestead for 5 years
1851	Seattle founded	Initial land use changes
1852	King County is established	Settlers' first major governance system in WRIA
1853	Washington Territory is established	
1853	Extension of Land Act through 1855	Additional land claims filed
1855-56	Indian Wars	Settlers move to Seattle for protection - settlement slows
1858	King County Drainage Laws	County passes laws permitting ditches for drainage, swampland drainage begins
1862	Homestead Act	Settlement of territory encouraged
1876	Lands between Lake Union and Duwamish valley platted	Settlement encouraged
1870s	Major railroads build lines	Pace of coal mining and logging increases in WRIA 8. By 1871 up to 100 tons of coal per day were being shipped to San Francisco
1875	Channel Improvement Act	County road funds used for improvement of rivers
1880's	Sluice channel cut between Lakes Union and Washington	Logs moved out of Lake Washington into Lake Union and Puget Sound
1880-1910	Majority of logging occurs in WRIA 8	
1897 and 1900	Klondike and Alaska Gold Rushes	Influx of gold miners and suppliers to Seattle
1889	Washington granted statehood	
1895	Drainage District Act	County Drainage Districts formed
1899	Federal Rivers and Harbors Act	Encouraged federal actions to protect navigation rights
1896	City of Seattle initiates land purchases in upper Cedar River watershed	
1901	City of Seattle begins water diversions out of Cedar River for water supply.	Landsburg Dam blocks anadromous fish migration to upper cedar River.
1916	Black and Cedar Rivers diverted into Lake Washington. Ship Canal cut to Lake Union draining Lake Washington to Puget Sound	This diversion reduced flooding in the Duwamish River lowlands, provided flushing for Lake Washington, and created access to fresh water for ships in Lakes Union and Washington.
1918	Coal production peaks and is one of the state's largest exports	Mines east of Lake Washington peak production

Table 39. Chronology of Policies and Events in the WRIA 8: 1790-2000 (continued).

Date	Policies and Events	Notes
1926	King County Planning Commission appointed and releases recommendations	Report includes preparation of county road plan, acquisition of parks, regulation of platting, and formation of a metropolitan sewer district
1935	Washington State Planning Enabling Act	Counties and jurisdictions allowed to regulate land use
1938	The first soil survey was initiated as a cooperative effort of the United States Department of Agriculture (USDA), the Washington Agricultural Experiment Station, and the Washington State Planning Council	Described and located numerous types of soil and documented the productive capacity of various soils for different types of agricultural crops
1964	King County adopts its first comprehensive plan	Recognizes the need for an effective means of guiding and coordinating the physical development of the County; a means for coordinating programs and services; a source of reference to aid in developing coordinated official plans and regulations for the County and municipalities within it; and a means of promoting a desirable environment for housing, commerce, industry, agriculture, and recreation
1970	National Environmental Policy Act	Requires environmental review for all development which has a federal nexus
1971	Washington State Shoreline Management Act	Requires local jurisdictions to create master plans that protect and regulate coastal resources while also allowing development activities
1972	Federal Coastal Zone Management Act	Unique federal/state partnership to encourage states to develop programs that preserve, protect, and restore coastal resources
1973	Washington State Land Use Act	Allowed lands that are undeveloped and left in the natural state to be taxed at a lower rate than developed land
1973	Federal Endangered Species Act	Federal agencies required to protect endangered species and their habitat from harmful human activities
1974	U.S. v WA (Boldt) Decision	United States Supreme Court interpreted the Treaty of Point Elliott to mean that Native American tribes were entitled to half of the total allowable catch of fish in the tribe's usual and accustomed fishing grounds
1977	Clean Water Act (Amendment to the Federal Water Pollution Control Act of 1972)	Generally halted filling of wetlands or required mitigation for filling of freshwater or marine wetlands
1978	King County Growth Management Program	Directed future comprehensive plans to deal with growth while incorporating environmental protection, energy conservation, and farm land preservation
1979	King County voters pass Farmland Preservation Program	$50 million bond issue to purchase development rights on agriculture lands in King County
1984	City of Bellevue first city in US to tax property owners for stormwater management.	Funding generated to address regional stormwater issues
1985	King County Comprehensive Plan--1985	Addressed expected population and employment growth; established urban areas, transitional areas, rural areas, open space, and natural resource lands
1990	Washington State Growth Management Act	Requires local governments to plan for growth; all urban counties and their cities are required to plan comprehensively and jointly for the future
1994	King County Comprehensive Plan--1994 Cities begin to adopt comprehensive plans County and city plans are guided by the Countywide Planning Policies	Urban Growth Area established in the western one-third of the County where most future growth and development will occur to reduce urban sprawl, enhance open space, protect rural areas including the establishment of the Agriculture Production District, and more efficiently use human services, transportation, and utilities
1999	Federal listing of chinook salmon and bull trout as threatened species	Protection and recovery of species in Puget Sound Region is required

PRE-1850: THE YEARS BEFORE THE SETTLERS

Before settlers arrived in the region, streams of the Puget Sound lowland were a network of sloughs, islands, beaver ponds, and estuaries (Fuerstenberg, 1999). Historians estimate about several hundred Native American people lived in the Cedar - Sammamish Basin area during the 18th century. The primary daily activities of the Native Americans were social activities, fishing, hunting, and food gathering. Shellfish and salmon were the primary foods of Native Americans. Gardens and camas fields (maintained by burning) are the only evidence of forest clearing by Native Americans.

1850-1917: SETTLERS AND THE YEARS OF RESOURCE EXTRACTION

SETTLERS LAND USE POLICY 1850-1917

Human Settlement

Native American's, including members of the Muckleshoot, Suquamish and Tulalip Tribes have lived in the WRIA 8 watershed for thousands of years. However, the native peoples' land use and natural resource use patterns were less disruptive to the natural ecosystem than the settlers' subsequent land use patterns. The Treaty of Point Elliott, signed in 1855, allowed the European settlers to begin to dominate land use in the watershed. This treaty moved local tribes to various reservations that were a fraction of the land area that the tribes used to occupy. The federal policies of "manifest destiny," the Oregon Donation Land Act of 1850, the Homestead Act of 1862, and the laissez faire economic policies of the federal government influenced the settlers' development of the Cedar - Sammamish Watershed. The results of these policies were the rapid settlement of the area and the exploitation of natural resources in the latter part of the 19th Century (Benoit, 1979).

Navigation/Transportation

The lakes and river of the Cedar - Sammamish watershed were a significant transportation corridor during early settlement, fostering development of communities along the edge of the lakes and rivers. As communities sprang up, the shorelines were cleared and adjacent wetlands were drained under drainage laws established by King County in 1858. Policies that encouraged these settlements and federal policies that encouraged use of the ship canal for navigation, resulted in extensive development of land. In turn, this development supported the growth of communities along the shorelines of Lakes Union, Washington and Sammamish.

As the land was settled, federal policy encouraged the expansion of the railroad. Two distinct land use patterns developed as a direct result:

- The routes taken by the railroads and early primitive wagon roads shaped the growth of local communities and industry; and
- Later patterns of highway development were influenced by early rail routes, thus further reinforcing the geographic development of commercial and industrial land uses.

The Federal Rivers and Harbors Act of 1899 provided the policy basis for federal actions in and around the navigable waters of King County and gave responsibility for conducting water projects to the U.S. Army Corps of Engineers. In 1916, the completion of the construction of the Hiram M. Chittenden Locks and the Lake Washington Ship Canal occurred under the auspices of the Rivers and Harbors Act. These major projects diverted the Cedar River and Lake Washington outflow via the Black River away from the Duwamish estuary and into Puget Sound via the ship canal and locks.

Tidelands Development

At the time of statehood, ownership of all tidelands in Washington State was transferred from the federal government to the state under the equal footing doctrine of the U.S. Constitution (Good and Ridlington, 1992). The tidelands were supposed to be held in the "public trust" per the Public Trust Doctrine, which is a common law doctrine protecting shorelands in the public interest. Over time, 70 percent of Washington's inland marine water tidelands were sold to private upland owners (Broadhurst, 1998). The Public Trust Doctrine and the "takings" clause of the Fifth Amendment of the U.S. Constitution protecting private property rights have been invoked many times in court battles over shoreline land use regulation since the beginning of the 20th century.

Flood Control

The nation had long been engaged in issues of flood control, especially in the Mississippi River basin (MRC, 2000). Flood control measures in the southern region of the United States influenced the policy foundation for flood control in WRIA 8, including the diking of the Cedar and Sammamish rivers. The purpose of flood control was to protect the economic well-being of the region by preventing floods, that disrupt agricultural land uses.

Commercial Forestry

Land dedicated to railroads was often transferred to subsidiary commercial forestry companies (e.g., Plum Creek Timber Company which was originally part of Burlington Northern, which was the successor company to both the Great Northern and the Northern Pacific Railroads) or sold to other commercial forestry interests. In addition, the federal government, recognizing the value of forestlands, established a policy to create federal forest reserves in 1897. The creation of the Snoqualmie National Forest and the implementation of a federal policy of allowing logging on public lands, ensured that land uses in the Upper Cedar River subarea would focus on timber production and mineral extraction. The National Forest Management Act later broadened the mandates of federal forestlands to include recreation, fish and wildlife habitat, and other current forest uses.

Culminating with a significant land exchange in 1996, the vast majority of the upper Cedar River subarea was taken out of commercial forest management and managed as a municipal drinking water supply watershed.

EUROPEAN SETTLERS LAND USE PATTERNS 1850-1917

After significant numbers of Euro-Americans arrived in the 1850s, the landscape changed dramatically. The Treaty of Point Elliott in 1855 moved native peoples to a small reservation to the south in Green-Duwamish Watershed (WRIA 9), allowing Euro-Americans to move further into areas previously occupied by native peoples. The forests of WRIA 8 were among the first areas west of the Cascade Mountains to be logged.

In 1888, the Northern Pacific Railroad was the first transcontinental railroad to the Pacific Northwest. Initially with Tacoma serving as its terminus, the railroad quickly moved northward through the Puyallup and Green River valleys making its way to Seattle and into the lands of the Cedar - Sammamish Basin. This, along with the proximity of the large lakes in the basin made almost all parts of the basin accessible to timber production. The railroad companies acquired land from the federal government and transferred it to Plum Creek or sold the land to other timber companies. Subsequent logging operations supplemented by frequent forest fires greatly depleted the original forest. In a survey from 1853 to 1861 of plant life west of the Cascades for the Northern Pacific Railroad, Cooper notes the excellent firewood characteristic of Douglas fir, “From its combustibility extensive tracts of this forest get burnt every year, taking fire from friction or any other slight cause.” Cooper described ascending the western slopes of the Cascade Range where “we passed for days through dead forests.” As the Northern Pacific Railroad had not yet constructed its line northward, Cooper probably observed and recorded evidence of natural fires or natural fires fostered by poor logging practices (Fuerstenberg, 1999).

As the land was cleared of vegetation for commercial forestry and agriculture operations, protection was needed from flooding and the excess water generated by lack of forest cover. (A 1919 Washington State Fish Commission report noted that “...as timber is cleared away, hatchery operations are more and more hampered by flood conditions. The water in streams rises more quickly now than was formerly the case when there was heavy timber growing...”).

THE REPLUMBING OF THE CEDAR RIVER AND LAKES UNION AND WASHINGTON

The seven years from 1910 to 1916 saw the most dramatic hydrologic change. During this period, the Cedar River was diverted from the Black River into Lake Washington. The Ship Canal and Hiram Chittenden Locks were completed, lowering the level of Lake Washington and providing a new outlet to Puget Sound through the two lakes.
In 1901, the City of Seattle completed the first Landsburg Dam and blocked anadromous fish access to the historic spawning and rearing areas of the upper Cedar River. The Landsburg Diversion Dam further served to reduce the flow of the lower Cedar River. When the City first began the diversion in 1901, Washington State was still 16 years away

from adopting its first statutory water code. Thus, at the time Seattle's Cedar River water rights were first established, the common law doctrine of prior appropriation governed water rights matters. Ultimately, Washington State established both a permit process for granting new water rights, and an adjudication process for resolving disputes concerning attributes of water rights such as quantities and priority dates. In 1967 Washington State enacted a new claim registration statute to validate water claims. The City documented its water claim on the Cedar River in 1974, indicating a priority date of 1888 and a right to divert an annual average of up to 300 million gallons per day (mgd) for municipal and industrial use, with daily diversions that could exceed 300 mgd at certain times of the year. However, like most water right claims in Washington State, the City's claim has not gone through an adjudication process, which is a legal proceeding where the court determines if a water right is valid and vested.

After Washington State granted City of Seattle the right to remove a maximum of 300 million gallons per day of water from the Cedar River, The City of Seattle subsequently began purchasing land in the municipal watershed (see Upper Cedar River chapter).

By 1916, the Cedar River had been diverted from the Duwamish River as part of the project to connect Lake Washington and Puget Sound. This diversion provided flushing for Lake Washington and navigational access from Puget Sound to Lake Washington via the Hiram M. Chittenden Locks and the Lake Washington Ship Canal. As a result, the Cedar River currently flows into Lake Washington.

1917-1970: THE YEARS OF ECONOMIC DEVELOPMENT

ECONOMIC DEVELOPMENT POLICY 1917-1970

Flood Control

At the federal level, continued discussion of flooding on the Mississippi River provided the basis for approaches to further control flooding in the Sammamish River and Cedar River valleys. Private levees that had been permitted by State and County legislation were supplemented by publicly financed levee construction under the Flood Control Act of 1936 (33 USC Chapter 15). The U.S. Army Corps of Engineers took the lead in creating a system that would protect the agricultural, commercial, industrial, and residential land uses that were growing throughout the region. This policy was followed by the Watershed Protection and Flood Prevention Act of 1954, which reaffirmed previous policy (16 USC Chapter 18). The Act stated:

> *"Erosion, flood water, and sediment damages in the watersheds of the rivers and streams of the United States, causing loss of life and damage to property, constitute a menace to the national welfare; and it is the sense of Congress that the Federal Government should cooperate with States and their political subdivisions, soil or water conservation districts, flood prevention or control districts, and other local public agencies for the purpose of preventing such damages, of furthering the conservation,*

development, utilization, and disposal of water and protecting and improving the Nation's land and water resources and the quality of the environment."

TRANSPORTATION

Federal highway construction policies emphasize increasing freight mobility across the continent. Federal funding for construction of Interstate 5 and Interstate 90 encouraged the development of industry in the Cedar - Sammamish Watershed. Highway access to major industrial development further encouraged commercial, residential and other infrastructure development outside of the core cities.

SHORELANDS DEVELOPMENT

During the 1917-1970 period, most of the development and shoreline armoring (bulkheading) along the WRIA 8 marine shoreline occurred. This was driven by Washington State sale of tidelands to private landowners with the landowners then protecting the land from erosion.

ECONOMIC GROWTH

Recognizing the need for an effective means of guiding and coordinating the physical development of King County, the County Commissioners in June 1959, initiated a reorganization of the County Planning Agency and provided the necessary budget to develop a modern planning program. By 1964, a Comprehensive Plan was prepared under the requirements of the State Planning Enabling Act (RCW 36.70). This initial plan was designed to serve a projected 1985 population of about 1.6 million people within the entire area of King County. The objective of the plan was to "assure the highest degree of public health, safety, and general welfare" while not "unduly jeopardizing the rights of the individual" (KCPD, 1964).

The policy construct of the 1964 King County Comprehensive Plan was to direct growth within the County to predominantly occur in the "Urban Area" outside the City of Seattle. The plan expected that the population of Seattle would increase slightly over its 1960 population of 557,100 persons while the County outside Seattle was expected to reach nearly a million people -- nearly triple its 1960 population. The rest of the County, or that area outside the Urban Area, was expected to grow from 28,700 in 1960 to 73,000 in 1985 (KCPD, 1964). As the population of the County increased, the density of population was expected to increase. Gross density (persons per total acres) for the whole County was expected to increase from 0.68 to 1.21 persons per acre; in Seattle, from 9.84 to 10.33 persons per acre; in the King County Urban Area outside Seattle from 1.17 to 5.34 persons per acre; and in King County outside the Urban Area from 0.3 to 0.7 persons per acre.

ECONOMIC DEVELOPMENT LAND USES & POPULATION CHANGE: 1917-1970

The Great Depression slowed timber harvest that had peaked during the early 20th Century. Coal production peaked in 1900s but quickly decreased as alternative energy sources were found, and other forms of mineral extraction such as sand and gravel production became more important as a result of the increased demand for industrial, residential, and road development (Fuerstenberg, 1999).

Between 1930 and 1960, the Puget Sound Region, consisting of King, Pierce, Snohomish, and Kitsap Counties, was one of the fastest growing areas of the State. The population of the region doubled during that time period, growing from 737,000 people to more than 1.5 million. Most of this growth occurred in the 1940s with the stepping up of defense production. Due to high birth rates and continued defense production, this growth continued throughout the 1950s but at a reduced rate. King County's growth during this period mirrored that of the region. Between 1930 and 1960, the population of King County increased from 464,000 to 935,000, most of which occurred between 1940 and 1950 (KCPD, 1964).

Transportation corridors in particular experienced a dramatic increase in urbanization. Land use practices had already shifted from commercial timber harvest and urban centers were expanding. Around the major transportation corridors of the interstate and state highway systems, lands were converted to warehouses, malls, and industry due to the proximity of roadway systems, reduced threat of flooding, and the flat, easily developable land.

1970-2000: Heightened Regional Planning & Environmental Awakening

ENVIRONMENTAL PROTECTION POLICY 1970-2000

Environmental Concerns Establish a Regulatory Framework: The United States Environmental Protection Agency (EPA) was established in 1970 to respond to nationwide concerns about environmental damage. The National Environmental Protection Act (NEPA), the first official federal action of 1970, established a national policy to weigh human land use activities with environmental concerns. Environmental impact statements were required for new development, alternatives were evaluated, and mitigation required for environmental damages (Lewis, 1985).

The Washington State Environmental Protection Act (SEPA) was adopted in 1971 (RCW 43.21c). It sought to strike a balance between development and environmental protection. SEPA aimed to avoid negative environmental impacts by requiring land use projects to consider impacts of various alternative project designs and mitigate for environmental damages. The passage of SEPA ushered in an era that saw a policy shift toward environmental considerations on both the state and local level that affected land use in WRIA 8.

SHORELANDS PROTECTION

The federal Coastal Zone Management Act (CZMA) was enacted in 1972 to preserve, protect, and restore the nation's coastal zone resources. The CZMA established a unique state-federal partnership designed to encourage and assist states in developing and implementing management programs to achieve a variety of goals, including the achievement of "wise use of the land and water resources of the coastal zone" (Good et. al., 1998).

Washington State was the first state in the nation to establish a federally approved coastal zone management program (CZMA). The State Shoreline Management Act (SMA) (RCW 90.58.020) is the primary means by which the state meets its CZMA requirements. The SMA states that shorelines should be managed to:

- Foster all reasonable and appropriate uses, particularly "water dependent uses;"
- Provide the public the opportunity to enjoy the physical and aesthetic qualities of natural shorelines; and
- Ensure uses are designed and conducted in a manner to minimize damage to the ecology and environment of the shoreline area and any interference with the public's use of the water.

The SMA is implemented and enforced by local governments in the form of Shoreline Master Programs (SMPs) and the State Department of Ecology serves in a support and review capacity to assist and ensure that local governments comply with the act (Broadhurst, 1998).

Specific uses and activities within the shoreline zone are governed/regulated by local SMPs, including aquaculture, mining, commercial development, industrial development, recreation, marinas, and shoreline modifications such as dredging, landfills, piers, and bulkheads. However, because the SMA is explicitly designed to balance public shoreline uses with the rights of private property owners, a number of activities within the shorezone are exempt from the mitigation and other requirements set forth in the SMA and local SMPs. These include:

- Developments having a fair market value less than $2,500;
- Maintenance of existing structures;
- Construction of single family bulkheads; and
- Construction of single family residences.

Approximately 90 percent of Puget Sound's shorelines are in private ownership. Single family residences are exempt from permitting requirements in the Shoreline Management Act and it is unclear if these shorelines are being afforded the necessary level of protection (Broadhurst, 1998). In November 2000 (too late to be reviewed for this document), the State finished reviewing and updating the Shoreline Master Program Guidelines to reflect best available science regarding the functions and values of shoreline resources.

FARMLANDS PRESERVATION

Recognizing that an unintended consequence of earlier flood control policies in the Green/Duwamish River Watershed was the rapid conversion of agricultural land to other, more intensive land uses, the 1964 Comprehensive Plan included "Land Used for Agriculture" as an element in its definition of Open Space and identified policies to ensure that these areas were retained within the County (KCPD, 1964). The County continued to categorize its agricultural lands and emphasize the need to protect them and in 1977 adopted Ordinance No. 3064 that established seven Agricultural Districts and designated specific areas within them as "Agricultural Lands of County Significance."

King County voters adopted the Farmlands Preservation Act in 1979, which created the Farmland Preservation Program. This ballot measure allowed the County to purchase $50 million worth of development rights on agricultural lands at fair market value in return for a guarantee that those lands would remain in agricultural use. This policy has helped slow the conversion of agricultural lands in the Green – Duwamish watershed but very little of these funds has been used in the Cedar - Sammamish Watershed (WRIA 8). The Farmland Preservation Program provides some protection and restoration of fish and wildlife habitat, since the covenants placed on agricultural properties prohibit non-agricultural uses. In 1985, the County took further action to protect farmland when it established agricultural land use policies and zoning regulations.

GROWTH MANAGEMENT

Changes in societal views about environmental issues in the 1970s coincided with an economic downturn in the Puget Sound region. Despite the economic downturn, the growth and development predicted by the 1964 King County Comprehensive Plan proved to be real. This growth presented many unanticipated growth-related problems, including energy shortages, congested highways, air pollution, disappearing farmlands, and rising cost for housing and public services. In response, King County established a growth management program in 1978 to reexamine and revise the 1964 document. The King County population increased 9.5 percent between 1970 and 1980. Forecasts at that time predicted the population to increase 9.3 percent between 1980 and 1990, then increase 19.1 percent between 1990 and 2000. The 2000 forecast population was 1,638,920 people, or nearly 30 percent greater than the 1980 population of 1,269,749.

The 1985 King County Comprehensive Plan established a pattern of countywide growth development, which would encourage population growth in areas with the infrastructure and facilities to support growth, the "Urban Growth Area" (UGA), while discouraging growth in areas designated as the "Rural Area" and "Resource Lands and Industries." In the Rural Area, low-density residential development was encouraged to maintain rural character and promote small-scale farming and forestry. The Rural Area was also to provide a buffer to Resource Lands from incompatible land uses while maintaining rural service levels. Resource Lands and Industries designations were intended to conserve farmlands, forestlands, and mineral resources, and to encourage and promote their productive management by resource industries (KCPD, 1985).

To address environmental quality impaired by growth, the 1985 Comprehensive Plan established policies to protect the quality of the natural environment through land use plans, regulations, and incentive programs and to encourage the retention of open space. One policy called for the following areas of the County to remain undeveloped:

- Floodways of 100-year floodplains;
- Slopes with a grade of 40 percent or more;
- Severe landslide hazard areas;
- Wetlands rated as unique/outstanding or significant; and
- Coal mine hazard areas.

These natural features were designated as Open Space and described, classified, and mapped in the Sensitive Areas Map Folio and the Inventory of King County Wetlands. These reports, along with all other available data, were the basis for specific land use regulations for "environmentally sensitive areas" (KCPD, 1985).

Washington State responded to problems associated with statewide growth by adopting the State Growth Management Act (GMA) of 1990 (RCW 36.70A), which was the first critical step in the development of comprehensive policies to sustain growth in Washington. For the first time in the State's history, all urban counties and their cities were required to develop and adopt comprehensive plans and regulations to implement these plans. To ensure comparable planning efforts, the GMA required that comprehensive plans address specific issues including (but not limited to) land use, transportation, housing, facilities and services, utilities, natural environment, and economic development. To achieve coordinated planning efforts, the GMA further required that counties and cities develop a set of framework policies to guide development of each jurisdiction's comprehensive plan. The King County Countywide Planning Policies define the countywide vision and establish the parameters for comprehensive plans of all the cities and the County. Implementing regulations were required that must be consistent with comprehensive plans (KCDDES, 1994). King County adopted a new Comprehensive Plan in 1994 to respond to the GMA. All of the cities followed suit between 1994 and the present.

The Countywide Planning Policies call for consistent approaches to protect critical areas (also known as environmentally sensitive areas) and directed the majority of future growth to within the Urban Growth Area of the western third of the County. In so doing, the intent was to limit urban sprawl, enhance open space, protect rural areas, and more efficiently use human services, transportation, and utilities. Within the Urban Growth Area, the Countywide Planning Policies designated "Urban Centers" within the boundaries of several cities. The 14 Urban Centers are areas in which concentrated employment and housing is to be achieved. The Urban Centers are to be directly serviced by high-capacity public transit. They contain a wide variety of land uses including retail, recreational, cultural and public facilities, parks, and open spaces. The policy construct is to establish well-designed, highly livable Urban Centers that will encourage people to work and live there. If successful, this will contribute to achieving the growth management goal of concentrating infrastructure

investments and preventing urban sprawl and environmental degradation. Eight of the 14 designated Urban Centers within King County are located in WRIA 8.

One of the basic goals of the Growth Management Act is to encourage affordable housing. The GMA directs all the jurisdictions' comprehensive plans to make adequate provisions for existing and projected housing needs of all economic segments of the communities. The Countywide Planning Policies call for each jurisdiction to specify the range and amount of housing needed for various income groups. A key component of meeting this housing objective is by providing sufficient land for housing in communities throughout the County. In particular, land must be available for affordable housing types: higher density single-family housing; multifamily housing; manufactured housing; accessory apartments; and mixed-use developments. All of these housing types provide opportunities for development of affordable housing (KCDDES, 1994). Efforts to provide sufficient land, infrastructure, and reduced development costs for affordable housing is difficult to balance with the need to establish and maintain an Urban Growth Area sized to reduce urban sprawl. This balance remains difficult as costs associated with new housing construction and the demand for housing in the Puget Sound region grow.

The Urban Growth Area created by the Countywide Planning Policies was established to provide sufficient land to accommodate the expected number of households through 2012 (20-year planning horizon). Ensuring that there was capacity to accommodate projected household growth was a key element of growth management planning efforts throughout the County in the early to mid 1990s (KCDDES, 1994B and KCCPPBP, 2000).

Land use indicators of the Countywide Planning Policies Benchmark Program indicate that there is ample capacity within the existing Countywide Urban Growth Area to accommodate the estimated remaining number of targeted households and jobs by 2012 (170 to 198 percent capacity of remaining target). However, these same indicators show that for the period of 1980 to 1990 there was an increase in population by 19 percent that was accompanied by a 37 percent increase in developed land (or as expressed as a ratio of 1:1.95). This indicative of an increase in the amount of infrastructure currently required over historic levels.

These land use indicators suggest that there is no need to increase the size of the Urban Growth Area to accommodate projected growth and to achieve affordable housing goals. The information also suggests that the growth capacity in the Rural Area is not needed. Indeed, the amount of growth in the Rural area has decreased from 1994 to 1999 from 11 percent to five percent of the total amount of Countywide household growth; the amount of growth in the Urban Growth Area increased from 88 percent in 1994 to 95 percent in 1999. Another trend is growth in urban core areas versus the outer portions of the Urban Growth Area. Urban core areas steadily increased from 47 percent of the total amount of household growth to 62 percent from 1994 to 1999. During this same period of time, the amount of growth in the outer fringe areas of the UGA decreased from 42 percent to 33 percent of the total Countywide household growth. However, while 95 percent of the new housing units in King County were permitted in Urban Areas in 1999, 5 percent (735 units) were permitted in Rural and Resource Areas. While this is part of a declining trend of housing

units in Rural and Resource Areas, in order to achieve the 20-year target growth of only 6-8,000 new units in rural areas, the annual growth rate would need to decrease to an average of 350 units annually (2000 King County Annual Growth Report).

ENDANGERED SPECIES PROTECTION

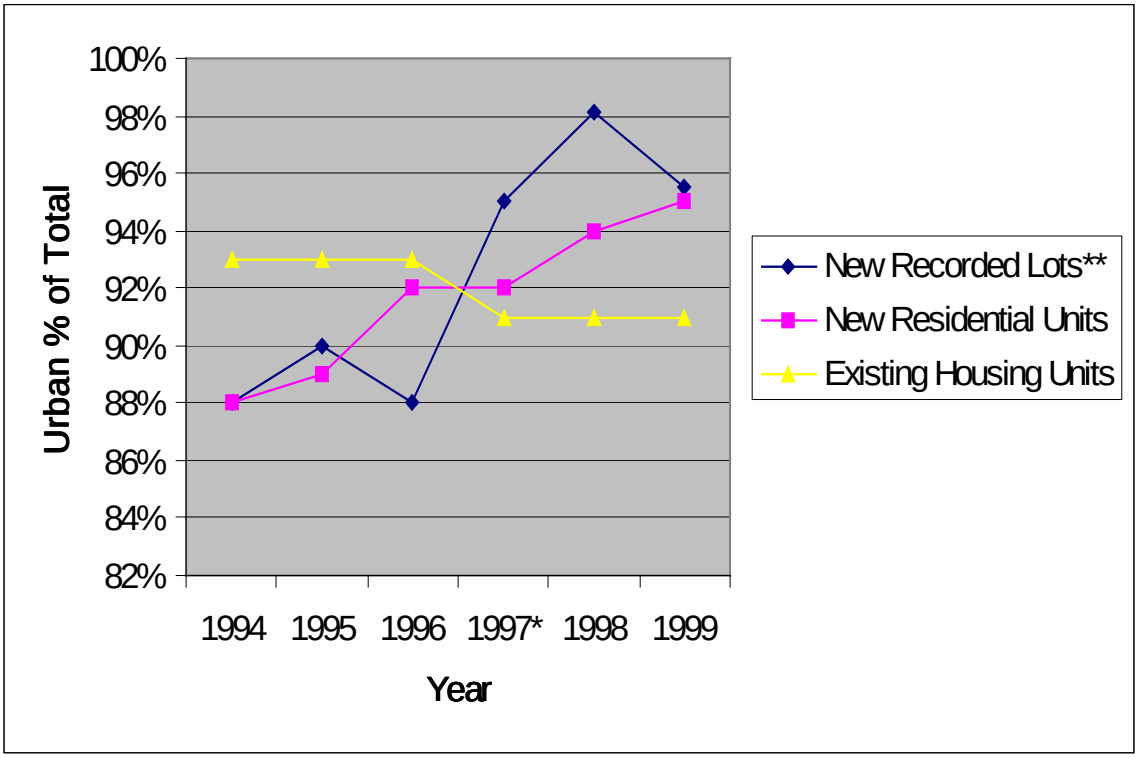
The latest policy to affect land uses in Cedar - Sammamish Watershed is the Endangered Species Act (ESA) of 1973, triggered locally by the 1999 listing of chinook and bull trout as threatened species. The purpose of the Endangered Species Act is "to provide a means whereby the ecosystems upon which endangered and threatened species depend may be conserved, and to provide a program for the conservation of these species." The ESA prohibits the "take" of any "endangered" or "threatened" species or the degradation of habitat critical to these species. The ESA involves a process of species listings (Section 4), definition of "take" (Section 4d), federal agency consultations to avoid "take" (Section 7), prohibition of "take" (Section 9) and a citizen suit provision (Section 11). The Act may affect land use activities if the land use is construed as a "take." It is unclear how the ESA will be implemented in the area. However, land use activities are one of many human activities that may be restricted in order to protect salmon populations. The effect of ESA on GMA are uncertain and may have new impacts on land use in WRIA 8 in the next 10 – 20 years.

LAND USES AND ENVIRONMENTAL PROTECTION 1970-2000

As the Puget Sound population centers continued to expand from the 1970s through the 1990s, WRIA 8 became increasingly urbanized in the Nearshore, and virtually all of the sub-watersheds of the basin. With the inception of the Washington State Growth Management Act in 1990, local governments have tried to slow growth in the rural area. Figures 43 and 44 show the King County development trends from 1994 to 1999. Figure 43 shows that from 1994 to 1999, or following implementation of the GMA, there has been a dramatic increase in the amount of residential development in the Urban Growth Area. Figure 44, shows that there has been a corresponding decrease in the amount of residential development in the Rural Area. Only eight percent of the permits issued by King County in 1997 were in the Rural Area, versus 20 percent for the Puget Sound region as a whole (PSCR, 1998).

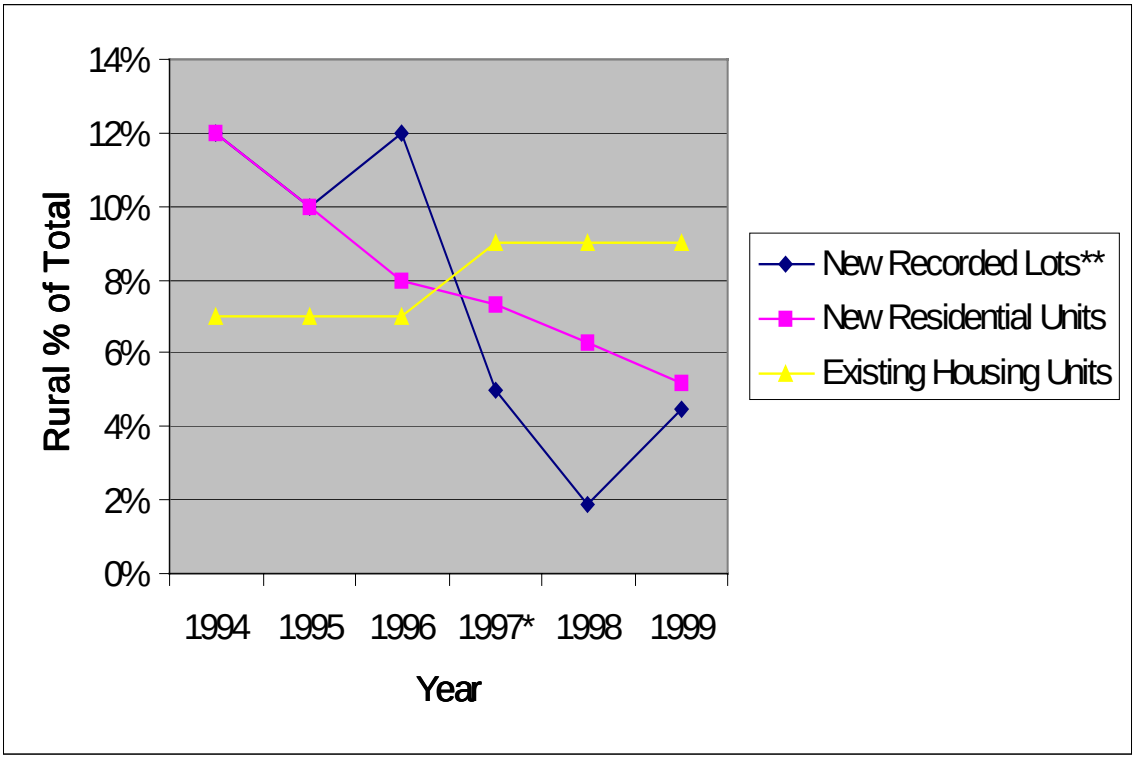
Despite this trend, which is driven by the successful implementation of growth management plans by all jurisdictions of the County, the Puget Sound Regional Council (PSRC) found that a 19 percent increase in population between 1980 and 1990 was also accompanied by a 37 percent increase in developed land (PSRC, 1998).

Figure 43. King County land development indicators – urban (KCORPP 2000)



* Data not comparable in previous years due to a change in measuring existing housing units.
** Does not include short plats.

Figure 44. King County land development indicators – rural (KCORPP, 2000).



* Data not comparable in previous years due to a change in measuring existing housing units.
** Does not include short plats.

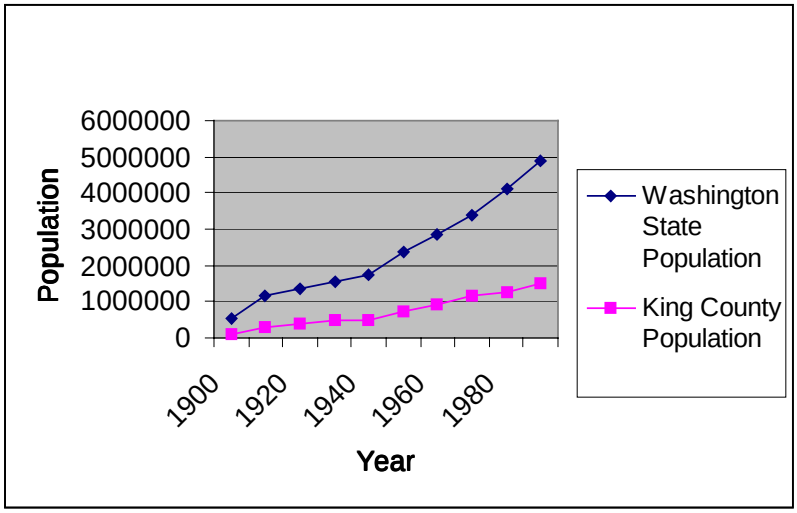
PRESENT DAY LAND COVER AND DESIGNATED LAND USE

The land area of WRIA 8 is approximately a 692 square-mile area. Thirty percent of the WRIA is within the Urban Growth Area (UGA). The land use/land cover statistics are categorized from 1995 King County land cover data. Designated land use statistics are categorized from recent Puget Sound Regional Council data that summarized current comprehensive plans.

POPULATION GROWTH

Population has increased dramatically since the beginning of the 19th century. In the early 20th century, the region experienced a dramatic increase in population predominantly in the urban areas such as Seattle and the other watershed cities. As the Puget Sound population centers continued to expand through the 1970s, 1980s, and 1990s, WRIA 8 has experienced increasing urbanization throughout its Urban Growth Area. The Puget Sound Regional Council has found that for every 1 percent increase in population growth there is a corresponding 2 percent or higher increase in developed land (PSRC, 1998). Figure 45 shows population growth in Washington State and King County since 1900.

Figure 45. Population growth 1900 – 1990 (U.S. Census Bureau, 2000).



It is difficult to accurately estimate the population of the Cedar - Sammamish Basin. Census numbers are linked to administrative boundaries that do not follow basin lines. The Cedar - Sammamish watershed is located in both King and Snohomish counties, portions of Renton and Seattle are located in the watershed. However, some regional trends are applicable and worthwhile mentioning here. The population of central Puget Sound was estimated to have reached 3,215,300 as of April 1, 2000. This represents an increase of 466,400 individuals or 17.0 percent. Another way of looking at this is that growth increased on average of 1.6 percent annually since 1990. For the same time period growth in King County increased by 11.8 percent and in Snohomish County by 27.5 percent (PSRC data 2000).

Table 40. Population distribution in the Lake Washington Basin (numbers are calculated as indicated in notes and may fall out of the watershed boundary)

Jurisdiction/Planning Area	1990	2000	Average Annual Growth Rate/ Percent per Year	Relative Rate
Bear Creek***	23,600*	30,600*	29.7	High growth
East Sammamish***	31,300*	45,000*	43.8	High growth
Northshore***	93,100*	105,000*	12.8	Moderate growth
Bellevue	86,872****	106,400****	22.5	Moderate growth
Bothell	12,345****	28,140****	128.0	High growth
Issaquah	7,786****	10,260****	31.8	High growth
Kirkland	40,059****	45,090****	12.6	Moderate growth
Mercer Island	20,816****	21,570****	3.6	Low growth
Redmond	35,800****	45,256****	26.4	High growth
Renton	41,688****	50,052****	20.0	Moderate growth
Sammamish	ND	30,793****		
Shoreline	48,195****	53,140****	10.3	Low growth
Seattle	516,259**	563,374**	9.1	Low growth
Tukwila	11,874****	14,870****	25.2	High growth
Woodinville	9,407****	10,280****	9.3	Low growth
King County (as a whole)	1,507,305**	1,737,034**	15.2	Moderate growth
Washington State	4,866,692**	5,894,121**	21.1	Moderate growth

Notes:
ND = no data available.
* Population estimates from King County.
** Population numbers from US Census Bureau
*** Community Planning Areas as defined by King County.
**** Source: Washington State Office of Financial Management

Clearly there are numerous additional issues to be considered as part of the overall recovery of salmonid populations in the Cedar - Sammamish Basin. One such issue is the way in which we apply manage the growth detailed above and apply land use regulations to the buffer zones around the lakes, streams and wetlands. Land use practices and their impacts to wetlands, streams and lakes are the result of decisions made by multiple jurisdictions (city, county, state, federal and tribal) and often times by multiple agencies within those jurisdictions. Inevitably, conflicts arise and compromises are made. Local jurisdictions have the responsibility and authority to develop and implement laws that are intended to preserve and protect streams. Local critical area ordinances (CAO's) or sensitive area ordinances (SAO's) have been adopted by King County and most cities in the Cedar - Sammamish Basin. These types of ordinances are intended to protect the physical process and ecological functions within streams and other critical areas.

Table 41 compares critical area ordinances (CAO) and the Shoreline Master Plan (SMP) of several local jurisdictions in WRIA 8 as of March 2000.

Table 41. Comparison of Critical Area Ordinances and the Shoreline Master Plan of several jurisdictions in the Lake Washington Basin (as of March 2000)

Name	CAO Adopt Date	CAO Amend Date	SMP Adopt Date	SMP Amend Date	Wetland Class	Wetland Buffer	Stream Class	Stream Buffer (feet)
King County	9/10/90			7/31/97	Class 1	100 feet	Salmonid	
					Class 2	50 feet	Streams	
					Class 3	25 feet	Class 1	100
							Class 2	100
							(Salmonid bearing)	
							Class 2 (no salmonids)	50
							Class 3	25
							Bear Ck.	
							Basin	150
Bellevue	3/1/92		2/26/75	9/19/96	Type A	50 feet	Type A	50
					Type B	25 feet	Type B	25
							Type C	15
							Type D	none
Bothell	2/28/92		2/27/75	8/19/97	Category 1	100 feet	Category 1	As required
					Category 2	75 feet		by SMP &
					Category 3	50 feet		Title 13 BMC
							Category 2	100
							(Salmonid bearing)	
							Category 2	75
							(Non-salmonid bearing	
							Category 3	50
Hunts Point	9/14/92		11/15/74	7/2/75				
Issaquah	5/9/94		10/2/90		Class 1	100 feet	Class 1	100
					Class 2	50 feet	Class 2	100
					Class 3	25 feet	(Salmonid bearing)	
							Class 2	50
							(Non-salmonid bearing	
							Class 3	25
Kirkland	2/4/92		8/27/74	1/2/90	Type 1	50 feet	Class A	50
					Type 2	25 feet	Class B	50
							Class C	20
Lake Forest	2/26/92		4/19/74		Class 1	100 feet	All streams	25
					Class 2	50 feet		
					Class 3	25 feet		
Medina	7/1/92		11/22/74	12/18/90	All	25 feet	All	25
					Wetlands		Streams	
Mercer Isd.	2/14/92		9/24/74	7/18/96			All	25
							Riparian	
							Corridors	
Redmond	6/7/92	10/21/97	9/20/74	8/7/95	Type 1	100-150 ft	Class 1	100-150
					Type 2	50-100 ft	Class 2	75 - 100
					Type 3	25-50 ft	Class 3	25 - 50
					Type 4	0 feet	Class 4	0

Table 41. Comparison of Critical Area Ordinances and the Shoreline Master Plan of several jurisdictions in the Lake Washington Basin (as of March 2000)

Name	CAO Adopt Date	CAO Amend Date	SMP Adopt Date	SMP Amend Date	Wetland Class	Wetland Buffer	Stream Class	Stream Buffer (feet)
Renton	9/14/92		1/23/96	4/13/98	Category 1 Category 2 Category 3	100 feet 50 feet 25 feet	All Streams	25
Seattle	7/13/92		3/29/76	11/3/97	Wetlands > 100 sq. ft.	50 feet	Class A Riparian corridors Class B Riparian corridors	50 25
Shoreline								
Woodinville	3/22/93		7/9/97		Class 1 Class 2 Class 3	100 feet 50 feet 25 feet	Class 1 Class 2 (Salmonid) Class 2 (w/o Salmonids) Class 3	100 100 50 25
Yarrow Point	9/10/91		3/13/75		Washington four tier system	50 feet		

Most jurisdictions have similar definitions for categorizing streams. Typically, streams are labeled by “Category” or “Class”, streams are generally broken into categories to accomplish this practice. Some jurisdictions subject to the Shoreline Management Act (SMA) designate larger streams and rivers as Class 1, making smaller salmon bearing streams Class 2. Regionally significant streams, such as Bear Creek in WRIA 8, are specifically identified in some ordinances. Buffer zones in Bear Creek are larger than other stream systems in King County. Some jurisdictions use the old Washington State Water typing criteria as developed by the Washington Department of Natural Resources (WDNR) for use in lands under their jurisdiction. New regulations recently adopted by WDNR have changed the way they classify streams. Land use buffers around salmonid bearing streams range from a minimum of 25 feet (several jurisdictions) to a minimum of 150 feet (Bear Creek Basin in King County). Variances to these minimums allow for impacts even closer to the water and in some instances structures are allowed have been constructed over salmonid bearing streams. Buffer zones around streams are generally greater for those streams that have salmonids present than for streams where salmonids are not present.

SALMONID HABITAT CONDITION RATING STANDARDS FOR IDENTIFYING HABITAT LIMITING FACTORS

SALMONID HABITAT CONDITION RATING STANDARDS FOR IDENTIFYING HABITAT LIMITING FACTORS

Pursuant to the Salmon Recovery Act (passed by the Washington State Legislature as Engrossed Substitute House Bill 2496 and later revised by Second Substitute Senate Bill 5595) the Washington Conservation Commission is charged with identifying the habitat factors limiting the natural production of salmonids throughout Washington State. This information should guide lead entity groups and the Salmon Recovery Funding Board in prioritizing salmonid habitat restoration and protection efforts seeking state and funds. Identifying habitat limiting factors requires a set of standards that can be used to compare the significance of different factors and consistently evaluate habitat conditions in individual WRIAs.

In order to develop a set of standards to rate salmonid habitat conditions several recent documents (Table 42) developed by natural resource management agencies that used some type of habitat rating system were reviewed by Conservation Commission staff . The goal of this review was to identify appropriate rating standards for as many types of habitat limiting factors as possible, with an emphasis on those standards that could be applied to readily available data. Based on this review, it was determined to rate habitat conditions into three categories: *Good, Fair*, and *Poor*. For habitat factors that had wide agreement on how to rate conditions, the accepted standard was adopted by the WCC. For factors that had a range of standards, one or more of them were adopted. Where no standard could be found, a default rating standard was developed by WCC staff, with the exception that it will be modified or replaced as better data become available. Table 44 shows the salmonid habitat condition rating criteria adopted by the WCC for the purposes of this report.

Table 42. Source documents

Code	Document (Publication Year)	Organization
WSP	Wild Salmonid Policy (1997)	WDFW and WWTIT
PHS	Priority Habitat Management Recommendations: Riparian (1995)	WDFW
WSA	Watershed Analysis Manual, v4.0 (1997)	Washington Forest Practices Board
NMFS	Coastal Salmon Conservation: Working Guidance (1996)	NMFS
Skagit	Skagit Watershed Council Habitat Protection and Restoration Strategy (1998)	Skagit Watershed Council
Hood Canal	Hood Canal/Eastern Strait of Juan de Fuca Summer Chum Habitat Recovery Plan (1999)	Point No Point Treaty Council and WDFW

Many of the lakes and tributaries of WRIA 8 are among the most hydrologically altered streams in the Puget Trough ecoregion. The streams typically exist in heavily urbanized locale and are subjected to the adverse habitat impacts that accompany this setting. These streams and their subbasins generally have high levels of impervious surfaces, altered hydrologic regimes, loss of floodplain connectivity, poor riparian conditions and water

quality problems. As one moves upstream into the middle reaches of the watershed, the habitat conditions of the tributary streams show some improvement and the land use becomes a mix of residential, agricultural and forestry. Streams in the middle reach still do not meet many of the criteria necessary for properly functioning habitats important for salmonid survival. In the Cedar River, upstream of the Seattle Landsburg Dam, the tributary streams are almost exclusively in lands previously utilized for forestry and now managed for old growth forest. The large lakes in the WRIA (Lakes Union, Washington and Sammamish) have highly altered shorelines, hydrology, and numerous introduced plant and animal species that further impact natural species interactions.

Table 43. Review of salmonid habitat condition rating factors

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Fine Sediment	WSP	Fines <0.85 mm in spawning gravels	All (except where natural values exceed 11%)	--	--	--
Large Woody Debris	WSA	Fines <0.85 mm in spawning gravel	All	>17%	12-17%	<12%
	NMFS	Fines <0.85 mm in spawning gravel	All - westside	>17%	12-17%	<12%
		Fines < 0.85 mm in spawning gravel	All – Eastside	>20%	12-20%	<12%
	Skagit		All (Westside only)	Use B-IBI		
	Hood Canal	Fines < 0.85 mm in spawning gravel	All (Westside only)	>17%	12-20%	<12%
	WSP/WSA	pieces/channel width	<20 m wide	<1	1-2	2-4
		key pieces/channel width*	<10 m wide (Westside only)	<0.15	0.15-0.30	>0.30
		key pieces/channel width*	10-20 m wide (Westside only)	<0.20	0.20-0.50	>0.50
	Minimum size to qualify as a key piece	BFW (m) 0-5 6-10 11-15 16-20	Diameter (m) 0.4 0.55 0.65 0.70	Width (m) 8 10 18 24		
	NMFS	pieces/mile >24" dia. and >50' length	All – Westside	Does not meet standard and does not have sufficient recruitment potential from riparian stand	Meets standard, but does not have sufficient recruitment potential from riparian stand	>80 and has sufficient recruitment potential from riparian stand

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Large Woody Debris	NMFS	pieces/mile > 12" dia. and > 35' length	All – Eastside	Does not meet standard and does not have sufficient recruitment potential from riparian stand	Meets standard, but does not have sufficient recruitment potential from riparian stand	>20 and has sufficient recruitment potential from riparian stand
Percent Pool	Skagit	pieces/m channel length	≤ 4% gradient, <15 m wide (Westside only)	-	-	> 0.4
	Hood Canal	pieces/m channel length	≤ 4% gradient, <15 m wide (Westside only)	< 0.2	0.2-0.4	> 0.4
	WSP/WSA	% pool, by surface area	<2% gradient, < 15 m wide	<40%	40-55%	>55%
		% pool, by surface area	2-5% gradient, < 15 m wide	< 30%	30-40%	> 40%
		% pool, by surface area	>5% gradient, < 15 m wide	< 20%	20-30%	> 30%
	NMFS	na	--	--	--	--
	Skagit	na	--	--	--	--
Pool Frequency	Hood Canal	% pool, by surface area	< 15 m	< 40%	40-55%	> 55%
		% pool, by surface area	> 15 m	< 35%	35-40%	> 50%
	WSP/WSA	channel widths per pool	< 15 m wide	> 4	2-4	< 2
	NMFS	channel width 5' 10' 15' 20' 25' 50' 75' 100'	pools/ mile 184 96 70 56 47 26 23 18	Does not meet pool frequency standards	Meets pool frequency standards (left), but LWD recruitment is inadequate to maintain pools over time	Meets pool frequency standards (left) and meets LWD standards
	Skagit	na	--	--	--	--
	Hood Canal	Channel widths per pool	< 15 m	< 2	2-4	> 4

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Pool Quality	WSP/WSA	Pools/km > 1 m deep with good cover and cool water	All	Few deep pools	--	Sufficient deep pools
	NMFS	Pools> 1 m deep with good cover and cool water	All	No deep pools and inadequate cover or temperature, major reduction of pool volume by fine sediments	Few deep pools or inadequate cover or temperatur e, moderate reduction of pool volume by fine sediments	Sufficient deep pools
	Skagit	na	--	--	--	--
	Hood Canal	na	--	--	--	--
Temperature	WSP (same as State water quality standards	degrees Celsius degrees Celsius degrees Celsius	Class AA Class A Class B	-- -- --	-- -- --	≤ 16º C ≤ 18º C ≤ 21º C
	WSA	% shade	Class A and AA only	Need meet water	sufficient quality	shade to standards
	NMFS	degrees Celsius	All	> 15.6º C (spawning) > 17.8º C (migration and rearing)	>14-15.6ºC (spawning) >14-17.8ºC (migration and rearing)	10 – 14º C
	Skagit	na	--	--	--	--
	Hood Canal	degrees Celsius	--	> 12º C	--	< 12º C
Fish Passage	WSP	--	All	--	--	Free and unobstructed passage for all wild salmonids, & 95% survival for passage thru dams and diversions
	WSA		All	Access blocked by low water, culvert, temperature, etc.	--	No blockages

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Fish Passage	NMFS		All	Any artificial barriers present do not allow upstream and/or downstream passage at all flows	Any artificial barriers present do not allow upstream and/or downstrea m passage at all flows	Any artificial barriers present do not allow upstream and/or downstream passage at all flows
	Skagit	--	--	--	--	--
	Hood Canal		ALL			Unobstructed passage
Flow	WSP	% impervious surface hydrologic maturity	All All	> 5 – 10% --	-- --	-- >60% of standing timber at age 25 or more
	WSA	hydrologic maturity	All	Hydrologic focused on	modeling rain-on-	exercise snow zone
	NMFS	hydrologic change	All	Pronounced changes in peak flow, baseflow and/or flow timing relative to an undisturbed reference watershed	Some evidence of altered peak flow, baseflow and/or flow timing relative to an undisturbed reference watershed	Watershed hydrograph indicates peak flow, base flow and flow timing are comparable to an undisturbed reference watershed
		drainage network density	All	Significant increases in drainage network density due to roads (e.g. 20-25%)	Moderate increases in drainage network density due to roads (e.g. 5%)	Zero or minimum increases in drainage network density due to roads
	Hood Canal	% impervious area	--	> 5%	--	--
		Hydrologic maturity	--	<60% of a watershed in native forest vegetation	--	--

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Flow	Skagit	% impervious area	Lowland basins	> 1%	3-10%	≤ 3%
		Hydrologic change	Forested mountain basins	2-yr flood magnitude exceeds 5-yr flood magnitude under natural conditions	--	--
		Range of Variability Approach	All	CHANGE GREATER THAN ONE STANDARD DEVIATION FROM ANNUAL 7-DAY MINIMUM FLOW OR OF THE ANNUAL PEAK FLOW	--	--
Sediment supply/mass wasting	WSP	--	--	--	--	--
	WSA	--	--	--	--	No increase in mass wasting events over natural levels
	NMFS	--	--	--	--	--
	Skagit	$m^3/km^2/yr$	All	> 100 or exceeds natural rate		< 100 or does not exceed natural rate
	Hood Canal	--	--	--	--	--
Roads	WSP	--	--	--	--	--
	WSA	--	--	--	--	--
	NMFS	mi/mi^2	All	>3 with many valley bottom roads	2-3 with some valley bottom roads	<2 with no valley bottom roads
	Skagit	--	--	--	--	--
	Hood Canal	--	--	--	--	--

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Riparian	WSP	buffer width	Type 1-3 and untyped salmonid streams >5' wide			Mature native vegetation. Buffer should be 100-150' or site potential tree height (whichever is greater) measured horizontally out from channel migration zone on each side.
		Buffer width	Type 4 and untyped perennial streams <5' wide			100' buffer of mature native vegetation on each side
		Buffer width	Type 5 and all other untyped streams			50' buffer of mature native vegetation on each side
	PHS	buffer width	Type 1 and 2 or shorelines of statewide significance			250 feet
		buffer width	Type 3 or other streams 5-20' wide			200 feet
		buffer width	Type 3 or other streams <5' wide			150 feet
			Other intermittent streams with low mass wasting potential			150 feet
		Buffer width	Other intermittent streams with high mass wasting potential			225 feet

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Riparian	WSA	Species, average tree size, and density within 100' of stream channel	All channels <20% gradient	HSS,HSD,MSS,MSD,CSS,CSD,HMS,HLS	HMD,MMS, CMS,CLS, HLD,MLS	CMD,MMD,MLD,CLD
			Column	Code	Class	Species
			1	C	Conifer	≥70% conifer
				H	Hardwood	≥70% hardwood
				M	Mixed	all other cases
						Average tree size
			2	S	Small	<12 inches dbh
				M	Medium	12-20 inches dbh
				L	Large	≥20 inches dbh
						Ground exposed
			3	S	Sparse	≥33% (W. WA) >50% (E. WA)
				D	Dense	≤33% (W WA) ≤50% (E WA)
	NMFS	--	--	--	--	--
	Skagit	Buffer width	All	< 20 m	20 – 40 m	≥ 40 m
	Hood Canal	Vegetation composition	(summer chum)	Deciduous dominated canopy (>70%)	Mixed	Conifer dominated (<70%)
		Average stand diameter	(summer chum)	< 12 " dbh	12-20" dbh	>20" dbh
		Stand density	(summer chum)	>80% ground exposure	33-80% ground exposure	<33% ground exposure
		Extent	(summer chum)	<66' wide forested buffer	66-132' wide forested buffer	>132' wide forested buffer
		Buffer width	Annual streams	--	--	250' buffer
Streambank Stability	WSP	% of banks not actively eroding	All	--	--	>90% stable
	WSA	--	--	--	--	--
	NMFS	% of banks not actively eroding	All	--<80% stable	80-90% stable	>90% stable
	Hood Canal	--	--	--	--	--
	Skagit	--	--	--	--	--

Table 43. Review of salmonid habitat condition ratings (continued).

Habitat Factor	Source	Parameter/ Unit	Channel Type	Poor	Fair	Good
Floodplain	WSP	--	--	--	--	--
	WSA	--	--	--	--	--
	NMFS	--	All	Severe reduction in hydrologic connectivity between off-channel, wetland, floodplain and riparian areas; wetlands extent drastically reduced and riparian vegetation/ succession altered significantly	Reduced linkage of wetland, floodplains and riparian areas to main channel; overbank flows are reduced relative to historic frequency, as evidenced by degradation of wetland function; riparian vegetation/succession	Off-channel areas are frequently hydrologically linked to main channel; overbank flows occur and wetland functions, riparian vegetation and succession
	Skagit	(in development)	--	--	--	--
	Hood Canal	--	--	--	--	--

Table 44. Salmonid habitat condition ratings

Habitat Factor	Parameter/Unit	Channel Type	Poor	Fair	Good	Source
Access and passage	% known/potential habitat blocked by artificial barriers	All	>20%	12-20%	<10%	WCC
Floodplains						
Floodplain connectivity	Stream and off-channel habitat length with lost floodplain connectivity due to incision, roads, dikes, flood protection, or other.	<1% gradient	>50%	10-50%	<10%	WCC
Loss of floodplain habitat	Loss of wetted area	<1% gradient	>66%	33-66%	<33%	WCC
Channel Conditions						
Fine sediment	Fines <0.85 mm in spawning gravel	All – westside	> 17%	11-17%	≤ 11%	WSP/ WSA/ NMFS/ Hood Canal
	Fines < 0.85 mm in spawning gravel	All – eastside	>20%	11-20%	≤ 11%	NMFS
Large Woody Debris	Pieces/m channel length	≤4% gradient, <15 m wide (westside only)	<0.2	0.2-.04	>0.4	Hood Canal and Skagit
	Or use Watershed Analysis	**piece and**	**key piece**	**standards**	**listed**	**below**
	Pieces/channel width	< 20 m wide	<1	1-2	2-4	WSP and WSA
	Key pieces/channel width*	<10 m wide (westside only)	<0.15	0.15-0.30	>0.30	WSP and WSA
	Key pieces/channel width*	10-20 m wide (eastside only)	<0.20	0.20-0.50	>0.50	WSP and WSA
	* minimum size to qualify as a key piece:	BFW (m) 0-5 6-10 11-15 16-20	Diameter (m) 0.4 0.55 0.65 0.7	Length (m) 8 10 18 24		

Table 44. Salmonid habitat conditions ratings (continued).

Habitat Factor	Parameter/Unit	Channel Type	Poor	Fair	Good	Source
Channel Conditions						
Pool quality	Pools >1 m deep with good cover and cool water	All	No deep pools and inadequate cover or temp., major reduction of pool volume by sediment	Few deep pools or inadequate cover or temp., moderate reduction of pool volume by sediment	Sufficient deep pool	NMFS, WSP, WSA
Streambank stability	% of banks not actively eroding	All	<80% stable	80-90% stable	>90% stable	NMFS and WSP
Sediment Input						
Sediment supply	$m^3/km^2/yr$	All	> 100 or exceeds natural rate*	--	< 100 or does not exceed natural rate*	Skagit
	* NOTE: This is a highly variable in natural conditions					
Mass wasting		All	Significant increase over natural levels for mass wasting events that deliver to stream	--	No increase over natural levels for mass wasting events that deliver to stream	
Road density	mi/mi^2	All	>3 with many valley bottom roads	2-3 with some valley bottom roads	<2 with no valley bottom roads	NMFS
	Or use results from Watershed Analysis where available					

Table 44. Salmonid habitat conditions ratings (continued).

Habitat Factor	Parameter/ Unit	Channel Type	Poor	Fair	Good	Source
Riparian Zones						
Riparian Condition	riparian buffer width (measured out horizontally from the channel migration zone on each side of the stream). Riparian composition	Type 1-3 and untyped salmonid streams >5' wide	<75' or <50% of site potential tree height (Whichever is greater) OR Dominated by hardwoods, shrubs, or non-native species (<30% conifer) unless these species were historically dominant.	75'-150' or 50-100% of site potential tree height (whichever is greater) AND Dominated by conifers or a mix of conifers and hardwoods (≥30% conifer) of any age unless hardwoods were historically dominant	>150' or site potential tree height (whichever is greater) AND Dominated by mature conifers (≥70% conifer) unless hardwoods were historically dominant.	WCC and WSP
	Buffer width Riparian composition	Type 4 and untyped perennial streams <5'wide	<50' with the same composition as above	50-100' with the same composition as above	> 100' with the same composition as above	WCC and WSP
	Buffer width Riparian composition	Type 5 and all other untyped streams	<25' with the same composition as above	25-50' with the same composition as above	>50' with the same composition as above	WCC and WSP
Water Quality						
Temperature	degrees Celsius	All	>15.6° C (spawning) >17.8° C (migration and rearing)	14-15.6° C (spawning) 14-17.8° C (migration and rearing)	10-14° C	NMFS
Dissolved oxygen	mg/L	All	<6	6-8	>8	ManTech
Hydrology						
Flow	Hydrologic maturity	All	<60% of watershed with forest stands aged 25 years or more	--	>60% of watershed with forest stands aged 25 years or more	WSP and Hood Canal
	Or use	**watershed**	**analysis where**	**available**		

Table 44. Salmonid habitat conditions ratings (continued).

Habitat Factor	Parameter/ Unit	Channel Type	Poor	Fair	Good	Source
Biological Processes						
Nutrients (carcasses)	Number of stocks meeting escapement goals	All anadromous	Most stocks do not reach escapement goals	Approximately half the stocks reach escapement goals	Most stocks reach escapement goals	WCC

Table 45. Identified salmonid habitat limiting factors in WRIA 8

Subbasin/ Stream Name	WRIA Stream Index Number	Fish Passage	Floodplain Connectivity	Bank Stability	LWD	Pools	Side Channel Habitat	Substrate Fines	Riparian	Water Quality	Hydrology	Estuarine
Nearshore Streams												
Big Gulch Creek	0001	G	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Upper Chenault Ck.	0002	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Lower Chenault Ck	0003	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Picnic Point Creek	0004	P	P	DG	DG	DG	DG	DG	DG	DG	P	ND
Norma Creek	0005	P	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Lunds Gulch Creek	0006	G	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Perrinville Creek	0007	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Unnamed tributary	0008	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Shell Creek	0009	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Shelleberger Creek	0010	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Deer Creek	0012	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Unnamed tributary	0013	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Unnamed tributary	0014	DG	DG	DG	DG	DG	DG	DG	DG	DG	P	ND
Boeing Creek	0017	F	DG	DG	P	DG	DG	P	P - G	DG	P	ND
Pipers Creek	0020	F	DG	DG	P	DG	DG	P	P	DG	P	ND
Salmon Bay	na	G	P	G	P	na	na	na	P	G	na	P
Hiram Chittendam Locks	na	P-G	na	na	na	na	na	na	P	P	na	na
Lake Union and Ship Canal	0028	G	P	P	P	na	P	na	P	P	na	na
Lake Washington Subbasin	na	G	na	P	P	na	na	na	P	G	na	na
Thornton Creek	0030	F	DG	DG	DG	P	DG	DG	P	P	P	
McAleer Creek	0049	F	DG	DG	DG	DG	DG	DG	P	P	P	na
Lyon Creek	0052	P	P	DG	P	DG	P	DG	P	P	P	na
Unnamed tributary	0056	DG	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Juanita Creek	0230	F	DG	G	P	P - G	DG	P	P	UC	DG	na
North Lake Washington Tributaries												
Bear Creek Subbasin	0105	F	P	DG	P	P	P	DG	P	P	P	na
Cottage Lake Creek	0122	NAD	DG	DG	P	DG	DG	DG	P	G	P	
Evans Creek	0106	NAD	DG	DG	P	DG	DG	DG	P	NAD	P	
Little Bear Creek Subbasin	0080	P	DG	DG	P	F	DG	P	P	NAD	P	na
North Creek Subbasin	0070	F	DG	DG	P	G	DG	DG	P	P	P	na
Swamp Creek Subbasin	0059	F	DG	P	P	P	P	DG	P	P	P	na
Lake Washington Tributaries												
Kelsey Creek	0259	G	P	DG	P	P	DG	P	P	P	P	na
Mercer Slough	0259	G	P	DG	DG	DG	DG	DG	P	P	P	na
Sturtevant Creek	0260	P	DG	DG	DG	DG	DG	DG	P	DG	P	na
Valley Creek NF	0266	G	DG	DG	P	P	DG	DG	P	DG	P	na
West Tributary	0264	G	DG	DG	DG	DG	DG	DG	P	DG	P	na
Goff Creek	0265	P	DG	DG	DG	DG	DG	DG	P	DG	P	na
Richards Creek	0261	G	DG	DG	P	P	DG	DG	P	DG	P	na
East Creek	0263	F	DG	DG	P	P	DG	DG	P	DG	P	na
Sunset Creek	0262	P	DG	DG	P	P	DG	DG	P	DG	P	na
Coal Creek	0268	U	P	DG	DG	DG	P	DG	P	P	F	na
May Creek	0282	P	P	DG	P	P	DG	DG	P	P	P	na
Meydenbauer Creek	0258	P	DG	DG	DG	DG	DG	DG	P	DG	P	na
Yarrow Creek	0252	P	DG	DG	DG	DG	DG	DG	P	DG	P	na

Table 45: Identified salmonid habitat limiting factors in WRIA 8 (continued)

Subbasin/ Stream Name	WRIA Stream Index Number	Fish Passage	Floodplain Connectivity	Bank Stability	LWD	Pools	Side Channel Habitat	Substrate Fines	Riparian	Water Quality	Water Quantity	Estuarine
Cedar River	0299	P	P	na	P	DG	P	DG	P - G	G	G	na
Upper Cedar River	0299	P*	G	G	G	G	G	G	G	G	G	na
Lower Cedar River	0299	P	P	P	P	F	P	DG	P	G	C	na
Cedar River tributaries												
Dorree Don	0336	P	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Walsh Lake Diversion	0341	P	P	P	F	P	P	DG	P	G	G	na
Lower Taylor Ck.	0351	G	G	DG	DG	DG	DG	DG	P	DG	DG	na
Lower Rock Creek	0338	P	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Peterson Creek	0328	G	G	DG	DG	DG	DG	DG	NAD	DG	DG	na
Maplewood Creek	0302	F	P	P	P	P	P	P	P	DG	DG	na
Molasses Creek	0304	P	P	DG	DG	DG	DG	DG	P	DG	DG	na
Madsen Creek	0305	G	P	DG	DG	DG	DG	DG	P	DG	DG	na
Ginger Creek	0300	F	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Unnamed Tributaries	0314	G	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Upper Cedar River		P	G	G	DG	DG	G	G	G	G	G	na
South Fork Cedar River Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
North Fork Cedar River Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Taylor Creek Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Chester Morse Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Rex Creek Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Upper Cedar River Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Lower Cedar River Subbasin		P	G	G	DG	DG	G	G	G	G	G	na
Lake Sammamish	na	UC	na	P	P	na	na	na	P	P	na	na
Lake Sammamish Tributaries												
Laughing Jacobs Creek	0166	G	DG	DG	DG	DG	DG	DG	P	DG	P	na
Many Springs Creek	0164A	F	DG	P	DG	DG	DG	DG	DG	DG	DG	na
Ebright Creek	0149	F	DG	P	DG	DG	DG	DG	DG	G	P	na
Pine Lake Creek	0152	G	DG	P	DG	DG	DG	DG	P	DG	DG	na
Zaccuse Creek	0145A	F	DG	P	DG	DG	DG	DG	DG	DG	DG	na
George Davis Ck.	0144	P	DG	DG	DG	DG	DG	DG	P	DG	P	na
Lower Issaquah Ck.	0178	P	P	F	NAD	P	DG	P	P	G	NAD	na
Upper Issaquah Ck.	0178	P	P	F	NAD	G	DG	DG	F	G	NAD	na
Holder Creek	0178	G	P	F	NAD	DG	DG	DG	F	G	NAD	na
Fifteen Mile Ck.	0207	G	P	F	NAD	DG	DG	DG	F	G	NAD	na
Carey Creek	0218	G	P	F	NAD	G	DG	DG	F	G	NAD	na
McDonalds Creek	0212	G	P	F	NAD	DG	DG	DG	F	G	NAD	na
E. F. Issaquah Ck.	0183	G	P	F	NAD	DG	DG	DG	F	G	NAD	na
N.F.Issaquah Ck.	0181	G	P	F	NAD	DG	DG	P	F	G	NAD	na
Tibbetts Creek	0169	G	P	F	NAD	DG	DG	P	F	G	NAD	na
Lewis Creek	0162	P	P	DG	DG	DG	P	DG	P	P	DG	na
Unnamed tributary	0143	P	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
NAD = Need Additional Data	**na = not applicable**		**DG = Data Gap**									

* Passage at the Upper Cedar River was rated as poor due Landsburg Dam and is not reflective of bull trout passage in the upper watershed.

Table 45. Identified habitat condition limiting factors in WRIA 8 (continued)

Subbasin/ Stream Name	WRIA Stream Index Number	Fish Passage	Floodplain Connectivity	Bank Stability	LWD	Pools	Side Channel Habitat	Substrate Fines	Riparian	Water Quality	Water Quantity	Estuarine
Lake Sammamish Tributaries (continued)												
Idylwood Creek	0143	**P**	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Wilkins Creek	0151	**P**	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Vasa Creek	0156	G	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Phanton Creek	0154	**P**	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Unnamed tributary	0160	**P**	DG	DG	DG	DG	DG	DG	DG	DG	DG	na
Unnamed tributary	0161	**P**	DG	DG	DG	DG	DG	DG	DG	DG	DG	na

na = not applicable
DG = Data Gap
NED = Not Enough Data

ACTION RECOMMENDATIONS

ACTION RECOMMENDATIONS

OVERVIEW

The following recommendations focus on salmonids while recognizing that this valuable resource coexists with our human population within the various WRIA 8 subbasins and the Puget Sound estuary. Healthy watersheds and estuaries are vital to naturally producing salmonids and a part of the quality of life that we have come to expect. However, human populations will continue to exist and modify habitat within WRIA 8. The recognition of this partnership is vital to achieve the type of support necessary for salmonid recovery. The science based recommendations below were developed by the WRIA 8 technical committee and directed towards providing healthy salmonid habitats and the ecological processes necessary for maintaining those habitats, while acknowledging human factors too.

These non-prioritized salmonid habitat protection, data collection, and restoration actions are recommended by limiting factor and apply to the mainstem rivers as well as all tributary and nearshore areas within the geographic scope of this report. Much of the synthesis work necessary to provide detailed recommendations has not been completed at the time of printing this report, so the recommendations presented here are general and initial. More detailed prioritized recommendations will be developed during the next phase of the WRIA 8 salmonid recovery planning process, which will include more comprehensive recommendations..

For the following recommendations, some or portions of them may be addressed as part of other programs (e.g.: Seattle HCP) under development in the basin. However, because these programs are still under development, the technical committee felt it was important to confirm the importance of some of these actions here. Other recommendations focus on preliminary data collection that is needed to assess some data gaps noted in this report before additional action is taken. There also are action recommendations that the technical committee sees as appropriate due to their review of existing scientific information.

FISH PASSAGE

- Build on the fish distribution work undertaken as a part of this report by conducting a comprehensive fish barrier and habitat assessment project to identify access barriers and the quantity and quality of habitat upstream throughout WRIA 8;

- Provide efficient fish passage and allow for natural migration rates, patterns, and timing through barriers that limit juveniles and adult salmon from reaching productive historic or rehabilitated habitats in freshwater and nearshore environments;

- Improve fish passage and access throughout the basin including at the Hiram M. Chittenden Locks and at the Landsburg Dam diversion facility.

- Reconnect side channel habitats that have been isolated from the main channel.

- Properly screen all water diversions to avoid fish entry.

- Assess the impacts of ground and surface water withdrawals on fish passage and salmonid habitats.

- Avoid construction or addition of nearshore fill, armoring, dikes, and overwater structures that would result in a disruption of normal migration rates and patterns, or access to shallow feeding and refuge areas.

HYDROLOGY

- Investigate the impacts of surface and groundwater withdrawals on tributary stream subbasins and mainstem hydrology and evaluate the effects on salmonids;

- Manage mainstem river flows to more closely emulate the natural flow regime that promotes habitat forming processes (e.g.: creation and maintenance of side channels, pools, river meanders, etc.) and long term salmonid survival (e.g.: incubation/fry emergence, flood refugia, migration, etc.);

- Conduct a basin wide investigation of (legal and illegal) surface and ground water withdrawal;

- Perform a regionally consistent baseline assessment of existing conditions and current land use impacts to the natural stream hydrology. Studies should be carried out on a subwatershed or smaller scale to help prioritize recovery efforts. A similar assessment is needed at an appropriate scale for the nearshore;

- Develop and implement stormwater management programs designed to restore natural hydrologic processes and protect water quality;

- Protect the natural headwater areas of rivers and streams;

- Minimize new impervious surfaces;

- Implement forest retention and restoration mechanisms;

- Protect and restore natural stream flow conditions sufficient for salmonid spawning, incubation, rearing, and migration;

- Determine areas where floodplain connectivity can be restored through the removal of levees and dikes or the modification of these structures;

- Avoid the establishment of hydrologic regimes that are detrimental to the survival of fish; and

- Identify and protect important areas of groundwater recharge that contributes to the maintenance of baseflow conditions.

SEDIMENT TRANSPORT

- Identify the source of excessive fine sediment inputs into streams and reduce or eliminate these inputs;

- As deemed appropriate, repair all culverts to allow the passage of juvenile and adult salmonids, organic matter, and sediment;

- Eliminate or minimize increased sedimentation that can result from new construction and development;

- Continue Lake Sammamish's phosphorus and sediment control program and expand to rest of watershed;

- Monitor streambed scour and deposition on a WRIA wide basis and take remedial actions where necessary; and

- Determine current and historic sediment sources, distribution patterns, and budgets in the nearshore and Lake Washington Basin. Compare current and historic conditions to identify the extent to which sediment transport processes require restoration.

HYDROMODIFICATION

- Reestablish and protect side channel habitat along the mainstem Cedar River and other streams as appropriate;

- Encourage the natural channel migration of streams and rivers;

- Maintain the existing natural shorelines of the river, streams, lakes, and marine nearshore;

- Remove, or set back, flood and erosion control facilities whenever feasible, to allow for the reestablishment of natural habitat producing stream and estuarine shoreline processes; and

- Where levees and revetments cannot be practically removed or set back due to infrastructure considerations, maintain and repair them using design approaches that maximize the use of native vegetation and LWD.

RIPARIAN

- Conduct a regionally consistent detailed assessment of current riparian conditions throughout the watershed to determine functional value and for evaluating potential protection, enhancement, or restoration opportunities and constraints;

- Establish, enhance, and protect appropriately-sized riparian buffers around rivers, streams, wetlands, lakes, and marine nearshore areas to protect salmonid habitat and as to not compromise salmonid recovery efforts ; base these buffers on scientific data and principles of landscape ecology, ecosystem and conservation biology, as well as long-term feasibility;

- Protect riparian habitat and shorelines (streambanks, lakeshores, and nearshore) from degradation resulting from human activities;

- Continue and enhance educational activities based on the WRIA 8 technical reports to provide technical training, materials, or other assistance for participants that encourages individual actions and teaches skills necessary to protect and restore salmonid habitat;

- Avoid the construction of new roads within the flood plain and riparian areas;

- Protect and preserve areas containing mid- to late-seral stage riparian habitat;

- Avoid new bank hardening projects in locations where natural bank conditions currently exist; where and when opportunities exist, remove or retrofit existing hardened bank stabilization projects with softer, more environmentally compatible bank treatments to increase riparian functional values;

- Revegetate existing degraded riparian habitats with an emphasis on native plant species that will contribute to bank stabilization and become a future source of LWD recruitment to riverine, lacustrine and estuarine ecosystems;

- Identify opportunities to protect riparian areas surrounding wetlands; when feasible, enhance or restore riparian areas surrounding wetlands where functions have been lost or compromised;

- Identify the appropriate conditions under which levee construction and vegetation maintenance programs, regulations, and guidelines can allow the propagation of native riparian vegetation upon these structures to provide shade and restore instream habitat processes;

- Protect riparian areas surrounding wetlands. Enhance or restore riparian areas surrounding wetlands where functions have been lost or compromised if feasible; and

- Re-examine levee construction and vegetation maintenance programs, regulations and guidelines to allow propagation of native riparian vegetation buffers.

WATER QUALITY

- Provide for water temperature regimes that support all phases of salmonid life history;

- Protect significant source areas (especially connected and isolated wetlands) of groundwater infiltration that contribute to stream water temperature control, especially during seasonal low-flow conditions;

- Protect or restore significant groundwater to surface water interfaces;

- Revegetate mainstem, tributary, and nearshore riparian areas with native coniferous and deciduous plant communities to assist in reduction of water temperature through increased shading, to improve soil stability, and to increase terrestrial insect production and input as determined necessary;

- Reduce or eliminate the source of inputs of detrimental metals, organic, and inorganic contaminants into all water bodies in the watershed;

- Reduce the discharge of pesticides and organic compounds into all surface water within the watershed; and

- Reduce excess nutrient loading in areas (e.g., Lake Sammamish) that are sensitive to eutrophication or excessive primary production.

NON-NATIVE SPECIES

- Prohibit new introductions of non-native animal and terrestrial plant species that directly impact salmonids through predation, competition, and potential genetic interactions.

- Remove or control, non-native aquatic plants that adversely impact salmonid survival.

- Determine non-native fish species interactions with salmonids.

- Investigate the impacts of non-native aquatic vegetation and non-native vegetation management activities on salmonid growth and survival.

GLOSSARY

4(d) Rule - (ESA Section): The protective rule promulgated by the lead federal agency at the time it makes a final decision to list a species as threatened. This rule is developed only for a single species at a time. The content of a 4(d) rule may be a restatement of Section 9(a) prohibitions on **take** of a species, but also may specify activities which have been determined to be adequately regulated and therefore can be given legal coverage for the **incidental take** of the listed species.

Abandoned side-channels: typically formed when a channel avulsion causes the river to move from its former route.

Adaptive management: Monitoring or assessing the progress toward meeting objectives and incorporating what is learned into future management plans.

Adfluvial: Life history strategy in which adult fish spawn and juveniles subsequently rear in streams but migrate to lakes for feeding as subadults and adults. Compare fluvial.

Aggradation: The geologic process of filling and raising the level of the streambed or floodplain by deposition of material eroded and transported from other areas.

Anadromous fish: Species that are hatched in freshwater mature in saltwater, and return to freshwater to spawn.

Aquifer: Water-bearing rock formation or other subsurface layer.

Backbar channels: overflow channels located on the apex of point bars, frequently wetted during moderately high flows, and generally do not support perennial vegetation. Multiple backbar channels may form across the top of a point bar as a result of lateral accretion of sediment during high flow events.

Baseflow: That component of streamflow derived from groundwater inflow or discharge. Can be presented in a variety of measurement units including: cubic feet per second (cfs) and inches (in).

Basin: The area of land that drains water, sediment and dissolved materials to a common point along a stream channel.

Basin flow: Portion of stream discharge derived from such natural storage sources as groundwater, large lakes, and swamps but does not include direct runoff or flow from stream regulation, water diversion, or other human activities.

Bioengineering: Combining structural, biological, and ecological concepts to construct living structures for erosion, sediment, or flood control.

Biological Assessment: Information prepared by or under the direction of the lead federal agency concerning listed and proposed species and designated and proposed critical habitat that may be present in the action [i.e., project] area and the evaluation of potential effects of the action on such

species and habitat [50 CFR 404.02]; this assessment would be evaluated by the federal agency and the results potentially incorporated into a Biological Opinion.

Biological Diversity (biodiversity): Variety and variability among living organisms and the ecological complexes in which they occur; encompasses different ecosystems, species, and genes.

Biotic Integrity: Capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region; a system's ability to generate and maintain adaptive biotic elements through natural evolutionary processes.

Biological Opinion: Part of the Section 7 consultation process, a written statement provided to the affected federal agency that details how the reviewed action affects the species or its critical habitat. If jeopardy or adverse modification of critical habitat is found to be a result of the activity the opinion will contain suggestions for reasonable and prudent alternatives for that action which would minimize its impacts and allow the activity to proceed [Endangered Species Habitat Conservation Planning Handbook].

Biological oxygen demand: Amount of dissolved oxygen required by decomposition of organic matter.

Braided stream: Stream that forms an interlacing network of branching and recombining channels separated by branch islands or channel bars.

Buffer: An area of intact vegetation maintained between human activities and a particular natural feature, such as a stream. The buffer reduces potential negative impacts by providing an area around the feature that is unaffected by this activity.

Candidate Species: Under US Fish and Wildlife Service regulations, "those species for which the Service has on file sufficient information on biological vulnerability and threat(s) to support proposals to list them as endangered or threatened species [but] [p]roposal rules have not yet been issued because this action is precluded...". For those species under the jurisdiction of National Marine Fisheries Service (NMFS), this term refers to a species for which concerns remain regarding their status, but for which more information is needed before they can be proposed for listing. Species protections, e.g., prohibitions on take, provided by the ESA do not apply to candidate species [Endangered Species Habitat Conservation Planning Handbook].

Carrying capacity: Maximum average number or biomass of organisms that can be sustained in a habitat over the long term. Usually refers to a particular species, but can be applied to more than one.

Channelization: Straightening the meanders of a river; often accompanied by placing riprap or concrete along banks to stabilize the system.

Channelized stream: A stream that has been straightened, runs through pipes or revetments, or is otherwise artificially altered from its natural, meandering course.

Channel Stability: Tendency of a stream channel to remain within its existing location and alignment.

Check dams: Series of small dams placed in gullies or small streams in an effort to control erosion. Commonly built during the 1900s.

Confluence: Joining.

Connectivity: Unbroken linkages in a landscape, typified by streams and riparian areas.

Critical Stock: A stock of fish experiencing production levels that are so low that permanent damage to the stock is likely or has already occurred.

Depressed Stock: A stock of fish whose production is below expected levels based on available habitat and natural variations in survival levels, but above the level where permanent damage to the stock is likely.

Debris torrent: Rapid movements of material, including sediment and woody debris, within a stream channel. Debris torrents frequently begin as debris slides on adjacent hillslopes.

Degradation: The lowering of the streambed or widening of the stream channel by erosion. The breakdown and removal of soil, rock and organic debris.

Deposition: The settlement of material out of the water column and onto the streambed.

Distinct Population Segment (DPS): A portion of the overall population of a species which is both a discrete and significant part of that population. "Discrete" means that the group in question is separated from others due to physical, physiological, ecological, or behavioral factors, or if it is separated by a jurisdictional boundary that denotes significant differences in protective mechanisms for the species. "Significant" means that, at least, 1) the discrete group in question persists in an ecological setting unusual or unique for the species; 2) loss of the discrete group would create a significant gap in the range of the species; 3) the discrete group represents the only natural occurrence of a species that may be more abundant elsewhere as an introduced population outside its historic range; or 4) the genetics of the discrete group differ markedly from that of other populations of the species. This term is used by United States Fish and Wildlife Service (USFWS) in its status determinations for inland salmonid populations [61 FR 4721].

Distributaries: Divergent channels of a stream occurring in a delta or estuary.

Diversity: Variation that occurs in plant and animal taxa (i.e., species composition), habitats, or ecosystems. See *species richness.*

Drainage Area: the area, measured in a horizontal plane, which contributes surface runoff to a stream gage.

Ecological restoration: Involves replacing lost or damaged biological elements (populations, species) and reestablishing ecological processes (dispersal, succession) at historical rates.

Ecosystem: Biological community together with the chemical and physical environment with which it interacts.

Ecosystem management: Management that integrates ecological relationships with sociopolitical values toward the general goal of protecting or returning ecosystem integrity over the long term.
Endangered Species Act: A 1973 Act of Congress that mandated that endangered and threatened species of fish, wildlife and plants be protected and restored.

Endangered Species: Means any species, [including subspecies or qualifying distinct population segment] which is in endanger of extinction throughout all or a significant portion of its range other than a species of the Class Insecta as determined by the Secretary to constitute a pest whose protection under would provide an overwhelming and overriding risk to man.

Escapement - The number of fish that have survived all causes of mortality and will make up the spawning population.

Estuarine: A partly enclosed coastal body of water that has free connection to open sea, and within which seawater is measurably diluted by fresh river water.

Eutrophic: Water body rich in dissolved nutrients, photosynthetically productive, and often deficient in oxygen during warm periods. Compare *oligotrophic.*

Evolutionary Significant Unit (ESU): A definition of a species used by National Marine Fisheries Service (NMFS) in administering the Endangered Species Act. An ESU is a population (or group of populations) that is reproductively isolated from other conspecific population units, and (2) represents an important component in the evolutionary legacy of the species.

Extinct Species - A species no longer present in its original range or as a distinct species elsewhere.

Extirpation: The elimination of a species from a particular local area.

Factor of Decline: Natural and anthropogenic induced factors that contribute to the decline of salmonids. These not only include climate and ocean conditions and natural predation but also the factors that are more commonly thought to be within human control such as habitat modification, harvest, hatchery practices and introduction of non-native species.

Flood: An abrupt increase in water discharge.

Floodplain: Lowland areas that are periodically inundated by the lateral overflow of streams or rivers.

Flow regime: Characteristics of stream discharge over time. Natural flow regime is the regime that occurred historically.

Fluvial: Pertaining to streams or rivers; also, organisms that migrate between main rivers and tributaries. Compare *adfluvial*.

Freshet: a sudden increase in stream discharge that results from the rapid melting of accumulated snow.

Gabion: Wire basket filled with stones, used to stabilize streambanks, control erosion, and divert stream flow.

Genetic Diversity Unit (GDU) is defined as: A group of genetically similar stocks that is genetically distinct from other such groups. The stocks typically exhibit similar life histories and occupy ecologically, geographically and geologically similar habitats. A GDU may consist of a single stock.

Geomorphology: Study of the form and origins of surface features of the Earth.

Glides: Stream habitat having a slow, relatively shallow run of water with little or no surface turbulence.

Harm - Defined in regulations implementing the ESA as an act "which actually kills or injures" listed wildlife. Harm may include "significant habitat modification or degradation where it actually kills or injures wildlife by significantly impairing essential behavioral patterns, including breeding, feeding, or sheltering"

Healthy Stock: A stock of fish experiencing production levels consistent with its available habitat and within the natural variations in survival for the stock.

Hydrograph: Chart of water levels over time.

Hydrology: Study of the properties, distribution, and effects of water on the Earth's surface, subsurface, and atmosphere.

Hydromodification: The channelization and armoring of natural banks to prevent flooding or protect stream adjacent property and structures from erosion; navigation activities (ditching, dredging and channel straightening); anthropogenic alterations in channel morphology (planform, cross-sectional area, bed and bank configuration); and anthropogenic changes in the amount of in-channel LWD.

Intermittent stream: Stream that has interrupted flow or does not flow continuously. Compare *perennial stream*.

Intraspecific interactions: Interactions within a species.

Jeopardy - A determination, reached through the consultation process, that an activity would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species.

Kokanee – The freshwater resident life history form of *O. nerka* and can be composed of residualized sockeye or landlocked *O. nerka*. Also sometimes called: little redfish, silver trout, kickininee, land locked sockeye, or Kennerly's salmon.

Large Woody Debris (LWD): Large woody material that has fallen to the ground or into a stream. An important part of the structural diversity of streams. LWD is also referenced to as "coarse woody debris" (CWD). Either term usually refers to pieces at least 20 inches (51 cm) in diameter.

Limiting Factor: Single factor that limits a system or population from reaching its highest potential.

mg/L: milligrams per liter. For dissolved oxygen concentrations in water it may also be expressed as ppm.

Macroinvertebrates: Invertebrates large enough to be seen with the naked eye (e.g., most aquatic insects, snails, and amphipods).

Mass failure: Movement of aggregates of soil, rock and vegetation down slope in response to gravity.

Mile measurement: A nautical mile.

Native: Occurring naturally in a habitat or region; not introduced by humans.

Non-Point Source Pollution: Polluted runoff from sources that cannot be defined as discrete points, such as areas of timber harvesting, surface mining, agriculture, and livestock grazing.

Nearshore marine zone: Habitats that lie between the lower limit of the photic zone (approximately at minus 30 meters MLLW) and the upland–aquatic interface.

Outermost upland: Those lands not covered by water during an ordinary high tide.

ppm: Parts per million, for dissolved oxygen it may also can be expressed as mg/L

Parr: Young trout or salmon actively feeding in freshwater; usually refers to young anadromous salmonids before they migrate to the sea. See *smolt*.

Plunge pool: Basin scoured out by vertically falling water.

Properly Functioning Condition (PFC) - State of the physical, chemical, and biological aspects of watershed ecosystems which will sustain a healthy salmonid population(s). Properly functioning

condition generally defines a range of values for several measurable criteria rather than specific, absolute values. The range for these values may vary from watershed to watershed based upon a variety of factors, e.g., geology, hydrology, and stream geomorphology, and the improved understanding of how these factors shape ecosystem functions.

Rain-on-snow events: The rapid melting of snow as a result of rainfall and warming ambient air temperatures. The combined effect of rainfall and snow melt can cause high overland stream flows resulting in severe hillslope and channel erosion.

Rearing habitat: Areas required for the successful survival to adulthood by young animals.

Recovery: The process by which the decline of an endangered or threatened species is arrested or reversed, and threats neutralized so that its survival in the wild can be ensured. The goal of the ESA is for the recovery of listed species to levels where protection under the ESA is no longer necessary.

Redds: Nests made in gravel (particularly by salmonids); consisting of a depression that is created and the covered.

Resident fish: Fish species that complete their entire life cycle in freshwater.

Riffle: Stream habitat having a broken or choppy surface (white water), moderate or swift current, and shallow depth.

Riparian: Type of wetland transition zone between aquatic habitats and upland areas. Typically, an area on or by land bordering a stream, lake, tidewater, or other body of water.

Riprap: Large rocks, broken concrete, or other structure used to stabilize streambanks and other slopes.

River mouth: The waters of any river or stream, including sloughs and streams, upstream and inside of a line projected between the outermost uplands at the mouth.

Rootwad: Exposed root system of an uprooted or washed-out tree.

SASSI: Salmon and Steelhead Stock Inventory.

SSHIAP: A salmon, steelhead, habitat inventory and assessment program directed by the Northwest Indian Fisheries Commission.

Salmonid: Fish of the family salmonidae, including salmon, trout chars, and bull trout.

Salmon: Includes all species of the family Salmonid

Sediment: Material carried in suspension by water, which will eventually settle to the bottom.

Sedimentation: The process of sediment being carried and deposited in water.

Side channel: A portion of an active channel that does not carry the bulk of stream flow. Side channels may carry water only during high flows, but are still considered part of the total active channel.

Sinuosity: Degree to which a stream channel curves or meanders laterally across the land surface.

Slope stability: The degree to which a slope resists the downward pull of gravity.

Smolt: Juvenile salmon migrating seaward; a young anadromous trout, salmon, or char undergoing physiological changes that will allow it to change from life in freshwater to life in the sea. The smolt state follows the parr state. See *parr*.

Stock: Group of fish that is genetically self-sustaining and isolated geographically or temporally during reproduction. Generally, a local population of fish. More specifically, a local population – especially that of salmon, steelhead (rainbow trout), or other anadromous fish – that originates from specific watersheds as juveniles and generally returns to its birth streams to spawn as adults.

Stream order: A classification system for streams based on the number of tributaries it has. The smallest unbranched tributary in a watershed is designated order 1. A stream formed by the confluence of 2 order 1 streams is designated as order 2. A stream formed by the confluence of 2 order 2 streams is designated order 3, and so on.

Stream reach: Section of a stream between two points.

Stream types:

Type 1: All waters within their ordinary high-water mark as inventoried in "Shorelines of the State".

Type 2: All waters not classified as Type 1, with 20 feet or more between each bank's ordinary high water mark. Type 2 waters have high use and are important from a water quality standpoint for domestic water supplies, public recreation, or fish and wildlife uses.

Type 3: Waters that have 5 or more feet between each bank's ordinary high water mark, and which have a moderate to slight use and are more moderately important from a water quality standpoint for domestic use, public recreation and fish and wildlife habitat.

Type 4: Waters that have 2 or more feet between each bank's ordinary high water mark. Their significance lies in their influence on water quality of larger water types downstream. Type 4 streams may be perennial or intermittent.

Type 5: All other waters, in natural water courses, including streams with or without a well-defined channel, areas of perennial or intermittent seepage, and natural sinks. Drainage ways having a short period of spring runoff are also considered to be Type 5.

Sub Watershed: One of the smaller watersheds that combine to form a larger watershed.

Thalweg: Portion of a stream or river with deepest water and greatest flow.

Wall-base channels: groundwater-fed side-channels typically found at the base of a steep sideslope. Wall base channel may form as seepage that emerges from the base of the slope converges and flows toward the mainstem or they may represent former river channels that have been abandoned.

Watershed: Entire area that contributes both surface and underground water to a particular lake or river.

Watershed rehabilitation: Used primarily to indicate improvement of watershed condition or certain habitats within the watershed. Compare *watershed restoration*.

Watershed restoration: Reestablishing the structure and function of an ecosystem, including its natural diversity; a comprehensive, long-term program to return watershed health, riparian ecosystems, and fish habitats to a close approximation of their condition prior to human disturbance.

Watershed-scale approach: Consideration of the entire watershed in a project or plan.

Weir: Device across a stream to divert fish into a trap or to raise the water level or divert its flow. Also a notch or depression in a dam or other water barrier through which the flow of water is measured or regulated.

Wild Stock: A stock that is sustained by natural spawning and rearing in the natural habitat regardless of origin.

ACRONYMS and ABBREVIATIONS

ac-ft	acre feet
USACE	US Army Corps of Engineers
° C	degrees Centigrade
cfs	cubic feet per second
CC	Washington Conservation Commission
CSO	Combined sewer overflow
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
ESA	Endangered Species Act
° F	degrees Fahrenheit
H_2S	Hydrogen sulfide
KC	King County
LWD	Large Woody Debris
MIT	Muckleshoot Indian Tribe
MITFD	Muckleshoot Indian Tribe Fisheries Department
MSL	Mean Sea Level
NMFS	National Marine Fisheries Service
NWIFC	Northwest Indian Fisheries Commission
ppt	parts per thousand
RM	River Mile
SaSI	Salmonid Stock Inventory
SASSI	Salmon and Steelhead Stock Inventory
SCS	Soil Conservation Service
SPU	Seattle Public Utilities
SFH	State Fish Hatchery
USGS	United States Geological Survey
USFWS	United States Fish and Wildlife Service
WAU	Watershed Administrative Unit
WDF	Washington Department of Fisheries (superceded by WDFW)
WDFW	Washington Department of Fish and Wildlife
WDOE	Washington Department of Ecology
WDNR	Washington Department of Natural Resources
WDW	Washington Department of Wildlife (superceded by WDFW)
WRIA	Water Resources Inventory Assessment
WWTIT	Western Washington Treaty Indian Tribes

LITERATURE CITED

Adams, B., W. Zaugg, and L. McLain. 1975. Inhibition of saltwater survival and Na-K-ATP-ase elevation in steelhead trout (*Salmo gairdneri*) by moderate water temperatures. In: Chapman, D., M. Peven, T. Hillman, A. Giorgi, and F. Utter. 1994. Status of summer steelhead in the mid-Columbia River. Don Chapman Consultants, Boise, ID. 235 pp.

Aiken, S. A., Newroth, P. R., and Wile, I. 1979. The biology of Canadian weeds. 34. *Myriophyllum spicatum*. L. Can. J. Plant Sci. 59:201-215.

Aldrich, R. 2001. Robert Aldrich (Snohomish County) personal communication to Frank Leonetti (Fisheries Biologist) Snohomish County.

Allan, J.H.. 1980. Life history notes on the Dolly Varden char (*Salvelinus malma*) in the Upper Clearwater River, Alberta. Manuscript report. Red Deer, AB, Canada: Energy and Natural Resources, Fish and Wildlife Division. 58 p.

Andersen, D. E, R. N. Brenner, and A. W. Johnson. (no date) Coal Creek stream resource inventory-technical input to the King County and City of Bellevue Coal Creek basin plan

Anderson, D. 1987. Water Quality Impact Supplement, University Regulator

Anderson, G.C. 1954. A limnological study of the seasonal variation of phytoplankton populations. Ph.D. Dissertation. University of Washington, Seattle.Apr. 1954 Assessment Division. Personal communication. Associates for the City of Seattle, June 2000.224 p.

Anuszewski, J. 1992. Internal Memorandum dated May 20, 1992 from Jacek Anuszewski to Jim Bucknell, WDOE. Northwest Regional Office, Bellevue, WA.

Arkoosh, M.R. E. Casilla, P. Huffman, E. Clemons, J. Evered, J.E. Stein, and U. Varanasi. 1998b. Increased susceptibility of juvenile chinook salmon from a contaminated estuary to Vibrio anguillarum. Transactions of the American Fisheries Society 127:360-374.

Arkoosh, M.R., E. Casillas, E. Clemons, A.N. Kagley, R. Olson, P. Reno, and J.E. Stein. 1998a. Effect of pollution on fish diseases: potential impacts on salmonid populations. Journal of Aquatic Animal Health 10:182-190.

Arkoosh, S., E. Casillas, E. Clemons, B. McCain, and U. Varanasi. 1991. Suppression of immunological memory in juvenile chinook salmon (*Oncorhynchus tshawytscha*) from an estuary. Fish and Shellfish Immunol. 1:261-277.

Arkoosh, S., E. Casillas, P. Huffman, E. Clemons, J. Evered, J.E. Stein, and U. Varanasi. 1998. Increased susceptibility of juvenile chinook salmon (*Oncorhynchus tshawytscha*) from a contaminated estuary to Vibrio anguillarum. Trans. Am. Fish. Soc. 127:360-374.

Assessment: Associates. 2000. *Factors Affecting Chinook Populations, Background Report*. Prepared for the City of Seattle. Seattle, WA.

Bartoo, N. W. 1972. The vertical and horizontal distributions of northern squawfish (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), yellow perch (*Perca flavescens*), and adult sockeye salmon (*Oncorhynchus nerka*) in Lake Washington. M. S. Thesis, University of Washington, Seattle. 60 pp.

Basin Condition Reports, Prescriptions, and Restoration Opportunities.

Beak Consultants Incorporated, 1997. Port Quendall Project Mitigation Analysis Memorandum (Draft). Prepared for Remediation Technologies, Inc. 23 May 1997

Bean, T.H. 1891. Kennerly's Salmon. Trans. Amer. Fish. Soc., Twentieth Annual Meeting, Washington D.C.

Beauchamp, D. A. 1987. Ecological relationships of hatchery rainbow trout in Lake Washington. Ph.D. thesis, University of Washington, Seattle. 237 pp.

Beauchamp, D.A. 1990. Seasonal and diel food habits of rainbow trout stocked as juveniles in Lake Washington. Transactions of the American Fisheries Society 119: 475-482.

Beauchamp, D.A., S.A. Vecht, and G.L. Thomas. 1992. Temporal, spatial, and size-related foraging of wild cutthroat trout in Lake Washington. Northwest Science 66:149-159.

Beauchamp, D. A. 1994. Spatial and temporal dynamics of piscivory on planktivorous fishes: implications for food web stability and the transparency of Lake Washington. Lake and Reservoir Management. 10:21-24.

Beauchamp, D. A., E.R. Byron, and W. Wurtsbaugh. 1994. Summer habitat use by littoral-zone fishes in Lake Tahoe and the effects of shoreline structures. North American Journal of Fisheries Management 14:385-394.

Beauchamp, D. A. 1995. Riverine predation on sockeye salmon fry migrating to Lake Washington. North American Journal of Fisheries Management 15:358-365.

Beauchamp, D.A., C.M. Baldwin, J.L. Vogel, and C.P. Gubala. 1999. Estimating diel, depth-specific foraging with a visual encounter rate model for pelagic piscivores. Canadian Journal of Fisheries and Aquatic Sciences 56(Supplement 1): 128-139.

Beedle, Dave. Hydrologist, Seattle Public Utilities, City of Seattle. Burton, Karl, Fisheries Biologist, Seattle Public Utilities, City of Seattle. Foster Wheeler Environmental Corporation. 1995. Cedar River Watershed Assessment:Basin Condition Reports, Prescriptions, and Restoration Opportunities.

Bell, M.C. and A.C. DeLacy. 1972. A compendium on the survival of fish passing through spillways and conduits. Contract Number DACW 57-67-C-0105. U.S. Army Corps of Engineers, Portland, Oregon. 121 pp.

Bellevue Utilities, 2000 Geographic Information Services (GIS) coverages. Bellevue Utilities, Geographical Information Services (GIS) 2000.

Benke, R.J. 1997. Evolution, systematics, and Structure of *Oncorhynchus clarki clarki*. Pages 3-6 in J.D. Hall, P.A. Bisson, and R.E. Gresswell, eds. Sea-run cutthroat trout: biology, management and future conservation. Oregon Chapter, American Fisheries Society. Corvallis, OR.

Bennett, B. 1998 Personal Communication, , Lake Forest Park citizen.

Berman, C.H. and T.P. Quinn. 1989. The effects of elevated holding temperatures on adult spring chinook salmon reproductive success. Timber/Fish/Wildlife Rpt. No. TFW-009-89- 005. Prepared for the Cooperative Monitoring, Evaluation and Research Committee of TFW. University of Washington, Seattle. 34pp.

Berrgren, T.J. 1974. Seasonal Changes in the Abundance, Biomass, Production, Distribution, and Feeding of the 1971 Year Class of Sockeye Salmon in Lake Sammamish. Master's Thesis, University of Washington. Seattle, WA. 80 p.

Bilby, R.E. and J.W. Ward. 1991. Characteristics and function of large woody debris in streams draining old-growth, clear-cut, and second-growth forests in southwestern Washington. Canadian J. Fisheries and Aquatic Sciences 48.

Bishop, S. and A. Morgan. 1996. Critical habitat issues by basin for natural chinook salmon stocks in the coastal and Puget Sound areas of Washington state. Northwest Indian Fisheries Commission, Olympia, WA. 105 pp.

Bisson, P.A. 1987. Large woody debris in forested streams in the Pacific Northwest: past, present, and future. In: E.O. Salo and T.W. Cundy, eds. Symposium on Streamside Management: Fishery and Forestry Interactions. College of Forest Resources. Contr. No. 57. Univ. of Wash., Seattle, WA.

Bjornn. T. C. and D.W. Reiser, 1991. Habitat requirements of salmonids in streams.

Boehm, William. 1994. Boeing Creek Stream Survey and Special Study

Booth, D. B, September 2000, Forest Cover, Impervious-Surface Area

Booth, D. B., and Jackson, C. J., 1997, Urbanization of aquatic systems—degradation thresholds, stormwater detention, and the limits of mitigation: Water Resources Bulletin, v. 33, p. 1077-1090.

Bortleson, G.C. & D.A. Davis. 1997. Pesticides in selected small streams in the Puget Sound Basin 1987-1995. USGS Fact Sheet 067-97.

Bouck, G.R. 1977. The importance of water quality to Columbia River salmon and steelhead. American Fisheries Society Special Publication 10:149-154.

Bouck, G.R. and S.D. Smith. 1979. Mortality of experimentally descaled smolts of coho salmon (Oncorhynchus kisutch) in fresh and saltwater. Transactions of the American Fisheries Society 108:67-69.

Bradbury, A. and B. Pfeifer. 1992. Lake Sammamish creel survey – 1982-83. Part IV. Fisheries investigations of Lake Washington and Sammamish – 1980-1990. Washington Department of Fish and Wildlife. Unpublished draft report.

Brett, J.R. 1952. Temperature tolerance in young Pacific salmon, Genus Oncorhynchus. Journal of the Fisheries Research Board of Canada 9:265-323.

Brett, J.R. 1956. Some principles of the thermal requirements of fishes. The Quarterly

Brett, J.R.; Charke, W.C.; Shelbourn, J.E. 1982. Experiments on thermal requirements for growth and food conversion efficiency of juvenile chinook salmon, Oncorhynchus tshawytscha. 1982; 33 pp; Can. Tech. Rep. Fish. Aquat. Sci.; No. 1127.

Brocksmith, R. 1999. Abundance, feeding ecology and behavior of a native piscivore northern pikeminnow (*Ptychocheilus oregonensis*) in Lake Washington. M.S. Thesis, University of Washington, Seattle.

Brooks, K.M. 1996. Evaluating the environmental risks associated with the use of chromated copper arsenate-treated wood products in aquatic environments. Estuaries 19: 296-305.

Brown, E.R., 1985. Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington. USDA Forest Service, Corvallis OR.

Brown, L.G.. 1992. Draft management guide for the bull trout *Salvelinus confluentus* (Suckey) on the Wenatchee National Forest. Wenatchee, WA. Washington Department of Wildlife. 75 p.

Bryan, M.D., and D.L. Scarnecchia. 1992. Species richness, composition, and abundance of fish larvae and juveniles inhabiting natural and developed shorelines of a glacial Iowa lake. Environmental Biology of Fishes 35:329-341.

Bryant, J. 1995. The Effects of Urbanization on Water Quality in Puget Sound Lowland Streams. Masters Thesis, University of Washington, Seattle WA.

Buckley, R. 1965. Incidences of Beach Spawning Sockeye Salmon in Lake Washington and Lake Sammamish. Washington Department of Fisheries Annual Report 1964. 28 p.

Buerge, D. 1984. Indian Lake Washington. The Weekly [now Seattle Weekly], Aug. 1-7, 1984: 29-33.

Bulletin No. 41, University of Washington Engineering Experimental Station, May 1, 1927.

Bumgarner, J. et al. 1997. Tucannon River spring chinook salmon hatchery evaluation program. 1996 Annual Report. Washington Department of Fish and Wildlife Hatcheries Program Assessment and Development Division, Report No. H97-07. Produced for U.S. Fish and Wildlife Service, Cooperative Agreement 14-48-0001-96539.

Burgner, R. 1991. The life history of the sockeye salmon (*Oncorhynchus nerka*). Pages 3-117 in C. Groot and L. Margolis (editors). University of British Columbia Press, Vancouver, B.C.

Burgner, R.L. 1991. Life history of sockeye salmon (Oncorhynchus nerka). Pp 212-291 in C. Groot and L. Margolis (eds.) Pacific Salmon Life Histories. University of British Columbia Press, Vancouver, British Columbia.

Busby, P.J., T.C. Wainwright, G.J. Bryant, L.J. Lierheimer, R.S. Waples, F. W. Waknitz, and I.V. Lagomarsino. 1996. Status Review of West Coast Steelhead from Washington, Idaho, Oregon, and California. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-27, 261 p.

Butler, V.L. 1987. Chapter 10, Fish Remains. In URS Corp., The Duwamish No. 1 Site: 1986 Data Recovery, p. 10-1 to 10-37. METRO, Seattle.

California Department of Water Resources. 1988. Water Temperature Effects on Chinook Salmon (Oncorhynchus tshawytscha) with emphasis on the Sacramento River: A Literature Review. Northern District Office Report. Red Bluff, California. 42 p.

Carr, M., August 1996, WRIA 8 - Bear Creek Electro-Shocking Fish Counts –

Cederholm, C.J. and W.J. Scarlett. 1981. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981, p. 98-110. In: E.L. Brannon and W.O. Salo (eds.). Proceedings of the Salmon and Trout Migratory Behavior Symposium. School of Fisheries, University of Washington, Seattle, WA.Francis,

Center for Urban Water Resource Management (CUWRM), http://140.142.16.146/cuwrm, fall, 1999.

Center for Urban Water Resources Management.1999. Regional, Synchronous Field Determination of Summertime Stream Temperatures in Western Washington. http://depts.washington.edu/cuwrm/

CH2MHill. 1997. North Creek comprehensive flood hazard management plan. Prepared for Snohomish County Surface Water Management, Everett, WA.

Chamblin, M. 2001. Mike Chamblin (Habitat Biologist), WDFW personal communication to Frank Leonetti (Fisheries Biologist) Snohomish County.

Chapman, D., A. Giorgi, T. Hillman, D. Deppert, M. Erho, S. Hays, C. Peven, B. Suzumoto, and R. Klinge. 1994. Status of summer/fall chinook salmon in the mid-Columbia region. Don Chapman Consultants Inc., Boise, ID. 411 pp.

Chigbu, P. 1993. Trophic role of longfin smelt in Lake Washington. Ph.D. thesis. University of Washington. 221 pp.

Christensen, D.L., B.R. Herwig, D.E. Schindler, and S.R. Carpenter. 1996. Impacts of lakeshore residential development on coarse woody debris in north temperate lakes. Ecological Applications 6:1143-1149.

Chrzastowski, M. 1983. Historical changes to Lake Washington and route of the Lake Washington Ship Canal, King County, Washington. Dept. of the Interior, U. S. Geological Survey Water Resources Investigations WRI 81-1182. 9 p.

Cierebiej-Kanzler, S. 2000. Washington Department of Fish and Wildlife. Lewis Creek Fish Barrier Evaluation and Habitat Assessment. Personal Communication between Kollin Higgins and Susan Cierebiej-Kanzler (WDFW), December 4, 2000.
City of Bellevue and King County. 1987. Coal Creek basin plan and final EIS.
City of Bellevue GIS, 2000. Unpublished data, landuse coverages.
City of Bellevue Planning and Community Development. GIS landuse and development coverage, 2000.
City of Bellevue Stream Team, unpublished data, 1990.
City of Bellevue Utilities Dept. 2000. Unpublished data, multispectral image analyses.
City of Bellevue, 1988. Comprehensive Drainage Plan, Appendix A: Stream flow History.
City of Bellevue, 2000. Multispectral analysis for impervious area, Geographic Information Services.
City of Bellevue, January, 1999. Richards Creek Basin Plan, Fish Habitat/Fish Passage pp.42-49.
City of Bellevue, November, 2000. Geographical Information Services (GIS) multispectral image data analyzed for impervious area.
City of Bellevue, Utilities Department, 1996. Unpublished data, Stream Team Habitat Assessment, Coal Creek.
City of Bellevue, Utilities Department, 1998. Unpublished data, JFE habitat assessment.
City of Bellevue. 1971. Environmental focus: a City of Bellevue planning study. Bellevue, WA
City of Bellevue. 1984. Bellevue Urban Runoff Program Summary Report (BURP).
City of Bellevue. 1995. Characterization and source control of urban stormwater quality. Volume 1 Technical Report. (NURP)
City of Bellevue. 1995. Characterization and source control of urban stormwater quality. Volume 1 Technical Report. (NURP)
City of Kirkland and King County Department of Natural Resources (KCDNR). In preparation. Year 2000 habitat inventory and assessment of Juanita Creek.
City of Seattle, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. 1999b. Response to Public Comments on the Public Review Draft of the Environmental Assessment/Environmental Impact Statement for the proposed Issuance of a Permit to Allow Incidental Take of Threatened and Endangered Species City of Seattle.
City of Seattle. 1998. Draft Cedar River Watershed Habitat Conservation Plan.
City of Seattle. 2000 b. Technical Appendices for the Final Cedar River Watershed Habitat Conservation Plan.
City of Seattle. U.S. Fish and Wildlife Service, and National Marine Fisheries Service. 1999a. Environmental Assessment/Final Environmental Impact Statement for the Proposed Issuance of a Permit to Allow Incidental Take of Threatened and Endangered Species.
City of Seattle. 2000. Final Cedar River Watershed Habitat Conservation Plan.
Clarke, W.C. and Shelbourn, J.E. 1985. Growth and development of seawater adaptability by juvenile fall chinook salmon (*Oncorhynchus tshawytscha*) in relation to temperature. Aquaculture 45: 21-31.
Cobb, J. N. 1911. The Salmon Fisheries of the Pacific Coast. Report of the Commissioner of Fisheries for the Fiscal Year 1910 and Special Papers, 180 p.
Cobb, J. N. 1914. The Species of Pacific Salmon and the Runs. Pac. Fisherman Yearbook 1914, 12(2):31-33.

Cobb, J. N. 1927. Preliminary Report of Fishway Work. Trans. Am. Fish. Soc. 57:181-201.
Cobb, J. N. 1930. Pacific Salmon Fisheries, 4th Edition. Bureau of Fisheries, Washington, D.C. 704 p.
Collias, E. and G. Seckel. 1954. Lake Washington Ship Canal Data, Special Collins, R. S. 1997. History of Sydnor's Blueberry Farm. Manuscript on file at Bellevue
Columbia Basin Subbasin Assessment Team. April 20, 2000. A Template for Subbasin Assessment - Draft.
Comis, J. G., et al. 1971. Stream ecology study: an interdisciplinary watershed study of Kelsey and Coal Creeks, King County, WA.
Cooke, G. D., E. B. Welch, S. A. Peterson, and P. R. Networth. 1993. Coordinator (Washington Conservation Commission).
County - Wastewater Treatment Division, Nov. 2000. County Department of County Department of Natural Resources, Wastewater Treatment Division. County Department of Public Works. Surface Water Management
Coutant, C.C. 1970. Thermal resistance of adult coho and jack chinook salmon, and adult steelhead trout from the Columbia River. BNWL-1508. Battelle Memorial Institute, Richland, WA. 24 pp.
Couto, Adam. Personal Communication to Kit Paulsen, March 19, 1999.
CSO Control Predesign Project, METRO, Mar. 1987.
Cubbage, J. 1992. Survey of contaminants in sediments in Lake Union and adjoining waters (Salmon Bay, Lake Washington Ship Canal, and Portage Bay). Prepared for Deborah North, Urban Bay Action Team, Washington Department of Ecology, Northwest Regional Office. Prepared by Environmental Investigations and Laboratory Services Program: Toxics, Compliance, and Groundwater Investigations Section. Olympia, Washington. 72 p.
Dames & Moore, Inc. 1994. Lewis Creek: General Site Survey and Level II Stream Survey, Final Report. June, 1994.
Dauble, D.D. and R.P. Mueller. 2000. Upstream passage monitoring: difficulties in estimating survival of adult chinook salmon in the Columbia and Snake Rivers. Fisheries 25(8):24-34.
Davis, D.A., 1993. Washington State pesticide monitoring program: reconnaissance sampling of surface waters 1992.
Davis, G.E., J. Foster, C.E. Warren, and P. Doudoroff. 1963. The influence of oxygen concentration on the swimming performance of juvenile Pacific salmon at various temperatures. Trans. Am. Fish. Soc. 92: 111-124.
DeVries, P. 2000. PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Year 2000 Pilot Study Results. U.S. Army Corps of Engineers, Nov. 2000.
Dilley, S. J., and R.C. Wunderlich. 1992. Juvenile anadromous fish passage at Howard Hanson Project, Green River, Washington, 1991. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.
Dilley, S. J., and R.C. Wunderlich. 1993. Juvenile anadromous fish passage at Howard Hanson Project, Green River, Washington, 1992. U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, WA.
Dillion, F. 1993a. Lake Union: Baseline Environmental Characterization.
Dillon, F.S. 1993b. *University regulator CSO control project: Lake Union* Division, Lake Washington Basin Steward. 1998-2000.

Division, Seattle, Washington.
Dinicola, R.S. 1990. Characterization and Simulation of Rainfall-Runoff Relations for Headwater Basins in Western King and Snohomish Counties, Washington. USGS Water Resources Investigations Report 89-4052.
Donaldson, L.R. 1947. Letter to D. Clark, Washington Department of Game dated April 8, 1947.
Donigian, A.S., B.R. Bicknell, and J.C. Imhoff. 1994. Hydrologic Simulation Program-FORTRAN. Chapter 12. In: Computer Models in Watershed Hydrology. V.P. Singh (ed). Water Resources Publications. Littleton, CO.
Downen, M. 2001. Mark Downen, WDFW (Area Fisheries Biologist), to John Kerwin, Washington Conservation Commission (Regional Technical Coordinator).
Edmondson, W. T. and A. H. Litt. 1982. *Daphnia* in Lake Washington. Limnology and Oceanography 27:272-293.
Edmondson, W. T., and S. E. B. Abella. 1988. Unplanned biomanilpulation in Lake Washington. Limnologica 19:73-75.
Edmondson, W.T. 1991. The Uses of Ecology. Lake Washington and beyond. University of Washington Press. Seattle.
Edmondson, W. T. 1994. Sixty years of Lake Washington: a Curriculum Vitae. Lake and Reservoir Management 10:75-84.
Eggers, D.M., N.W. Bartoo, N.A. Rickard, R.E. Nelson, R.C. Wissmar, R. L. Burgner, and A. H. Devol. 1978. The Lake Washington ecosystem: The perspective from the fish community production and forage base. Journal of the Fisheries Research Board of Canada 35:1553-1571.
ENTRANCO Engineers, 1981. Lyon Creek Comprehensive Drainage Plan. Prepared for Cities of Mountlake Terrace and Lake Forest Park.
Entranco, Herrera Environmental Consultants and Peter Moy and Associates. 1996. Lake Sammamish Water Quality Management Plan -1996. Prepared for King County and the Cities of Bellevue, Redmond and Issaquah.
Entranco, King County Water and Land Resources Division*, Bear, Evans, Cottage Lake, and Mackey Creeks, Habitat Problems, Prioritization, and Solution Development, Technical Memorandum*.
Environmental Protection Agency (EPA). 1992. Impacts of Urban Runoff on Fish Populations in Kelsey Creek, WA.
Evaluation Program Monitoring Report 1995 to 1998 Part I. Report to King County.
Everest, F.H., N.B. Armantrout, S.M. Keller, W.D. Parante, J.R. Sedell, T.E. Nickelson, J.M. Johnston, and G.N. Haugen. 1985. Salmonids. Pages 199-230 in E.R. Brown (ed.). Management of Wildlife and Fish Habitats in Forests of Western Oregon and Washington. Publication R6-F$WL-192-1985. U.S. Department of Agriculture, Forest Service, Pacific Northwest Region. Portland, Oregon.
Evermann, B.W. and E.L. Goldsborough. 1907. The Fishes of Alaska. U.S. Bur. Fish., Bull. 26:219-360, 144 figs.
Fayram, 1996. Impacts of largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieui*) predation on populations of juvenile salmonids in Lake Washington. M. S. Thesis. University of Washington, Seattle.
Fayram, A. H., and T. H. Sibley. 2000.Impact of predation by smallmouth bass on sockeye salmon in Lake Washington. North American Journal of Fisheries Management 20:81-89.

Federal Register, March 10, 1998, Endangered and Threatened Species: Proposed Threatened Status and Designated Critical Habitat for Ozette Lake, Washington Sockeye Salmon.

Federal Register. Feb. 16, 2000. Designated Critical Habitat: Critical Habitat for 19 Evolutionarily Significant Units of Salmon and Steelhead in Washington, Oregon, Idaho, and California. Vol. 65, No. 32. P 7764.

Fletcher, D.H. 1973a. Letter to Cliff Millenbach, Washington Department of Game, Fisheries Management Division dated May 7, 1973. Olympia, WA

Fletcher, D.H. 1973b. Comparison of Kokanee from Selected Western Washington Lakes. Internal Memo. Washington Department of Game. Olympia, WA

Foley, S. 2001. Steve Foley (Area Fisheries Biologist), WDFW personal communication to Frank Leonetti (Fisheries Biologist) Snohomish County.

Foley, S. 2000. Steve Foley, Washington Department of Fish and Wildlife (Fisheries Biologist, Region 4, Mill Creek), personnel communication to John Kerwin (Washington Conservation Commission).

Folmar, L.C., and W.W. Dickhoff. 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. A review of selected literature. Aquaculture 21:1-37.

Foote, C.J., Wood, C.C., and R.E. Withler. 1989. Biochemical genetic comparison of sockeye salmon and kokanee, the anadromous and non-anadromous forms of *Oncorhynchus nerka*. Canadian Journal of Fisheries and Aquatic Sciences 46:149-159.

Footen, B. 2000. Preliminary results of an Investigation into the impacts of piscivorous predation on juvenile chinook (*Oncorhynchus tshawytscha*) and other salmonids in Salmon and Shilshole Bays, King County, Washington. Preliminary data presented at the workshop chinook Salmon in the Cedar - Sammamish Watershed. Muckleshoot Indian Tribe, Auburn, Washington.

Fore, Leska. 1999. Technical report. Measuring the Effects of Urbanization on Bellevue Streams.

Foster Wheeler Environmental Corporation, 1998. *May Creek Basin Plan.* Prepared for King County and the City of Renton.

Foster Wheeler Environmental Corporation. 1995. Cedar River Watershed

Fox, W.W., B. Delong, P. Dygert, S. Foley, P. Gearin, S. Jeffries, and J. Scordino. 1996. Environmental assessment on conditions for lethal removal of California sea lions at the Ballard Locks to protect winter steelhead (Supplement). NOAA, NMFS, Seattle, Washington.

Francis, R.C. and T.H.Sibley. 1991. Climate change and fisheries: What are the real issues? Northwest Environ. J. 7:295-307.

Franklin, J.F., 1992. Scientific basis for new perspectives in forests and streams, pp. 25-72. In: Naiman, R.J., ed. Watershed Management: Balancing Sustainability and Environmental Change. Springer-Verlag, NY.

Fresh, K.L. 1994. Lake Washington fish: A historical perspective. Lake and Reservoir Management 9:148-151.

Fresh, K.L. 1997. The role of competition and predation in the decline of Pacific salmon and steelhead. Pages 245-275 in D.J. Stouder, P. A. Bission, and R.J. Naiman editors. Pacific salmon and their ecosystems. Status and Future Options. Chapman and Hall, New York.

Fresh, K., Warner, E., et al. 1999. Draft Lake Washington Chinook Salmon Recovery Plan

Fresh, K..L, E. Warner, R. Tabor, and D. Houck. 1999. Migratory behavior of adult

chinook salmon spawning in the Lake Washington watershed in 1998 as determined with ultrasonic telemetry. Draft Progress Report, October 1999.

Fresh, K. 2000. Distribution of juvenile Chinook salmon in Lake Washington. Preliminary data presented at the workshop Chinook Salmon in the Greater Lake Washington Watershed. Washington Department of Fish and Wildlife, Olympia.

Fresh, K., E. Warner, R. Tabor, D. Houck. 2000. Migratory Behavior of Adult Chinook Salmon Spawning in the Lake Washington Watershed in 1998 and 1999 as Determined with Ultrasonic Telemetry. King County - Wastewater Treatment Division, Nov. 2000.

Fresh, K..L, E. Warner, R. Tabor, and D. Houck. 2000. Migratory behavior of adult chinook salmon spawning in the Lake Washington watershed in 1998 and 1999 as determined with ultrasonic telemetry. Extended abstract and presentation prepared for the Lake Washington Chinook Salmon Workshop, November, 2000.

Fresh, K.L. and G. Lucchetti. 2000. Protecting and restoring the habitats of anadromous salmonids in the Lake Washington Watershed, an urbanizing ecosystem. Pages 525-544 in E.E. Knudsen, C.R. Steward, D.D. MacDonald, J.E. Williams, and D.W. Reiser (editors). Sustainable Fisheries Management: Pacific salmon. CRC Press LLC, Boca Raton.

Fresh, Kurt. 2000. Kurt Fresh (Washington Department of Fish and Wildlife, Research Scientist) to John Kerwin (Washington Conservation Commission, Regional Technical Coordinator).

Fresh, Kurt. 1999. Personal Communication. November 5, 1999.

Frodge, J.D., D.A. Marino, G. B. Pauley, and G.L. Thomas. 1995. Mortality of largemouth bass (*Micropterus salmoides*) and steelhead trout (*Oncorhynchus mykiss*) in densely vegetated littoral area tested using in situ bioassay. Lake and Reserv. Manage. 11(2):343-358.

Fujioka, J.T. 1970. Possible effects of low dissolved oxygen content in the Duwamish River estuary on migrating adult chinook salmon. M.S. thesis, University of Washington, Seattle. 77 p.

GAIA Northwest, Inc. 1997. Pipers Creek Rehabilitation Erosion and Sedimentation Management Program and Design Manual. Final Report to Seattle Public Utilities, October 1997.

Gay, B. 2001 Brain Gay (Seattle Parks Department) personal communication to Katherine Lynch (Seattle Public Utilities).

Gilhousen, P. 1990. Prespawning Mortalities of Sockeye Salmon in the Fraser River System and Possible Causal Factors. International Pacific Salmon Fisheries Commission Bulletin XXVI. Vancouver, B.C., Canada.

Goetz, F. 1989. Biology of the bull trout, *Salvelinus confluentus*, a literature review. Eugene, OR.: US Department of Agriculture, Forest Service, Willamette National Forest. 53 p.

Goetz, F.A., J.J. Dawson, T. Shaw, and J. Dillon. 1999. Evaluation of low-frequency underwater sound emitters for guiding salmon and steelhead smolts away from a navigation lock at the Hiram M. Chittenden Locks, Seattle, Washington. A report to Portland District, USACE, and the Lake Washington Ecological Studies Group.

Goetz, F. 2000. Fred Goetz, Fisheries Biologist (U.S. Army Corps of Engineers) to John Kerwin, Regional Technical Coordinator (Washington Conservation Commission).

Goetz, Fredrick. 2001. Personal communication of February 6, 2001. Biologist, U.S. Army Corps of Engineers, Seattle, Washington.

Grady, J. Flow data from Pipers Creek. 1999. Unpublished data. University of Washington School of Fisheries.

Gray, R.H. 1990. Fish behavior and environmental assessment. Environ. Toxicol. Chem. 9:1:53-67.Green, J., and M.W. Trett. 1989. The fate and effects of oil in freshwater. Elsevier Science Publishers, London, England.

Grette, G. 1985. Fish monitoring program: Hiram M. Chittenden Locks. Summary Letter Report to Seattle District, Evans Hamilton, Seattle, WA.

Griggs, D. T. 1971. Characteristics and estimations of the fish populations of Kelsey and Coal creeks with emphasis upon cutthroat and coho salmon. Pages 107-121 in Welch, E.B. (faculty advisor). Stream ecology study: an interdisciplinary watershed study of Coal and Kelsey creeks, King county, Washington. Seattle, University of Washington Department of Civil Engineering and City of Bellevue.

Hall, J.D., P. A. Bisson, and R.E. Gresswell (eds). 1997. Sea-run cutthroat trout: biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis, OR.

Hallock, M., and P.E. Mongillo. 1998. Washington State status report for the

Hallock, R.J., R.F. Elwell, D.H. Fry, Jr. 1970. Migrations of Adult King Salmon (*Oncorhynchus tshawytscha*) in the San Joaquin Delta as demonstrated by the use of sonic tags.. California Department of Fish and Game Fish Bulletin 151, 92 p.

Hansen, L., T. Georgianna, D. Houck, J. Frodge. 1994. Lake Union data

Hanson, L. 1993. Lake Union Data Compilation and Review, METRO

Hare, R.C. and S.R. Hare. 1994. Decadal-scale regime shifts in the large marine ecosystems of the Northeast Pacific: A case for historical science. Fish. Oceanogr. 3:279-291.

Hart Crowser and Associates, Inc. 1983. Technical Report Cedar Falls-Morse Lake

Hartley, D. and G. Lucchetti. 2000. Forest Retention, Runoff Response, and Implications for Salmonids. Forest Retention, Runoff Response, and Implications for Salmonids. Technical Memorandum prepared for the Tri-County ESA Stormwater Group, May, 2000, 6 p.

Hartley, D. 2000. Effect of Recent Seattle Operations on Cedar River Flow Regime- A General Picture Based on Mean Monthly Flow Comparisons. Technical Memorandum prepared for Cedar River Instream Flow Interests, May, 2000, 13 p.

Hatch, D., A. Wand, A. Porter, and M. Schwartzberg. 1992. The feasibility of estimating sockeye salmon escapement at Zosel Dam using underwater video technology. 1992 Annual Progress Report. Prepared for Public Utility District No. 1 or Douglas County.

Hatfield, Doug, 1999. WDFW Cascade Complex Hatchery Manager, personnel communication to John Kerwin, Washington Conservation Commission (Regional Technical Coordinator).

Healey, M.C. 1980. Utilization of the Nanaimo River estuary by juvenile chinook salmon, Oncorhynchus tshawytscha. Fisheries Bulletin 77:653-668.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system, pp. 315-341 in: V.S. Kennedy (ed.). Estuarine comparisons. Academic Press, New York, NY.

Healey, M.C. 1991. Life history of chinook salmon. Pages 310-393 in C. Groot and L. Margolis (eds.), Pacific Salmon Life Histories. Univ. British Columbia Press., Vancouver, B.C

Heller, R. 2000. Ray Heller, (King County Department of Natural Resources) personnel communication to John Kerwin (Washington Conservation Commission).

Heller, Ray. 2000. Bear Creek Basin Steward Personal Observation

Hendrick, Don. 1978. Edmonds area stream survey report. Washington Department of Wildlife.

Hendry, A.P. 1995. Sockeye salmon (*Oncorhynchus nerka*) in Lake Washington: an investigation of ancestral origins, population differentiation and local adaptation. M.S. Thesis, University of Washington, Seattle.

Hendry, A.P., and T.P. Quinn. 1997. Variation in adult life history and morphology among Lake Washington sockeye salmon (*Oncorhynchus nerka*) populations in relation to habitat features and ancestral affinities. Canadian Journal of Fisheries and Aquatic Sciences 54:75-84.

Hennick, D. 1999. Doug Hennick personal communication (Washington Department of Fish and Wildlife), Area Habitat Biologist. 1999 to Scott Brewer (King County).

Herrera Environmental Consultants, and Brown and Caldwell Consultants. 1994. Lake Union water quality/environmental assessment project. Executive and technical summary (Vol. 1), project report (Vol. 2), and stormwater and basin maps (Vol. 3). Herrera Environmental Consultants, Seattle, Washington

Herrera Environmental Consultants, University of Washington, and Seattle Laboratory Services Division. 1993. Pipers Creek Bacteriological Source Tracking Investigation. Report to Seattle Engineering Division Drainage and Wastewater Utility.

Herrera Environmental Consultants. 1995. Final Project Report: Lewis Creek Monitoring Program.

Hicks, M. 2000. Evaluating standards for protecting aquatic life in Washington's surface water quality standards temperature criteria. Draft Discussion Paper and Literature Summary. Washington Department of Ecology. 176 pp. Historical Society, Bellevue, Washington.

Hill, K., E.B. Botsford, and D. B. Booth. 2000. A Rapid Land Cover Classification Method for Urban Watershed Analysis. Report of the Center for Urban Water Resources, University of Washington, October, 2000, 19 p.

Hoar, W.S. 1958. The evolution of migratory behaviour among juvenile salmon of the genus *Oncorhynchus*. J. Fish. Res. Board. Can. 15:391-428.

Horner, R.R. and C.W. May. 1998. Watershed urbanization and the decline of salmon in Puget Sound streams. Pages 19-40 in Salmon in the City Conference Proceedings, held May 20-21 in Mt. Vernon, Washington. American Public Works Association, Washington Chapter, Washington State University.

Houck, D. 2001. *Unpublished Data*, King County- Wastewater Treatment Division, Jan. 2001.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16:835-886

Hydroacoustic Technology Inc. 2000. Using Acoustic Tags for Monitoring Adult Chinook Salmon Behavior at the Hiram. M. Chittenden Locks. Draft Report Prepared for the Seattle District, US Army Corps of Engineers, for the Lake Washington Investigation Studies. Seattle, WA.

Improvements Project No. OA1755 General Site Survey and Level 1 Stream

Infometrix, Inc. 1994. Statistical and pattern recognition multivariate analysis of winter steelhead passage rate, environmental and operational variables at the Lake Washington Ship Canal/Ballard Locks fishway. Final Report, Infometrix, Inc., Seattle, WA.

Isaac, G.W., R.I. Matsuda and J. Welker. 1966. A limnological investigation of water quality conditions in Lake Sammamish. Municipality of Metropolitan Seattle, Seattle, WA.

Ivankov, V.N. and V.L. Andreyev. 1971. The South Kuril chum (*Oncorhynchus keta*) ecology, population structure and the modeling of the population. J. Ichthyol. 11:511-524.

Jacobson, J. 2000. Jake Jacobson, Snohomish County personal communication to Frank Leonetti (Snohomish County)

Johnson, A. and G. Minton (Aquatic Resource Consultants and Resource Planning Assoc.). 1998. Lower Thornton Creek evaluations of salmonid habitat conditions and opportunities. Report to Seattle Public

Johnson, A. W. and C. Menconi. 1997. Inventory of lower Coal Creek, Bellevue, WA.

Johnson, O.W., M.H. Ruckelhaus, W.S. Grant, F. W. Waknitz, A.M. Garrett, G.J. Bryant, K. Neely, and J.J. Hard. 1999. Status Review of Coastal Cutthroat Trout from Washington, Oregon, and California. U.S. Dept. of Commer., NOAA Tech.Memo. NMFS-NWFSC-37, 292 p.

Johnson, P.N., F.A. Goetz, M.E. Hanks, and G.R. Ploskey. 2001. Fish Passage Investigations at the Hiram M. Chittenden Locks, Seattle, Washington: A Year 2000 Focus on the Large Lock Culvert Intakes and Smolt Passage Flumes. Draft Report Prepared for the Seattle District, US Army Corps of Engineers, for the Lake Washington Section 1135 and General Investigation Studies. Waterways Experiment Station, Bonneville, WA.

Johnson, R.L. 1970a. Fingerling fish mortalities at 57.5 fps. Report Number 22 in Forth Progress Report on Fisheries Engineering Research Program 1966-1972. U.S. Army Corps of Engineers. Portland, Oregon. 14 pp.

Johnson, R.L. 1970b. Fingerling fish research effect of mortality at 67-fps velocity. Report Number 23 in Forth Progress Report on Fisheries Engineering Research Program 1966-1972. U.S. Army Corps of Engineers. Portland, Oregon. 6 pp.

Johnson, R.L. 1970c. Tests of fingerling fish passage at Bonneville Dam. Report Number 18 in Forth Progress Report on Fisheries Engineering Research Program 1966-1972. U.S. Army Corps of Engineers. Portland, Oregon. 4 pp.

Johnson, R.L. 1972. Fingerling fish research, high velocity flow through four-inch nozzle. Report Number 24 in Forth Progress Report on Fisheries Engineering Research Program 1966-1972. U.S. Army Corps of Engineers. Portland, Oregon. 5 pp

Jones, J.G., J.E.M. Horne, P. Moorhouse, and D.L. Powell. 1980. Petroleum hydrocarbons in fresh waters, a preliminary desk study and bibliography. Freshwater Biological Association, Occasional Publications No. 9. 51 p.

Jordan, D.S. and B.W. Evermann. 1896.The Fishes of North and Middle America. U.S. Natl. Mus. Bull. 47(Part 1), 954 p.

Kahler, T., M. Grassley, and D. Beauchamp. 2000. A Summary of the Effects of Bulkheads, Piers and other Artificial Structures and Shorezone Development on ESA-listed Salmonids in Lakes. Final Report prepared for the City of Bellevue.

Karr, James R. and Ellen W. Chu. 1999. Restoring Life in Running Waters- Better Biological Monitoring. Island Press. Washington D.C.

KCM, Inc. 1993. Phantom/Larsen Lakes phase II restoration project: final report. Vols. 1 & 2.

Kelley, Roger. Snohomish County Surface Water Management, Salmon Watchers Program. Personal communication, 2/14/2001.

Kemmerich, J. 1945. A Review of the Artificial Propagation and Transplantation of the Sockeye Salmon of the Puget Sound area in the State of Washington Conducted by the Federal Government from 1896 to 1945. Unpubl. Manusc., 76 p. plus tables (Available from the West Coast Sockeye Salmon Administrative Record, Environmental and Technical Services Division. NMFS. Portland, OR.
King County - Wastewater Treatment Division, Nov. 2000.
King County, 1892. Engineer's Report of Ditch Sammamish Valley, September 22, 1892, King County Board of Commissioners
King County, 1911. Testimony on Hearing on the Proposed Drainage District Number 3, King County, Washington, January 11, 1911, King County Board of Commissioners
King County. 1987. Reconnaissance Report No. 5 East lake Sammamish Basin. June 1987. 7 p plus appendices.
King County, Water and Land Resources Division, March 1989, Bear Creek Basin Current and Future Conditions Analysis.
King County 1990. Proposed Bear Creek basin plan. King County Department of Natural Resources.
King County, Water and Land Resource Division, July 1990, *Bear Creek Basin Plan*
King County 1990. East Lake Sammamish Basin Conditions Report—Preliminary Analysis. September 1990.
King County, 1991. Issaquah Creek Basin Current/Future Conditions and Source Identification Report. October.
King County, 1991. Current/Future Conditions and Source Identification Report, Issaquah Creek Basin, 307 p. plus appendices.
King County 1992. Draft East Lake Sammamish Basin and Nonpoint Action Plan. Volume 1. May 1992.
King County, 1993. Current River Current and Future Conditions Report, Issaquah Creek Basin, 322 p. plus appendices.
King County Surface Water Management Division. 1993. *Cedar River Current and Future Conditions Report.*
King County, 1993. Current River Current and Future Conditions Report, Issaquah Creek Basin, 322 p. plus appendices.
King County. 1993. Cedar River Current and Future Conditions Report. King County Department of Public Works, Surface Water Management Division, Seattle.
King County. 1994. East Lake Sammamish Basin Watershed Management Committee Basin and Nonpoint Action Plan. 95 p. plus appendices.
King County, 1994. Issaquah Creek Watershed Management Committee – Proposed Basin and Nonpoint Action Plan, September.
King County, 1994b. Appendix to the Issaquah Creek Basin and Nonpoint Action Plan. September 1994.
King County 1994. Final East Lake Sammamish Basin and Nonpoint Action Plan.
King County 1994. North Lake Washington Basin Annual Report.
King County Department of Metropolitan Services. 1994. Water quality of small lakes and streams Western King County 1990-1993.
King County. 1995. Lake Sammamish Total Phosphorus Model. King County Department of Metropolitan Services and King County Surface Water Management Division. Seattle WA.

King County, Water and Land Resources Division, February 1996, *Cottage Lake Management Plan*.
King County, 1996a. Issaquah Creek Final Basin and Nonpoint Action Plan. December 1996.
King County, 1996b. 1995 Status Report: Abundance of Spawning Kokanee in the Sammamish River Basin: Addendum to 1994 Status Report. November.
King County 1997. 1997 Volunteer Salmon Watcher Program in the Lake Washington Watershed. April 2000.
King County Surface Water Management, Drainage Services Section. Complaint reports and field assessments, 1997.
King County and Washington Department of Fish and Wildlife, 1998-2000. Unpublished data from kokanee surveys.
King County Department of Natural Resources (King County). In preparation. 1999 habitat inventory and assessments of three tributaries to the Sammamish River: North, Swamp, and Little Bear Creeks. DRAFT November 21, 2000. Report to: King County Department of Natural Resources Wastewater Treatment Division, Water and land Resources Division.
King County Wastewater Treatment Division. 1999. Special Study on Water Quality – Lyon Creek.
King County. 1999. Sammamish-Washington Analysis and Modeling Program - Scope of Work. King County Department of Natural Resources, Seattle, WA.
King County. 2000 Lewis Creek Habitat Enhancement and Bank Stabilization project. Amended version July 14, 2000. King County Dept. Natural Resources, Department of Natural Resources, Ecological Services Unit. Seattle, WA
King County. 2000. Historic and Current Status of Kokanee in the Lake Washington Basin. Discussion Draft dated March 13, 2000. Seattle, WA. 44 p.
King County. 2000. Unpublished Data - Lake Sammamish Chemistry Data
King County. 2000. Hydrologic Change in the Green River Near Palmer. Unpublished Draft Report. 30 pp.
King County environmental lab analytical reports. 1991-1995. Loose data sheets.
King County, Department of Natural Resources. 2000. Unpublished gauging data.
King County, Department of Natural Resources. 2000. Unpublished Salmon Watcher Program data.
King County, Water and Land Resources Division, 2000, *Draft Bear Creek Basin Management Evaluation Program*, 1995-1998.
King County, Water and Land Resources Division, September 8, 1994, *Waterways 2000 Basin and Reach Report*.
King County Department of Natural Resources (King County). 2001. 1998 and 1999 volunteer salmon watcher program in the Lake Washington watershed. King County Department of Natural Resources Water and Land Resources Division.
King County. 2001. DRAFT *State of the Nearshore Ecosystem: Eastern Shore of Central Puget Sound including Vashon and Maury Islands (WRIAs 8, 9 and portions of 15)*.
Kjelson, M.A. P.F. Raquel, and F.W. Fisher. 1981. Influences of freshwater inflow on chinook salmon (Oncorhynchus tshawytscha) in the Sacramento-San Joaquin estuary, pp. 88-102 in: R.D. Cross and .L. Williams (eds.). Proceedings of the National Symposium on Freshwater Inflow to Estuaries. U.S. Fish and Wildlife Service Biol. Serv. Prog. FWS/OBS-81/04(2).

Kleindl, W. J. 1995. A benthic index of biotic integrity for Puget Sound lowland streams, Washington, USA (1994 data only).

Koehler, M. 2000. Feeding ecology of juvenile chinook salmon in Lake Washington. Preliminary data presented at the workshop chinook salmon in the Greater Lake Washington Watershed. University of Washington, Seattle.

Kohler, A. 2001. Andy Kohler, Northwest Indian Fisheries Commission (SSHIAP Biologist) to John Kerwin, Washington Conservation Commission (Regional Technical Coordinator).

Kraemer, C. 2001. Curt Kraemer (Area Fisheries Biologist), WDFW personal communication to Frank Leonetti (Fisheries Biologist) Snohomish County 2/2/01.

Kramer, Chin and Mayo Inc. April 1983. McAleer Creek Project. Produced for King County, Mountlake Terrace, and Lake Forest Park.

Kurko, Keith. Fisheries Biologist, Seattle Public Utilities, City of Seattle personnel communication to John Kerwin (Washington Conservation Commission)

Lackey, Brent. 2000. Personal communication from Brent Lackey to John Lombard.

Lackey, B. 2000. Brent Lackey personnel communication (King County) to John Kerwin (Washington Conservation Commission).

Lackey, B. 1998. Brent Lackey King County personal observation.

Lake Forest Park Streamwatcher Program. 1998-1999. Program chair, Bill Bennett, citizen-volunteer.

Lake Project Hydrologic Study, Phase 1: consulting report prepared for City of Seattle, City Light and Water Departments.

Larkin, P.A. 1977. Pacific Salmon, p. 156-186. In: J.A. Gulland (ed.). Fish population dynamics. J. Wiley & Sons, New York, NY.

Latimer, J.S., and J.G. Quinn. 1998. Aliphatic petroleum and biogenic hydrocarbons entering Narragansett Bay from tributaries under dry weather conditions. Estuaries 21: 91-107.

Lee, L. C. 1985. Richard's Creek restoration project: monitoring report 1985.

Lester, D. and D. Wilson. 2000. Sediment Quality in an Urban Lake - Lake Sammamish WA. Presented at the 20th Annual Society of Environmental Toxicology and Chemistry meeting. Nashville, TN.

Lester, D. 2000. Deb Lester (King County) personnel communication to John Kerwin (Washington Conservation Commission) December 2000.

Levings, C.D., C.D. McAllister, and B.D. Chang. 1986. Differential use of the Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile chinook salmon (*Oncorhynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Sciences 43:1386-1397.

Levy, D.A. and T.G. Northcote. 1981. the distribution and abundance of juvenile chinook salmon in marsh habitat of the Fraser River estuary. University of British Columbia Westwater Research Center Technical Report 25:117 pp.

Levy, D.A. and T.G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Canadian Journal of Fisheries and Aquatic Sciences 39:270-276.

Lister, D.B. and C.E. Walker. 1966. The effect of flow control on freshwater survival of chum, coho and chinook salmon in the Big Qualicum River. Canadian Fish Culturist. 37:3-26.

Lister, D.B., and H.S. Genoe. 1970. Stream habitat utilization by cohabiting under yearlings of chinook (Oncorhynchus tshawytscha) and coho (O. kisutch) salmon in the Big Qualicum River, British Columbia. J. Fish. Res. Board Can. 27: 1215-1224.

Lorz, H., and B. McPherson. 1976. Effects of copper or zinc in fresh water on the adaptation to sea water and ATPase activity, and the effects of copper on migratory disposition of coho salmon (Oncorhynchus kisutch). Journal of the Fisheries Research Board of Canada 33: 2023-2030.

Lucchetti, G.L., and R.B. Fuerstenburg. 1993. Urbanization, habitat conditions and fish communities in western King County with implications for management of wild coho salmon. Proc. Amer. Fish. Soc. Coho workshop, Nanaimo, British Columbia, May 1992.

Lucchetti, Gino. Fisheries Biologist, Department of Natural Resources, King County personal communication to John Kerwin (Regional Technical Coordinator (Washington Conservation Commission)

Ludwa et al, Kenneth. June 1997. Assessing Stream-Dwelling Fishes in Basins of the Lake Washington Watershed, Summer 1996.

Ludwa, K., G. Lucchetti, K. L. Fresh, and K. Walter. 1997. Assessing stream dwelling fishes in basins of the Lake Washington watershed, Summer 1996.

Lynch, J.D. 1941. Letter to C. Pautzke, Washington Department of Game dated August 4, 1941.

MacCoy, D.E. and R.W. Black. 1998. Organic compounds and trace elements in freshwater streambed sediment and fish from Puget Sound Basin. U.S. Geological Survey Fact Sheet 105-98.

Macdonald, J.S., I.K. Birtwell, and G.M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Canadian Journal of Fisheries and Aquatic Sciences 44:1233-1246.

MacDonald, L.H., *et al.* 1991. Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska. CSS/EPA.

Major, R.L. and J.L. Mighell. 1966. Influence of Rocky Reach Dam and the Temperature of the Okanogan River on the Upstream Migration of Sockeye Salmon. U.S. Fish and Wildlife Service Fishery Bulletin 66:131-147.

Malmgren, N. 1996. Carkeek Watershed Community Action Project Pipers Creek Salmon Program Overview.

Malmgren, N. 2001. Nancy Malmgren (Seattle Public Utilities), personal communication to Katherine Lynch (Seattle Public Utilities).

Marshall, A.R., C. Smith, R. Brix, W. Dammers, J. Hymer, L. Lavoy. 1995. Genetic diversity units and major ancestral lineages for chinook salmon in Washington. In: Genetic Diversity Units and Major Ancestral Lineages of Salmonid Fishes in Washington. Wash. Dept. Fish and Wildlife. Technical Report Number RAD 95-02.

Marshall, A.R.. 2000. Genetic Analysis of Cottage Lake Creek/Bear Creek and Issaquah Creek Naturally Spawning Fall-Run Chinook. Washington Department of Fish and Wildlife. Olympia, WA. 10 p.

Marshall, Anne, R., May 2000, *Genetic Analysis of Cottage lake Creek/Bear Creek and Issaquah Creek Naturally Spawning Fall-run Chinook.*

Martin, T. 2001. Lake Washington/Cedar River Consumptive Use Survey. Draft consultant technical memorandum, March, 2001, 6 p.

Martz, M., F. Goetz, and J. Dillon. 1996. Lake Washington ecological studies study element II: Early lake life history of sockeye salmon (Oncorhynchus nerka) in Lake Washington, Year 1: 1994. Seattle District Army Corps of Engineer, Seattle, Washington.

Martz, M., F. Goetz, J. Dillon, and T. Shaw. 1996. Study Element II: early lake life history of sockeye salmon (*Oncorhynchus nerka*) in Lake Washington, year 1: 1994. Final Report, U. S. Army Corps of Engineers, Seattle District, Seattle, Washington.

Martz, Valentine and Fitzgerald. 1999. "Sammamish River Temperature Study, 1998 Results from Temperature Modeling and Literature Review of Temperature Effects on Fish", U.S. Army Corps of Engineers, Seattle District.

Matilla, Jim. 1998. "Report Concerning Observations of Dead and Live Chinook in the Upper Sammamish River, 9/11/98". Unpublished report, King County Water and Land Resources Division

Maule, A.G., and S.P. VanderKooi. 1999. Stress-induced immune-endocrine interaction. Pages 205-245 in P.H.M. Balm, editor. Stress physiology in animals. CRC Press LLC, Boca Raton, Florida.

Maule, A.G., R.A. Tripp, S.L. Kaattari, and C.B. Schreck. 1989. Stress alters immune function and disease resistance in chinook salmon (Oncorhynchus tshawytscha). Journal of Endocrinology 12)135-142.

Mavros, B., Foley, S., Burton, K., Walter, K., *1999 Chinook Spawner Survey Data* Foster Wheeler Environmental Corp 1995. May Creek Current and Future Conditions Report, August 1995; prepared for King County Surface Water Management Division

May, C. W. 1996. Assessment of cumulative effects of urbanization on small streams of the Puget Sound lowland ecoregion: implications for salmonid resource management. Ph.D. thesis, Department of Engineering, University of Washington.

May, C. W., R. R. Horner, J. R. Karr, B. W. Mar, E. B. Welch. 1997. Effects of urbanization on small streams in the Puget Sound lowland ecoregion. Watershed Protection Techniques 2(4):483-494.

May, C.W., Welch, E.B., Horner, R.R., Karr, J.R., and Mar, B.W. 1997. Quality indices for urbanization effects in Puget Sound lowland streams. Final report prepared for Washington Department of Ecology, Water Resources Series Technical Report No. 154. 229 p.

McCullough, D.A. 1999. A review and synthesis of freshwater effects of alterations to the water temperature regime on freshwater life stages of salmonids, with special reference to chinook salmon. EPA 910-R-99-010. USEPA Region 10, Seattle, WA.

McDonald, L. 1984. Bellevue: its first 100 years. Fairfield, Washington, Ye Galleon Press.

McDonald, R. K. and L. McDonald. 1987. The coals of Newcastle

McIntosh, B., and Faux, R. 2000. Remote Sensing Survey of the Sammamish River, prepared for U.S. Army Corps of Engineers, Seattle District

McMillan, William. Personal communication. 11/21/00.

McPhail, J.D. and C.B. Murray. 1979. The early life-history and ecology of Dolly Varden (*Salvelinus malma*) in the Upper Arrow Lakes. Vancouver, B.C., Canada: University of British Columbia, Department of Zoology and Institute of Animal Resources. 113 p.

Meadowbrook Pond annual maintenance work 9/6/00.

Meehan, W.R., F.J. Swanson, and J.R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply. pp. 137-145. In: R.R. Johnson and D. A. Jones (eds.). Importance, Preservation and Management of Riparian Habitat: A Symposium held at Tucson, Arizona, July 9, 1977. U.S. Forest Serv. Gen Tech. Rep. RM-43

Menconi, Carl and Alan Johnson. Bellevue Culvert Inventory. Report to City of Bellevue. December 1998.

Mendel, G. and D. Milks. 1997. Upstream passage and spawning of fall chinook salmon in the Snake River. Washington Department of Fish and Wildlife, Olympia.

Mesa, M.G. 1994. Effects of multiple acute stressors on the predator avoidance ability and physiology of juvenile chinook salmon. Transactions of the American Fisheries Society 123:786-703.

Mesa, M.G., T.P. Poe, A.G. Maule, and C.B. Schreck. 1998. Vulnerability to predation and physiological stress responses in juvenile chinook salmon (Oncorhynchus tshawytscha) experimentally infected with Renibacterium salmoninarum. Canadian Journal of Fisheries and Aquatic Sciences 55:1599-1606.

METRO, 1988, *Quality of Local Lakes and Streams: 1986-1987 Status Report.*

Metro, 1993. Lake Union data compilation and review. Municipality of Metropolitan Seattle, Seattle, Washington. Prepared by Lisa Hansen, Primary Investigator, with Tom Georgianna, Doug Houck and Jonathon Frodge. Publication 851.

Metro, Water Resources Section, Water Pollution Control Department. Quality of local lakes and streams: 1989-1990 Update.

METRO. 1990. Quality of local lakes and streams: 1988-1989 Status Report. Water Resources Section, Municipality of Metropolitan Seattle, Seattle, WA.

METRO. 1991. Quality of local lakes and streams: 1989-1990 Status Report. Water Resources Section, Municipality of Metropolitan Seattle, Seattle, WA.

Miholovich, J. 1977. "Thornton Creek Basin in 1900". Lake City Journal May 18, 1977, Vol. 25 (33).

Miller, B. 2001. Beth Miller (Seattle Parks Department), personal communication

Miller, R. R. 1965. Quaternary freshwater fishes of North America. In: The Quaternary of the United States. Princeton University Press, Princeton, New Jersey. pp. 569-581.

Miller, T. and D. Kirkpatrick. Tina Miller and Deanne Kirkpatrick, (King County) personal communication to Scott Brewer (King County)

Minton, G. 1998. Review of water and sediment quality data, Thornton Creek. Report to Seattle Public Utilities, May 4, 1998.

Minton, G.R. 2000. Evaluation of Water Quality and Related Data Pipers Creek Watershed. In: Seattle Public Utilities Pipers Creek Watershed Action Plan 1999. Community/Agency Review and Course Corrections. Final Report, March 2000. *Mitigation of Urbanization Impacts in King County*, Washington.

Morgan, Amy. May, 1999. Winter Habitat Utilization by Juvenile Salmonids: A Literature Review. NW Indian Fisheries Commission. http://www.nwifc.wa.gov/TFW/reports/report5.htm

Morgenroth, Brian. Personal Communication November 3, 2000.

Morley, S.A. 2000. Effects of urbanization on the biological integrity of Puget Sound lowland streams: Restoration with a biological focus. Masters thesis. University of Washington, Seattle, WA. 55 p.

Moscrip, A.L. and Montgomery, D.R. 1997. Urbanization, flood frequency, and salmon abundance in Puget lowland streams. J. Amer. Water Res. Assoc. 33: 1289-1297.

Municipality of Metropolitan Seattle (METRO). 1989. Quality of local lakes and streams: 1987-1988 Status Report. Water Resources Section, Municipality of Metropolitan Seattle, Seattle, WA.

Murphy, M. L., and K. V. Koski. 1989. Input and depletion of woody debris in Alaska streams and implications for streamside management. North American Journal Fisheries Management 9:427-436.

Muto, M. and J. Shefler. 1983. Game Fish Distribution in Selected Streams Within the Lake Washington Drainage Basin. Washington State Game Department, Fisheries Management Division Report 83-9. 328 p.

Myers, J.M., R.G. Kope, G.J. Bryant, D. Teel, L.J. Lierheimer, T.C. Wainwright, W.S. Grand, F.W. Waknitz, K. Neely, S.T. Lindley, and R.S. Waples. 1998. Status review of chinook salmon from Washington, Idaho, Oregon, and California. U.S. Dept. Commerce., NOAA Tech. Memo. NMFS-NWFSC-35, 443 p.

National Marine Fisheries Service, Environmental and Technical Service Division, Habitat Conservation Branch. August 1996. Appendix II: Making Endangered Species Act Determinations of Effect for Individual or Grouped Actions at the Watershed Scale.

National Marine Fisheries Service, NW Fisheries Science Center. Analytical Tools for Science-Based Decision Support Regarding Salmonid Recovery Planning: Integrating Habitat, Harvest, Hatcheries, and Hydropower as Risk Factors. Unpublished discussion paper.

National Marine Fisheries Service, NW Fisheries Science Center. No date. Cumulative Risk Initiative. http://research.nwfsc.noaa.gov/cri/

National Marine Fisheries Service, NW Fisheries Science Center. No date. Freshwater Habitat and Salmon Recovery: Relating Landuse to Actions to Fish Population Response.

National Marine Fisheries Service, Protected Resources Division. June 1998. Factors Contributing to the Decline of Chinook Salmon: An Addendum to the 1996 West Coast Steelhead Factors For Decline Report.

National Marine Fisheries Service. September 15, 1996. Coastal Salmon Conservation: Working Guidance for Comprehensive Salmon Restoration Initiatives on the Pacific Coast. Portland Oregon.

Neave, F. 1949. Game fish populations of the Cowichan River. Bull. Fish. Res. Board Can. 84:1-32

Nehlson, W., J.E. Williams and J.A. Lichatowich. 1991. Pacific Salmon at the Crossroads: Stocks at Risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Neilson, J.D., and C.E. Banford. 1981. Chinook salmon (*Oncorhynchus tshawytscha*) spawner characteristics in relation to redd physical features. Can. J. Zool. 61:1524-1531.

Neilson, J.D., and G.H. Geen. 1985. Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile chinook salmon, Oncorhynchus tshawytscha. Fishery Bulletin 83:91-101.

Nelson, Erin, 1999. A Sediment Budget of the Issaquah Creek Basin. University of Washington Masters Thesis.

Nelson, Mike. Snohomish County Planning Department, Everett WA. Personal communication to Tom Murdoch, Environmental Coordinator, Snohomish County. January 28, 1991.

Nowak, G.M. 2000. Movement patterns and feeding ecology of cutthroat trout (*Oncorhynchus clarki clarki*) in Lake Washington. M.S. Thesis, University of Washington, Seattle.

O'Laughlin, Kate, King County. Personal Communication to Kit Paulsen, March 2000.

Olsen, J. C. 1968. Physical environment and egg development in a mainland beach area and an island beach area of Iliamna Lake, p. 169-197. In: R.L. Burgner (ed.). further studies of Alaska Sockeye Salmon. Univ. Wash. Publ. Fish. New Ser.3.

Olson, A.F. and T.P. Quinn. 1993. Vertical and horizontal movements of adult chinook

salmon Oncorhynchus tshawytscha in the Columbia River estuary. Fishery Bulletin 91:171-178.

Oregon Department of Fish and Wildlife. 1992. Effects of Lost Creek Dam on Fall Chinook Salmon in the Rogue River. Phase II Completion Report. Rogue Basin Fisheries Evaluation Project, Research and Development Section. U.S.A.C.O.E. contract number DACW57-77- C-003.

Ostergaard, E. 1996. 1995 Status Report: Abundance of Spawning Kokanee Salmon in the Sammamish River Basin. Addendum to 1994 Status Report. King County Surface Water Management Division. 22 p. plus 5 Appendices.

Ostergaard, E. 1998b. 1997 Kokanee Spawner Survey Data and Escapement Estimates for Selected Streams in the Lake Washington Watershed. King County Department of Natural Resources. Seattle, WA

Ostergaard, E. 1998. 1996 Salmon Spawning Surveys in the Lake Washington Watershed. King County Department of Natural Resources- December 1998.

Ostergaard, E. 1998a. 1996 Salmon Spawning Surveys in the Lake Washington Watershed: Results of the 1996 Spawning Survey Program and Kokanee Spawner Survey Program. King County Department of Natural Resources, Seattle WA.

Ostergaard, E. 1998b. Lake Washington and Lake Sammamish Kokanee: History and Documentation. King County Department of Natural Resources, Seattle WA

Ostergaard, E. and C.W. May. In Progress. *Big Bear Creek Basin Management*

Ostergaard, E. C. Young and K. Ludwa. 1995. Abundance of spawning kokanee in the Sammamish River Basin. 1994 Status Report. King County Surface Water Management Division, Seattle, WA.

Ostergaard, E., 1998, *1997* Kokanee Spawner Survey Data and Escapement Estimates for Selected Streams in the Lake Washington Watershed. King County Department of Natural Resources, Seattle, WA.

Pacific Fishery Management Council. January 1999. APPENDIX A: Description and Identification of Essential Fish Habitat, Adverse Impacts and Recommended Conservation Measures for Salmon, Amendment 14 to the Pacific Coast Salmon Plan.

Paige, Dwayne, Seattle Public Utilities, City of Seattle personnel communication to John Kerwin (Washington Conservation Commission).

Parametrix, Inc. 1992. Lake Union capping feasibility study. Report prepared for City of Seattle Planning Department. July 31, 1992.

Patmont, C. R., Davis, J. I., and Schwartz, R. G. 1981. Aquatic plants in selected waters of King County. Distribution and community composition of macrophytes. Municipality of Metropolitan Seattle, Water Quality Division. 89 pp.

Paul, F.H. 1937. *Report on Cedar River Flood Control Project.* King County, WA. October 1937.

Paulsen, Kit. 2000. Kit Paulsen (Fisheries Biologist, City of Bellevue) personal communication to John Kerwin (Regional Technical Coordinator) Washington Conservation Commission.

Paulsen, Kit. Personal observation, 1996-1999.

Pearcy, W.G. 1992. Ocean Ecology of North Pacific Salmonids. Washington Sea Grant Program, Univ. of Wash. Press, Seattle. 179 pp.

Perkins, M. A., J. Sloane, R. Pedersen, Q. J. Stober, C. R. Steward, J. Scott. 1980. Ecological impacts of stormwater run-off in urban streams.

Perkins, Michael A. An Evaluation of Instream Ecological Effects Associated with Urban Runoff to a Lowland Stream in Western Washington. U.S. Environmental Protection Agency, Corvallis Environmental Research Laboratory, Corvallis, Oregon. July, 1982.

Perkins, Susan J. 1994. The Shrinking Cedar River--Channel Changes Following Flow Regulation and Bank Armoring. American Water Resources Association.

Patmont, C. R., J. I. Davis, R. G. Swartz. 1981. Aquatic plants in selected waters of King County: Distribution and community composition of macrophytes. Municipality of Metropolitan Seattle, Water Quality Division. 89 pp.

Peterson, N.P, Hendry, A., and Quinn, T.P. 1992. Assessment of cumulative effects on salmonid habitat: some suggested parameters and target conditions. Washington Department of Natural Resources and Cooperative Monitoring, Evaluation, and Research Committee Timber-Fish-Wildlife Program. TFW-F3-92-001. 75 p.

Peterson, N.P. 1980. The role of spring ponds in the winter ecology and natural production of coho salmon (*Oncorhynchus kisutch*) on the Olympic Peninsula, Washington. M. Sc. Thesis. University of Washington Seattle, WA 96 p.

Peterson, N.P., and L.M. Reid. 1984. Wall–base channels: their evolution, distribution, and use by juvenile coho salmon in the Clearwater River, Washington. Pages 215–226, In: J.M. Walton and D.B. Houston, Eds. Proc. Olympic Wild Salmon Conf., March 23–25, 1983, Port Angeles, WA. USA.

Pfeifer, B. 1994. Analyses of winter steelhead passage through the Hiram Chittenden Locks fishway in relation to environmental conditions and steelhead run sizes, 1989-1994. Washington Department of Wildlife, Mill Creek, WA.

Pfeifer, B. 1995. Decision Document for the Management and Restoration of Indigenous Kokanee of the Lake Sammamish /Sammamish River Basins with Special Emphasis on the Issaquah Creek Stock. Washington Department of Fish and Wildlife, Inland Fisheries Division. Mill Creek, WA.

Pfeifer, B. and A. Bradbury. 1992. Evaluation of game fisheries of Lake Washington – 1980-1990. Part I. Fisheries investigations of Lake Washington and Sammamish – 1980-1990. Washington Department of Wildlife. Unpublished draft report.

Pfeifer, R.L. 1979. A survey of Lund's Gulch Creek in Edmonds, Washington. Washington State Game Department.

Pfeiffer, B. 1984. A survey of Pipers Creek in Seattle, Washington. Washington Department of Game. October 1984.

Pflug, D.E.. 1981. Smallmouth bass (*Micropterus dolomieus*) of Lake Sammamish: a study of their age and growth, food and feeding habits, populations size, movement and homing tendencies, and comparative interactions with large mouth bass. M.S. Thesis, University of Washington, Seattle, WA 80 p..

Pflug, D. E., and Pauley, G. B. 1984. Biology of smallmouth bass (*Micropterus dolomieui*) in Lake Sammamish, Washington. Northwest Science 58(2): 118 - 125.

Phelps, S. R., B.M. Baker, P.L. Hulett and S. A. Leider. 1994. Genetic Analysis of Washington Steelhead: Initial Electrophoretic Analysis of Wild and Hatchery Steelhead and Rainbow Trout. Washington Department of Fish and Wildlife Report 94-9. Olympia, WA

Piaskowski, R. and R. Tabor. 2000. Nocturnal habitat use of juvenile chinook salmon in the near shore areas of south Lake Washington. Preliminary data presented at the workshop chinook salmon in the Greater Lake Washington Watershed. U.S. Fish and Wildlife Service, Western Washington Fisheries Resource Office, Lacey.

Piper, R.G., I. B. McElwain, L.E. Orme, J.P. McCraren, L.G. Fowler, and J.G. Leonard. 1982. Fish Hatchery Management. U.S. Fish and Wildlife Service. Washington, D.C. 517 p.

Pitt, R. and P. Bissonnette. 1984. Bellevue urban runoff program—summary report. Bellevue, Washington, City of Bellevue Storm and Surface Water Utility.

Pleus, A. E. 1999. A.E. Pleus, D. Schuett-Hames, and L. Bullchild. June 1999. TFW Monitoring Program: Method Manual for the Habitat Unit Survey. Northwest Indian Fisheries Commission.

Proposed May Creek Basin Action Plan, December 1998, King County Water and Land Resources Division.

Quinn T.P., S. Hodgson, and C. Peven. 1997. Temperature, flow, and the migration of adult sockeye salmon (Oncorhynchus nerka) in the Columbia River. Can. J. Fish. Aquat. Sci. 54:1349-1360.

Quinn, T. P., D. J. Adams. 1996. Environmental Changes Affecting the Migratory Timing of American Shad and Sockeye Salmon. Ecology 77:4:1151-1162.

Quinn, T., J. Peterson, and V. Gallucci. 2000. Trends in adult coho and chinook salmon life history at the University of Washington's hatchery. University of Washington School of Aquatic and Fisheries Sciences Draft Annual Report to Metro King County. Seattle, WA.

R2 Resource Consultants. 1998. Annotated bibliography of literature regarding mechanical injury with emphasis on effects from spillways and stilling basins. Final Report prepared for U.S. Army Corps of Engineers, Portland District.

R2 Resource Consultants. 1999. Habitat Survey, Sammamish River, King County, Washington, 1999 Data Report--Final, prepared for U.S. Army Corps of Engineers, Seattle District

R2 Resource Consultants. 2000. PIT tagging of juvenile salmon smolts in the Lake Washington basin: year 2000 pilot study results. Draft Final Report Prepared for U.S. Army Corps of Engineers, Seattle District, Lake Washington Ecosystem Restoration General Investigation Study.

R2 Resources. 2000. Historic and Current Status of Kokanee in the Lake Washington Basin. Discussion Draft Document. Prepared for King County Department of Natural Resources. Seattle, WA.

R2 Resource Consultants. 2001. PIT tagging of juvenile salmon smolts in the Lake Washington basin: year 2000 pilot study results. Final Report Prepared for U.S. Army Corps of Engineers, Seattle District, Lake Washington Ecosystem Restoration General Investigation Study.

Ralph, S. C. 1990. Timber-Fish-Wildlife Stream Ambient Monitoring Field Manual. Version 2.0. TFW-16E-90-004, Center for Streamside Studies, University of Washington, Seattle, Washington.

Rathbun, R. 1900. A Review of the Fisheries in the Contiguous Waters of the State of Washington and British Columbia. Report of the Commissioner for the Year Ending June 30, 1899. U.S. Comm. Fish and Fisheries 25:251-350.

Ratliff, D.E. 1992. Bull trout investigations in the Metolius River-Lake Billy Chinook system. In: Howell, P.J.; Buchanan, D.V., eds. Proceedings of the Gearhart Mountain bull trout workshop; 1992 August: Corvallis, OR. Oregon Chapter of the American Fisheries Society: 37-44.

Rauscher, K. 2001. Ken Rauscher (King County GIS) personnel communication (e-mail) to John Kerwin (Washington Conservation Commission).

Reimers, P.E. 1973. The length of residence of juvenile chinook salmon in Sixes River, Oregon. Research Report of the Fish Commission of Oregon 4(2):1-43.

Reiser, D.W. and T.C. Bjorn. 1979. Habitat requirements of anadromous salmonids. USDA Forest Service General Tech. Rept. PNW-96. 54 pp.

Report #2, Office of Naval Research, Contract N8onr-520/III, Project NR 083012, Restoration and management of lakes and reservoirs. Lewis Review of Biology 31(2):75-87.

Rice, G. 1960. Use of coldwater holding facilities in conjunction with king salmon spawning operations at nimbus hatchery. Inland Fisheries Administrative Report No. 60-3. Region 2, Inland Fisheries, California Department of Fish and Game. Sacramento, California.

Richey, J. S. 1982. Effects of Urbanization on a Lowland Stream in Western Washington, Seattle, 1982.

Richey, J. S., M. A. Perkins, and K. W. Malueg. "The Effects of Urbanization and Stormwater Runoff on the Food Quality in Two Salmonid Streams." Verh. Internat. Verein. Limnol., vol. 21, pages 812-818, Stuttgart, October, 1981.

Richter, Brian D., Baumgartner, Jeffrey V., Powell, Jennifer, and David P. Braun. 1996. A Method for Assessing Hydrologic Alteration within Ecosystems. Conservation Biology, 10 (4): 1163-1174.

Richter, Brain D., Baumgartner, Jeffrey V., Wigington, Robert and David P. Braun. 1997. How Much Water Does a River Need? Freshwater Biology, 37: 231-249.

Rieman, B.E. and John D. McIntyre. 1993. Demographic and Habitat Requirements for Conservation of Bull Trout. United States Department of Agriculture, Forest Service, Intermountain Research Station. General Technical Report INT-302. September 1993.

Rigg, G.B., 1958. Peat Resources of Washington. Washington State Dept. of Natural Resources, Olympia, WA.

Rogowski, D. 2000. Saltwater Intrusion in Salmon Bay and Lake Union Sediments, WDOE, Publication No. 00-03-032, Aug. 2000.

Rosgen, D. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs.

Rounsefell, G.A., and G.B. Kelez. 1938. The Salmon and Salmon Fisheries of Swiftsure Bank, Puget Sound and the Fraser River. U.S. Bur. Fish., Bull. 49:693-823.

Royal, L.A., and A. Seymour. 1940. Building New Salmon Runs, Puget Sound Sockeye Salmon Plantings Show Varying Degrees of Success. Prog. Fish. Cult. (Memo I-131) 52:7 p.

Ruggerone, G.T., T.P. Quinn, I.A. McGregor, and T.D. Wilkinson. 1990. Horizontal and vertical movements of adult steelhead trout, Oncorhynchus mykiss, in the Dean and Fisher channels, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 47:1963-1969.

Sauter, S.T. and A.G. Maule. 1997. The role of water temperature in the smolt physiology of chinook salmon. Presentation given at Columbia, Snake River mainstem water temperature workshop. Integrated ecosystem management of the Columbia River basin, November 6-7. Portland State University, Portland, Oregon.

Scarlett, W.J. and C.J. Cederholm. 1984. Juvenile coho salmon fall-winter utilization of two small tributaries of the Clearwater River, Jefferson County, Washington, p. 227-242. In: J.M. Walton and D. B. Houston (eds.). Proceedings of the Olympic Wild Fish Conference, March 23-25, 1983. Fisheries Technology Program, Peninsula College, Port Angeles, WA.

Schindler, D. 2000. Predation and temperature. Preliminary data presented at the workshop chinook salmon in the Greater Lake Washington Watershed. University of Washington, Seattle.

Scholz N., N. Truelove, B. French, B. Berejikian, T. Quinn, E. Casillas, and T. Collier. Diazinon disrupts antipredator and homing behaviors in chinook salmon *(Oncorhynchus tshawytscha*). Can. J. Fish. Aquat. Sci. Vol 57 2000.

Schreck, C.B. 1982. Stress and rearing of salmonids. Aquaculture 28: 241-249.

Schreck, C.B. 1992. Glucocortoids: metabolism, growth, and development. Pages 367-392 in M.P. Schreibman, C.B. Scanes, and P.K.T Pang, editors. The endocrinology of growth, development and metabolism in vertebrates. Academic Press, New York.

Schreck, C.B. and T.P. Stahl. 2000. Evaluation of migration and survival of juvenile salmonids following transportation. Annual Report 1998, Project MPE-W-9-4. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., J.C. Snelling, R.E. Ewing, C.S. Bradford, L.E. Davis, and C.H. Slater. 1994. Migratory behavior of adult spring chinook salmon in the Willamette River and its tributaries. Oregon Cooperative Fisheries Research Unit, Oregon State University, Corvallis, Oregon. Project Number 88-1160-3. Prepared for Bonneville Power Administration, Portland, Oregon.

Schreck, C.B., L.E. Davis, and C. Seals. 1996. Evaluation of procedures for collection, bypass, and transportation of outmigrating salmonids, Objective 1: Migratory behavior and survival of yearling spring chinook salmon in the lower Columbia River estuary. Draft Annual Report 1996, Project MPE-96-10. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Schreck, C.B., L.E. Davis, and C. Seals. 1997. Evaluation of migration and survival of juvenile salmonids following transportation. Draft Annual Report 1997, Project MPE-95-3. U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington

Schreck, C.B., R. Patino, C.K. Pring, J.R. Winton, and J.E. Holway. 1985. Effects of rearing density on indices of smoltification and performance of coho salmon, *Oncorhynchus kisutch*. Aquaculture 45: 345-348.

Schuett-Hames, Dave; Allen E. Pleus; Jim Ward; Martin Fox; and Jeff Light. June 1999. TFW Monitoring Program: Method Manual for the Large Woody Debris Survey. NW Indian Fisheries Commission.

Schuett-Hames, Dave; Robert Conrad; Allen E. Pleus; and Michael McHenry. June 1999. TFW Monitoring Program: Method Manual for the Salmonid Spawning Gravel Composition Survey. NW Indian Fisheries Commission.

Schulze, Doug, City of Medina grant application for Medina Stream No. 0257 Restoration, October 15, 1999.

Scott, J., C. R. Steward, Q. J. Stober. 1982. Impacts of urban run-off on fish populations in Kelsey Creek, WA.

Scott, J. B., C. R. Steward, and Q. J. Stober. 1986. Effects of urban development on fish population dynamics in Kelsey Creek, Washington. Transactions of the American Fisheries Society 115:555-567.

Scrivener, J.C. and B.C. Andersen. 1982. Logging impacts and some mechanisms which determine the size of spring and summer populations of coho salmon fry in Carnation Creek, p. 257-272. In: G.F. Hartman (ed.) Proceedings of the Carnation Creek Workshop: a ten year review. Pacific Biological Station, Nanaimo, BC.

Seattle Drainage and Wastewater Utility. 1995. 1995 Comprehensive drainage plan update, Seattle, WA.
Seattle Public Utilities 1995-96 stream habitat surveys. Unpublished data.
Seattle Public Utilities GIS. Unpublished data.
Seattle Public Utilities Pipers Creek Watershed Action Plan For the Control of Nonpoint Source Pollution. Final Action Plan, August 1990.
Seattle Public Utilities Pipers Creek Watershed Action Plan. 1999 Community/Agency Review and Course Corrections. Final Report, March 2000.
Seattle Public Utilities. Habitat surveys 1995-96. Unpublished data.
Seattle Public Utilities. 1998. Unpublished water quality data.
Seattle, City of. 1999. Draft Cedar River Habitat Conservation Plan. Seattle, WA
Seiler, Dave. Washington Department of Fish and Wildlife. Resource Sensitive Areas Notebook, riparian corridor inventory data sheets.
Serdar, D., J. Cubbage, & D. Rogowski. 2000. Concentrations of Chemical Contaminants and Bioassay Response to Sediments in Salmon Bay, Seattle: Results of Phase III Sampling, WDOE, Publication No. 00-03-053, Dec. 2000.
Serl, J.D. 1999. The response of stream fish communities of Lake Washington *Services (GIS).*
Seymour, A.H. 1956. Effects of temperature upon young chinook salmon. Ph.D. Thesis. University of Washington, Seattle, Washington. 127 pp.
Shapiro and Associates, 1998. Proposed May Creek Basin Action Plan.
Shapovalov, L., and A.C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Onchorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Dep. Fish Game Fish Bull. 98, 375 p.
Simenstad, C.A. and E.O. Salo. 1982. Foraging success as a determinant of estuarine and near-shore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington, p. 21-37. In: B.R. Meltreff and .A. Neve (eds.) Proceedings of the North Pacific Aquaculture Symposium. Alaska Sea Grant Rep. 82-2.
Simenstad, C.S., J. Cordell, and R. Thom. 1999. Preliminary Lake Washington Ship Canal-Shilshole Bay juvenile salmon habitat assessment. Draft Letter Report Prepared for King County Metro.
Simmonds, R. and Purser, M. Unpublished data on Snohomish County sub-basins total impervious surface area and vegetation class land cover. Snohomish County Surface Water Management, Everett, WA.
Sisson, L. 2000. Personnel Communication from Larry Sisson (WDFW), Lake Whatcom SFH to John Kerwin (Washington Conservation Commission).
Skelley and Loy Engineers Consultants. February, 1985. Abandoned Coal Mine Survey-Coal Creek, King County, Washington: Final Report, vol. 1.
Sloane-Richey, J.S., Perkins, M.A., and Malueg, K.W. 1981. The effects of urbanization and stormwater runoff on the food quality of two salmonid streams. Internation. Vere. Limnol. Verhan. 21: 812-818.
Smith, V. and T. Thompson 1927. Salinity Of The Lake Washington Ship Canal
Snohomish County Planning and Development Services, Everett, WA. Unpublished data on nearshore tributary stream habitat surveys, including observations of fish conducted from 1985-1987.

Snohomish County Public Works Surface Water Management (SCSWM). 1994b. North Creek Watershed Management Plan and Technical Supplement. North Creek Watershed Management Committee.

Snohomish County Public Works Surface Water Management (SCSWM). 1994a. Swamp Creek Watershed Management Plan and Technical Supplement. Swamp Creek Watershed Management Committee.

Snohomish County Public Works. 1988. Snohomish County watershed ranking project. Final report to Washington State Department of Ecology, Centennial Clean Water Fund (grant number TAX88017).

Snyder, G. R., and T. H. Blahm. 1971. Effects of Increased Temperature on Cold-Water Organisms. Journal of the Water Pollution Control Federation 43:5:890-899.
Sound lowland streams. Masters thesis. University of Washington, Seattle, WA.

Spearman Engineering. October, 1997. Sustainable Flood Damage Protection Plan for the Skagit Key Reach of Coal Creek. p. 40-41.

Spence, Brian C., Gregg A. Lomnicky, Robert M. Hughes, and Richard P. Novitzki. December 1996. An Ecosystem Approach to Salmonid Conservation. Management Technology.

Stabler, D.F. 1981. Effects of altered flow regimes, temperatures, and river impoundment on adult steelhead trout and chinook salmon. Master of Science thesis, University of Idaho.

State of Washington, 1997, Water quality standards for surface waters in the State of Washington: Olympia, WA, WAC 173-201A-040.

Stickney, A.E. and L. McDonald. 1977. Squak Slough, 1870-1920. Evergreen Printing Company, Seattle, WA

Sturtevant, Pete. Dec. 2000. Technical Memorandum. Draft Coal Creek Stream Stabilization- Recommendations. Survey Draft Report). Prepared for King County Department of Public \Works Surface Water Management Division.

Swarts, Scott, David Evans and Associates, Personal Communication on electroshocking results for permit application for project # PUD-98-1496, 4/27/99.

Tabor, R, F. Mejia, D. Low, B. Footen, and L. Park. 2000. Predation of juvenile salmon by littoral fishes in the Lake Washington-Lake Union Ship Canal. Paper presented at the Lake Washington chinook salmon Workshop, November, 2000.

Tabor, R. and B. Footen 2000. Predation of Juvenile Salmon by Littoral Fishes in the Lake Washington - Lake Union Ship Canal, Preliminary Result, King

Tabor, R., B. Pfeifer, C. Whitmus, and G. Maxwell, and E.E. Knudsen. 1994. Sonic tagging and tracking of wild winter steelhead at the Ballard Locks, Seattle, Washington. Western Washington Fishery Resource Office, U.S. Fish and Wildlife Service, Olympia.

Taylor and Associates. 2000. Unpublished fish capture and removal data from Technical Report for the Lake Washington Watershed.

The Watershed Company. 1988. Lewis Creek Fish Habitat: Description and Assessment.

The Watershed Company. 1988. Lewis Creek Sedimentation/Erosion Study: Survey Results.

The Watershed Company. 1989. Lewis Creek Electrofishing Survey Results.

The Watershed Company. 1992. Lewis Creek Fish Habitat and Population Assessment Preceding Lakemont Division Four. June, 1992.
their downstream migration in the Green River, Washington

Thomas, G.L. 1992. The fish assemblage of Pipers Creek, Seattle, Washington. Interim report to Municipality of Metropolitan Seattle (METRO). March 1992.

Thornburgh, K. and Williams, G. 2000. The state of the waters: Water quality in Snohomish County's rivers, streams and lakes-2000 assessment. Snohomish County Public Works Surface Water Management. Everett, WA.

Thornton Creek Watershed Characterization Report 2000. Report prepared by Thornton Creek Watershed Management Committee under the direction of Seattle Public Utilities. November, 2000.
to Katherine Lynch (Seattle Public Utilities).

Tobin, C. and L. F. Pendergrass. 1993 [updated 1997]. Bellevue historic and cultural resources survey. City of Bellevue Design and Development Department.

Toft, J. (in preparation). Shoreline and dock modifications in Lake Washington. Prepared by the Wetland Ecosystem Team, Universiyt of Washington, School of Aquatic and Fishery Sciences for King County Department of Natural Resources.

Tomlinson, R. et al. 1977. A Baseline Study of the Water Quality and Sediments

Trimble, S.W. 1997. Contribution of stream channel erosion to sediment yield from an urbanizing watershed. Science 278: 1442-1444.

U.S. Geological Survey, Fact Sheet , #097-99, 4/99. Webpage address http://wa.water.usgs.gov/ps.nawqa.html

U.S. Army Corps of Engineers Portland and Walla Walla Districts (USACE). 1996. Dissolved gas abatement study, Phase I. U.S. Army Corps of Engineers Portland District and Walla Walla District. Portland, Oregon, and Walla Walla, Washington. 111 pp.

U.S. Army Corps of Engineers Portland District. 1997. Detailed statement of work for mechanical injury compendium. Contract Number DACW57-96-D-0007, Task Order Number 0003. U.S. Army Corps of Engineers Portland District, Portland, Oregon. 5 pp.

U.S. Army Corps of Engineers Seattle District. 1972. Lake Washington Ship Canal Design Memorandum No. 3: Fish Ladder Rehabilitation. Seattle District, Seattle, Washington.

U.S. Army Corps of Engineers Seattle District. 2000. White paper on fish passage at the Lake Washington Ship Canal. Draft report. U.S. Army Corps of Engineers, Seattle District.

U.S. Army Corps of Engineers, 1997. Final Environmental Assessment, Sammamish Weir 1135 Habitat Restoration, Redmond, Washington

U.S. Department of Interior, 1859. U.S. Bureau of Public Lands Survey

U.S. Environmental Protection Agency. 1971. Columbia River Thermal Effects Study. Volume I. Biological Effects Study. In cooperation with the Atomic Energy Commission, the National Marine Fisheries Service, and the U.S. Department of Commerce.

U.S. Geological Survey, Water Resources Data for Washington. http://wa.water.usgs.gov/waterdata.html .

U.S. Soil Conservation Service, King County, 1973.

University of Washington Center for Urban Water Resources Management Annual Stream Temperature Survey, 1998-2000. Unpublished data. University of Washington Department of Civil & Environmental Engineering.

Unknown Author. 1992. Unknown Author of spreadsheet titled Estimation of Irrigation Requirements for Lake Washington and Sammamish Lake Waterfront Properties to Ms. Linda Pilkey-Jarvis, WDOE) dated 12/30/92.

URS Corporation. 1987 North Village: Lewis Creek Habitat Survey,.

US Army Corps of Engineers Seattle District. 1999. Lake Washington Ship Canal Smolt Passage Section 1135 Restoration Project Seattle, Washington: Ecosystem Restoration Report/Environmental Assessment. Final Report Prepared 31 August 1999 by Seattle District.

Vanderhoof, J. January 2001.1998 and 1999 Volunteer Salmon Watcher Program in the Lake Washington Watershed.

Vanderhoof, Jennifer, Elissa Ostergaard, and Donna M. Gleisner. 2000. 1997 Volunteer Salmon Watcher Program in the Lake Washington Watershed.

Vanderhoof, Jennifer. January 2001. 1998 and 1999 Volunteer Salmon Watcher Program in the Lake Washington Watershed.

VanRijn, D. 2001. Cold water refuge at the Locks. Technical Report prepared

Verhoeven, L.A., and E.B. Davidoff. 1962. Marine tagging of Fraser River sockeye salmon. Int. Pac. Salmon Fish. Comm. Bull. 13. 132 p.

Vernon, E.H., A.S. Hourston, and G.A. Holland. 1964. The migration and exploitation of pink salmon runs in and adjacent to the Fraser River convention area in 1959. Int. Pac. Salmon Fish. Comm. Bull. 15. 296 p.

Voss, F.D., S.S. Embrey, J.C. Ebbert. 1997. Pesticides detected in urban streams during rainstorms and relations to retail sales of pesticides in King County, Washington. US Geological Surveys fact Sheet 097-99.

Voss, Frank and Sandra Embrey. 2000. Pesticides detected in urban streams during rainstorms in King and Snohomish Counties, Washington 1998. U.S. Geological Survey, Tacoma WA. October 2000.

Wakeham, S.G. 1977. Hydrocarbon budgets for Lake Washington. Limnology and Oceanography 22: 952-957.

Waller, T.N., T.L. Fagenberg, and D.C. McVan. 1998. Prototype evaluation of Lake Washington Ship Canal Navigation Lock, Seattle, Washington. U.S. Army Corps of Engineers, Waterways Experiment Station, Technical Report CHL-98, prepared for Seattle District. Vickburg, Mississippi.

Walters, C.J., R. Hilborn, R.M. Peterman, and M.J. Staley. 1978. Model for examining early ocean limitation of Pacific salmon production. Journal of the Fisheries Resource Board of Canada 35:1303-1315.

Warner, E. and K. Fresh. 1999. Draft Lake Washington Chinook Salmon Recovery Plan. Technical Review Draft dated March 25, 1999.

Warner, E. J., and T. P. Quinn. 1995. Horizontal and vertical movements of telemetered rainbow trout (*Oncorhynchus mykiss*) in Lake Washington. Canadian Journal of Zoology 73:146-153.

Warner, E.J., and K.L. Fresh.1998. Technical review draft: Lake Washington Chinook salmon recovery plan. Muckleshoot Indian Tribe and Washington Department of Fish and Wildlife. March 25, 1998. 141pp.

Warner, Eric. Personal Communication, 11/13/00.

Washington Department of Ecology. 1997. Statewide water quality assessment report 1996.

Washington Department of Ecology. 2000. Washington Department of Ecology 303d list at: www.ecy.wa.gov/programs/wq/303d/1998%20303(d)/wrias/wria8

Washington Department of Ecology. 1998. 1998 Final 303(d) Report. http://www.ecy.wa.gov/programs/wq/303d/wrias/wria8.pdf
Washington Department of Fish and Wildlife Gamefish Releases. Unpublished data
Washington Department of Fish and Wildlife Salmon Spawning Ground Surveys.
Washington Department of Fish and Wildlife. 1996. *Facilities Master Plan for the Issaquah Fish Hatchery*. July 1996. Olympia, WA. 71 p. plus appendices.
Washington Department of Fish and Wildlife. 1996. Ballard Locks 1996 smolt passage assessment: Summary Statement. Report prepared by Fish Management Section, Olympia,
Washington Department of Fisheries. 1971. Letter to the Seattle District U.S. Army Corps of Engineers. Printed as an Attachment to USACE 1972.
Washington Dept. Fish and Wildlife and Western Washington Treaty Indian Tribes. 1994. 1992 Washington State Salmon and Steelhead Stock Inventory. Appendices. Olympia, WA
Washington Dept. Fish and Wildlife. 1998. Salmonid Stock Inventory. Appendix Bull Trout and Dolly Varden. Olympia, WA 437 p.
Washington State Department of Ecology. 1998. Needs Assessment for the Cedar/Green Water Quality Management Area
Washington Trout and Seattle Public Utilities. Urban Creek Watershed Analysis.
Washington Trout/Seattle Public Utilities Watershed Analysis. Biological and physical analysis of six urban creek watersheds in Seattle initiated in 1999. Study in progress.
Water Resource Inventory Area 08, Technical Committee Chinook Distribution Map, 2000. Watershed Company. 1998. Kirkland's Streams, Wetlands and Wildlife Study watershed to various magnitudes of urbanization.
WDFW and WWTIT. 1994. Salmonid and Steelhead Stock Inventory. Appendix 1, South Puget Sound Volume. 371 p.
WDFW. 1998. Salmonid Stock Inventory (SaSI) Bull Trout/Dolly Varden. Washington Department of Fish and Wildlife. Olympia, WA
WDFW. 2001. Internal Memorandum from James B. Shaklee and Sewell Young to Bill Hopley. Preliminary Microsatellite DNA Results for Lake Washington and Lake Sammamish *O. nerka.* 2 p. plus attachments.
WDFW. 2000. Salmonid Stock Inventory Coastal Cutthroat. A. Blakley, B. Leland and J. Ames - eds. Washington Department of Fish and Wildlife. Olympia, WA 267 p.
WDG. Undated and unpublished file data.
Weaver, M.J., J.J. Magnuson, and M.K. Clayton. 1997. Distribution of littoral zone fishes in structurally complex marcrophytes. Canadian Journal of Fisheries and Aquatic Sciences 54:2277-2289.
Weaver, T.M. and R.G. White. 1985. Coal Creek fisheries monitoring study No. III. Quarterly progress report. Bozeman, MT. U.S. Department of Agriculture, Forest Service, Montana State Cooperative Fisheries Research Unit. 94 p.Washington Dept. Fisheries, Washington Dept. Wildlife, and Western Washington Indian Tribes. 1993. 1992 Washington State salmon and steelhead stock inventory. Olympia, WA 212 p.
Weiss, J.S., P. Weis, and T. Proctor. 1998. The extent of benthic impacts of CCA-treated wood structures in Atlantic coast estuaries. Arch. Contam. Toxicol. 34: 313-322.
Weitkamp, D. E., G.T. Ruggerone, L. Sacha, J. Howell, and B. Bachen. 2000. Factors Affecting Chinook Populations, Background Report. Report Prepared by Parametrix, Inc., Natural Resources Consultants, Inc. and Cedar River Associates. 224 p.
Weitkamp, D., G. Ruggerone, L. Sacha, J. Howell, and B. Bachen. 2000. Factors

Affecting Chinook Populations, Background Report.
Weitkamp, L.A., T.C. Wainwright, G.J. Bryant, G.B. Milner, D.J. Teel, R.G. Kope, and R.S. Waples. 1995. Status review of coho salmon from Washington, Oregon and California. NOAA Technical Memorandum NMFS-NWFSC-24. 258 pp.
Welch, D.W., A.I. Chigirinsky, and Y. Ishida. 1995. Upper thermal limits on the oceanic distribution of Pacific salmon (*Oncorhynchus spp.*) In the spring. Can. J. Fish. Aquat. Sci. 52:489-503.
Wendler, H.O. 1958. Migration and fishing mortality rates of Columbia River spring chinook salmon in 1955. Washington Dept. of Fisheries, Fish Res. Pap. 2:71-81.
Western Washington Treaty Tribes. 1993. 1992 Washington State salmon and steelhead stock inventory. Olympia, Washington. 211pp.
Wetherall, J.A. 1971. Estimation of survival rates for chinook salmon during
Wetherbee, P. and D. Houck. 2000. Reconnaissance Analysis of Water Quantity and Quality Trends in the Lake Washington Watershed. Presentation and Extended Abstract presented at the Workshop -- Chinook Salmon in the Greater Lake Washington Watershed. HDR, Inc. and King County Department of Natural Resources, Wastewater Treatment Division.
Whitmore, C.M., C.E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Transactions of the American Fisheries Society 89: 17-26.
Williams, R. W., R.M. Laramie and J.J. Ames. 1975. A catalog of Washington streams and salmon utilization. Volume 1, Puget Sound Region. Olympia, Washington Department of Fisheries.
Williams, R.N., L.D. Calvin, C.C. Coutant, M.W. Erho, J.A. Lichatowich, W.J. Liss, W.E. McConnaha, P.R. Mundy, J.A. Stanford, R.R. Whitney, D.L. Bottom, and C.A. Frissell. 1996. Return to the river: restoration of salmonid fishes in the Columbia River ecosystem. Report by the Independent Scientific Group to the Northwest Power Planning Council. Portland, OR. 584 pp.
Wilson, Andersen, Buckley and Henderson, 2001. "Sammamish River Irrigation Return Flow Water Sample". Unpublished report, King County Water and Land Resources Division
Wilson, D., H. Andersen, J. Buckley, S. Embrey, S. Magoon. 2000. Small Streams Toxicity/Pesticide Study, King County Washington. Presented at the 20th Annual Society of Environmental Toxicology and Chemistry meeting. Nashville, TN.
Wissmar, R.C. and C.A. Simenstad. 1997. Variability of riverine and estuarine ecosystem productivity for supporting Pacific salmon. In Change in Pacific Northwest Coastal Ecosystems: Pacific Northwest Coastal Ecosystems Regional Study, ed. G.R. McMurray and R.J. Bailey, pages 253-301, , Dept. of Commerce, National Oceanic and Atmospheric Administration, Decision Analysis Series no. 11.
Wood, C.C. 1995. Life history variation and population structure in sockeye salmon. Pages 195-216 in J.L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17: Bethesda, MD
Woodey, J. 1972. Distribution, feeding, and growth of juvenile sockeye salmon in Lake Washington. Ph.D. Dissertation, University of Washington, Seattle.
WRIA 8 Local Government Staff. 1999. Draft Subarea Summary for the Lower Cedar River (from Landsburg Dam to Mouth at Lake Washington)

Wydoski, R.S. and R.R. Whitney. 1979. Inland Fishes of Washington. University of Washington Press. Seattle, WA.

Wydzga, A. 1997. Effects of urbanization on fine sediment deposition in Puget Sound lowland streams. Masters thesis. University of Washington, Seattle, WA.

Young, C; Elissa Ostergaard, and Ken Ludwa. 1995. Abundance of Spawning Kokanee in the Sammamish River Basin:1994 Status Report.

Young, C. 2000. Snohomish County Surface Water Management, Everett, WA. Personal communication to Frank Leonetti (Snohomish County), 12/29/2000.

Young, S.F., M.R. Downen and J.B. Shaklee. 2001. A microsatellite DNA based characterization of Lake Washington/Lake Sammamish kokanee and sockeye salmon with notes on distribution, timing and morphology. Washington Department of Fish and Wildlife. Olympia, WA 17 pages plus 4 figures.

Yurk, H. and A.W. Trites. 2001. Experimental attempts to reduce predation by harbor seals on out-migrating juvenile salmonids. Transactions of the American Fisheries Society 129:1360-1366.

Zaugg, W.S. 1981. Relationships between smolt indices and migration in controlled and natural environments. Pp. 173-183 in: E.L. Brannon and E.O. Salo (eds.) Salmon and Trout Migratory Behavior Symposium. University of Washington, Seattle, WA.

APPENDIX A

Figures Depicting the Known and Potential Distribution of Salmonids in the Cedar – Sammamish Basin (WRIA 8)

APPENDIX B

Habitat types in the nearshore environment of WRIA 8

APPENDIX C

Upper Cedar River Land Cover Figures

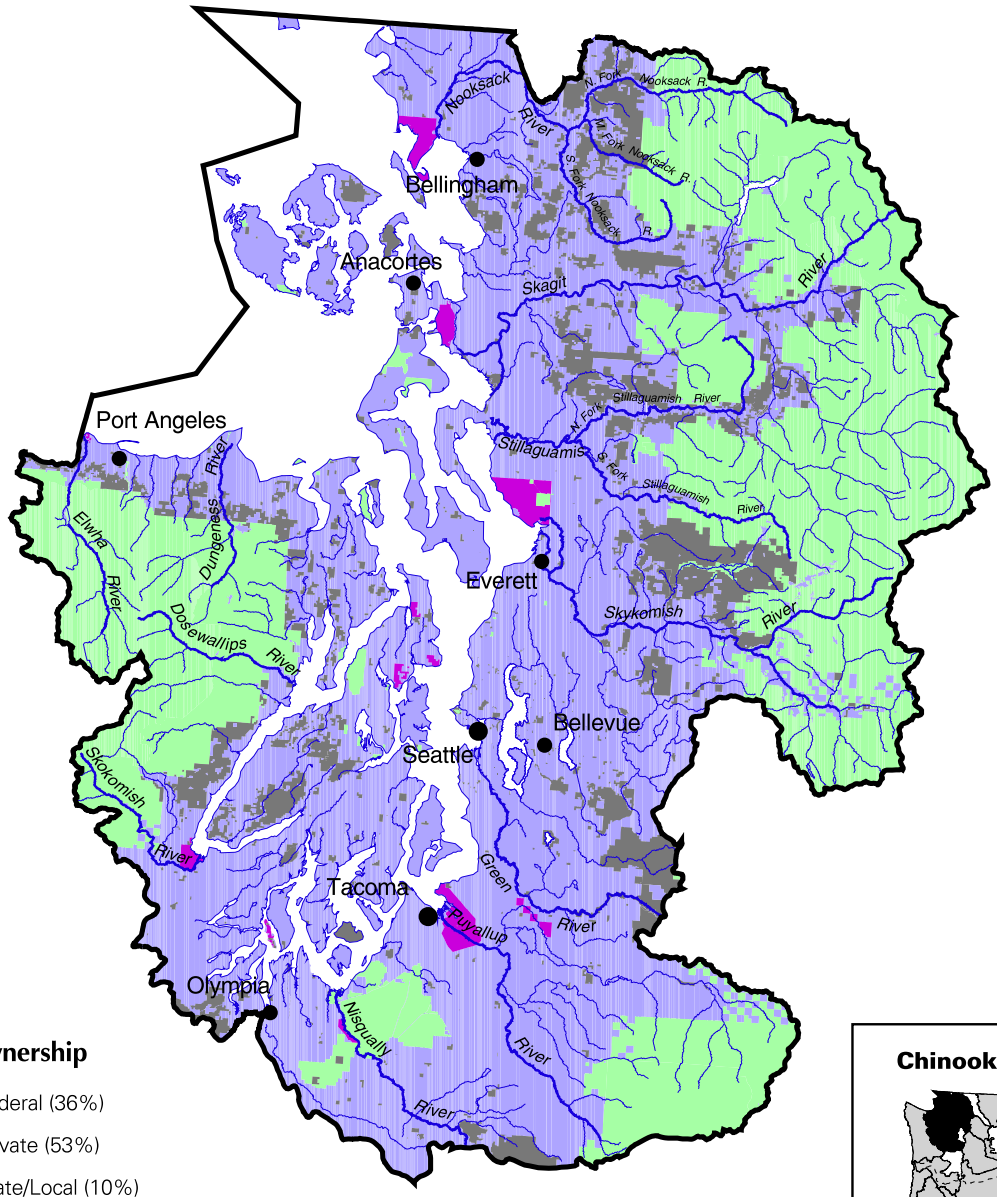
APPENDIX D

Known barriers to the movements of juvenile and adult salmonids in the Cedar – Sammamish Basin (WRIA 8)

APPENDIX E

National Marine Fisheries Service
Puget Sound ESUs

PUGET SOUND
CHINOOK SALMON ESU



Land Ownership

- Federal (36%)
- Private (53%)
- State/Local (10%)
- Tribal (1%)

Note: Map is for general reference only.

United States Department of Commerce
National Oceanic & Atmospheric Administration
NATIONAL MARINE FISHERIES SERVICE
HABITAT CONSERVATION DIVISION
525 N.E. Oregon St., Suite 410
Portland , OR 97232
Tel (503) 231-2223

Scale:

10 0 10 20 30 Miles

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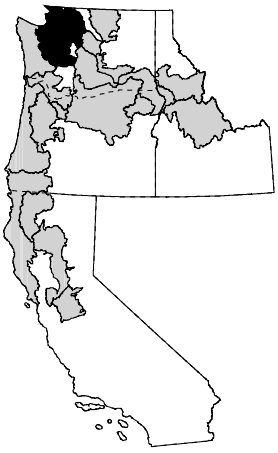
MAP DATE: 2/11/99

CREATED BY: D.H.
HCDGIS\RGN\WS\STONE\CHIN

Chinook Salmon ESUs



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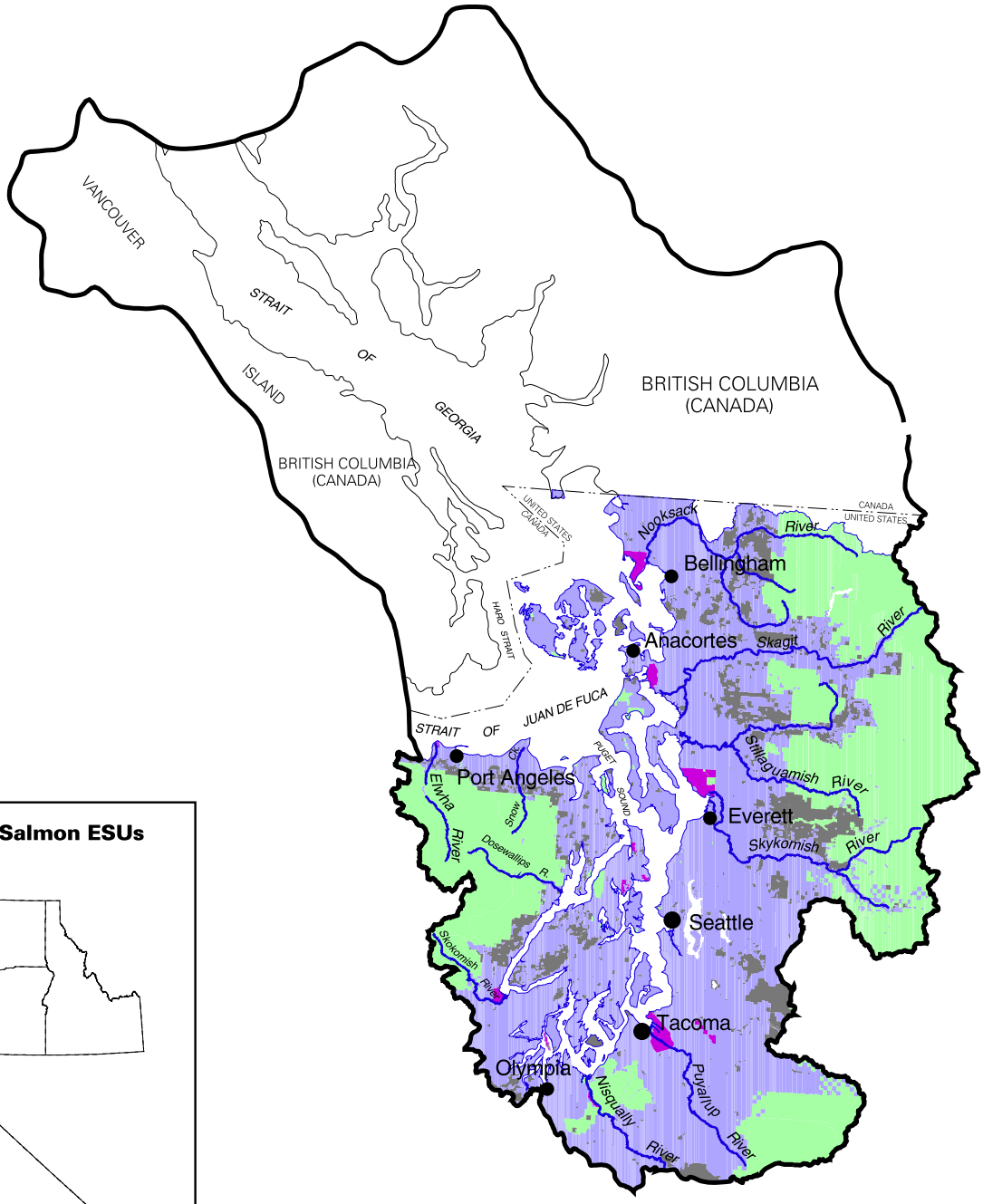
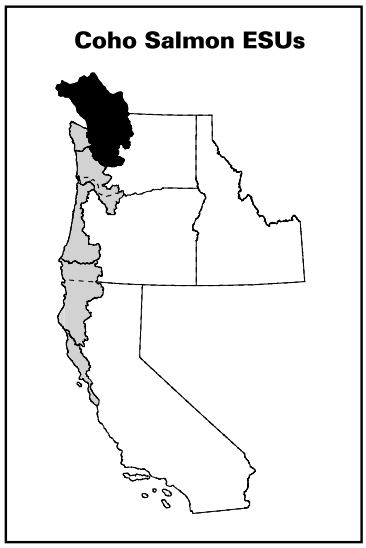
COHO SALMON ESU





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Scale:

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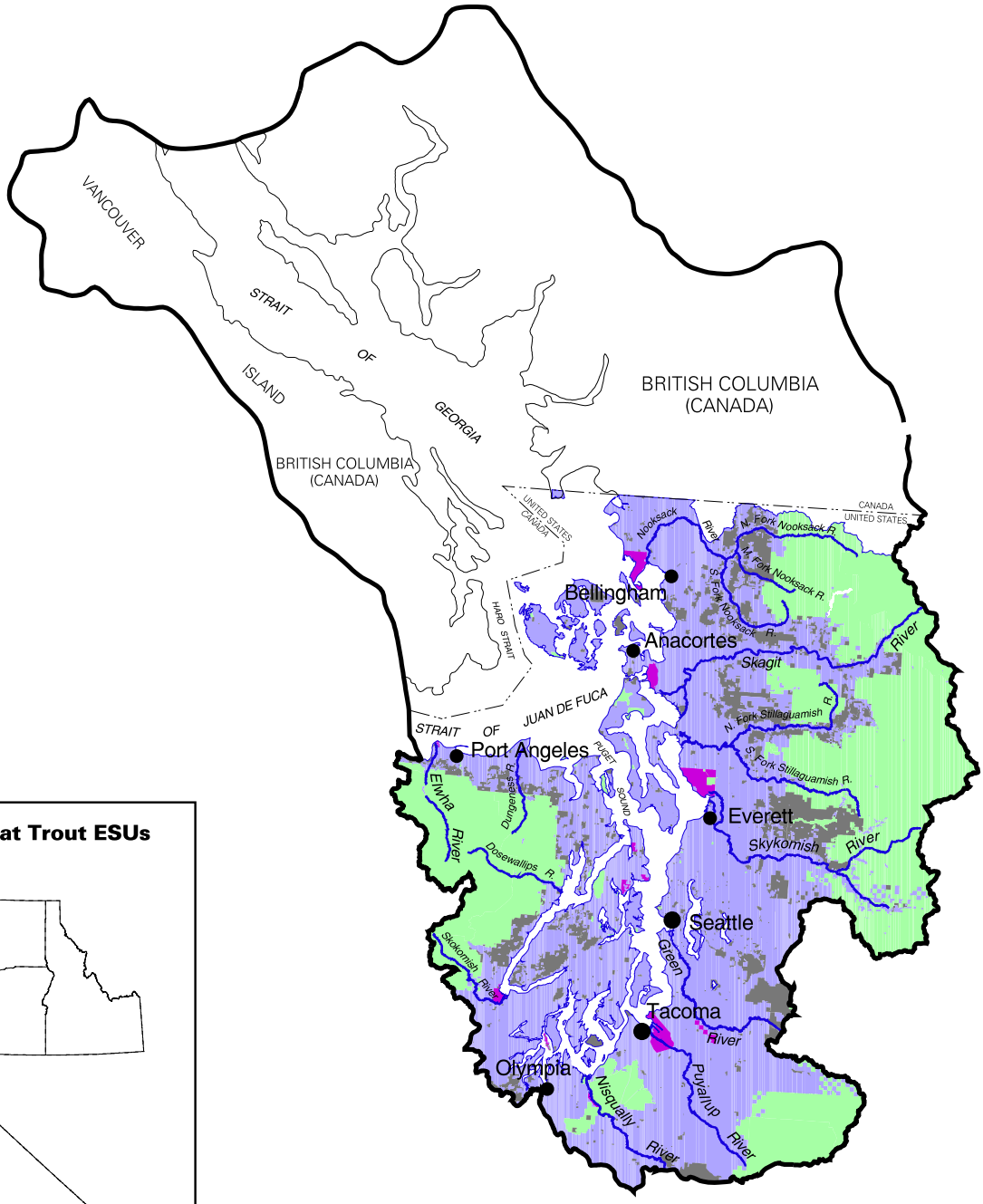
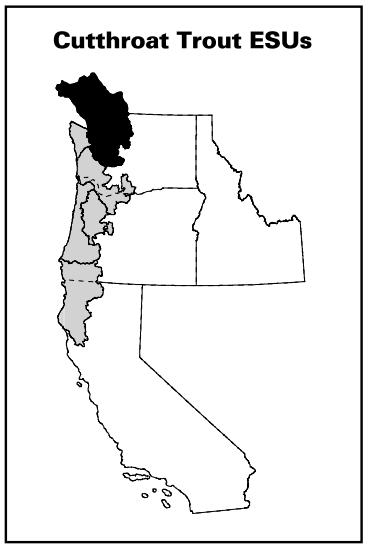
PUGET SOUND
CUTTHROAT TROUT ESU





Land Ownership

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Scale:

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MAP DATE: 2/11/99

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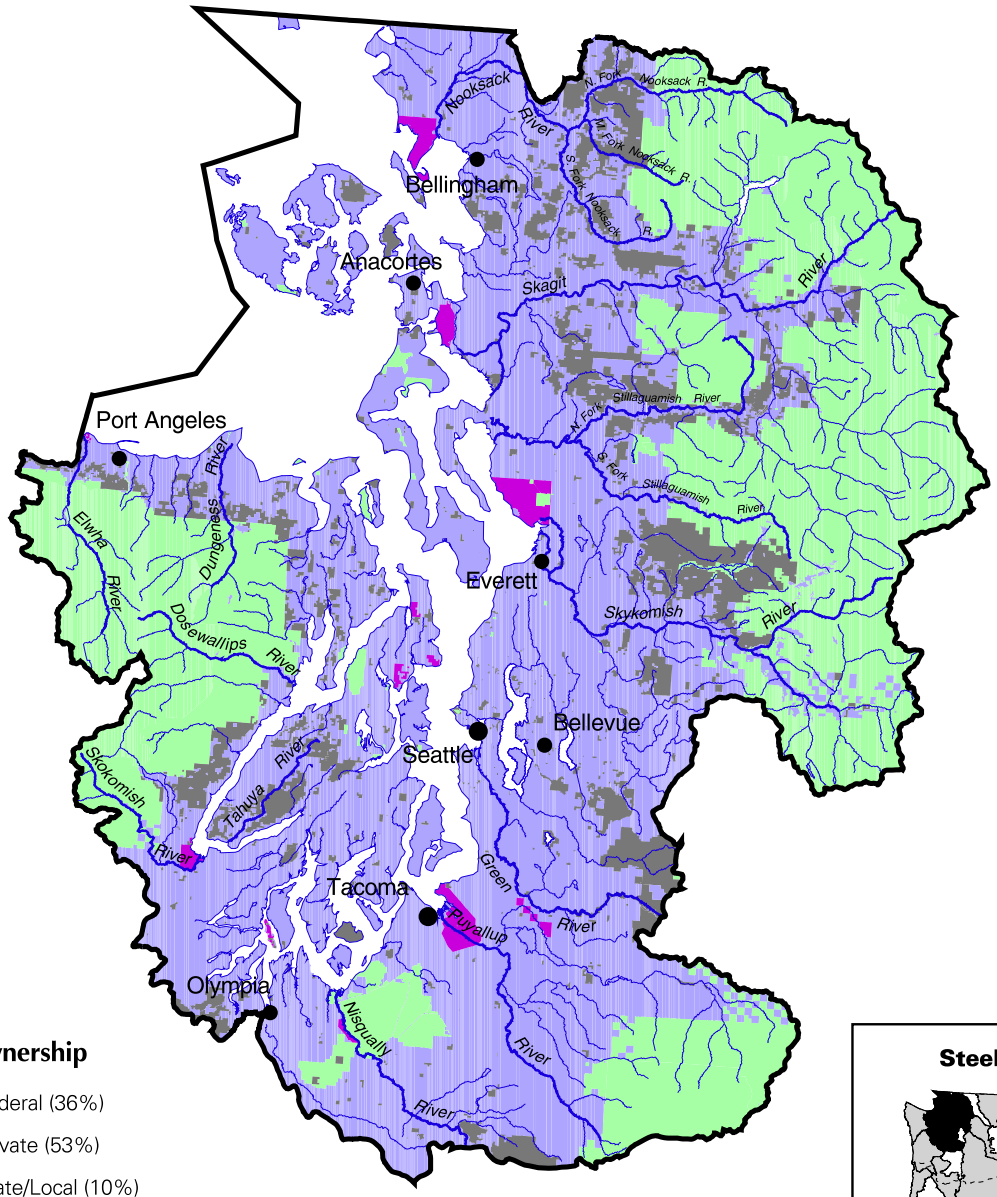
Note: Map is for general reference only.

PUGET SOUND STEELHEAD ESU



Land Ownership

- Federal (36%)
- Private (53%)
- State/Local (10%)
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Note: Map is for general reference only.

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Scale:

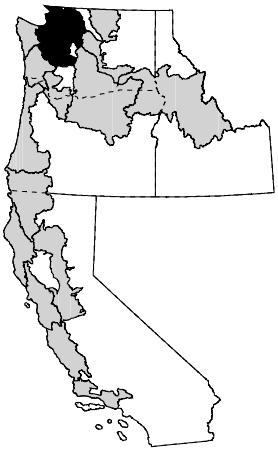
10 0 10 20 30 Miles

10 0 10 20 30 Kilometers

MAP DATE: 2/11/99

CREATED BY: D.H.
HCDGIS\RGN\WS\STONE\STEEL

Steelhead ESUs



APPENDIX F

Figures and Appendices

to

SCREENING LEVEL ANALYSIS OF 3RD ORDER AND HIGHER WRIA 8 STREAMS FOR CHANGE IN HYDROLOGIC REGIME

Appendix 1

Table I-1, Land Cover

Drainage Areas	DRAINAGE (SQ MI) AREA (SQ MI)	Stream Scale	% EIA	%FOREST	%GRASS /SHRUB	%WATER /WETLAND
Upper Cedar (above SPU diversion)	120.9	River	3.8%	84.8%	8.8%	2.6%
Walsh	6.6	3rd Order Stream	4.0%	82.8%	8.6%	4.7%
Lower Rock	12.9	3rd Order Stream	1.6%	71.1%	22.5%	4.8%
Cedar North Rural	7.5	Multiple Drainages	9.6%	63.5%	25.3%	1.7%
Cedar Main Rural	7.0	Multiple Drainages	9.6%	70.1%	20.1%	0.3%
Upper and Rural Cedar @ approx SE 209th	154.8	River	4.2%	81.9%	11.3%	2.7%
Peterson	6.4	3rd Order Stream	3.8%	74.5%	15.8%	5.9%
Cedar North Urban Tribs	2.8	Multiple Drainages	20.6%	41.6%	37.4%	0.4%
Cedar South Urban Tribs	5.0	Multiple Drainages	21.9%	40.8%	35.0%	2.3%
Cedar Main Urban	13.9	Multiple Drainages	20.9%	48.0%	29.3%	1.9%
Cedar River @ Mouth	182.9	River	6.2%	77.3%	13.8%	2.7%
Upper Issaquah	14.9	3rd Order Stream	4.0%	84.9%	10.9%	0.1%
Middle Issaquah	7.2	Multiple Drainages	7.3%	73.7%	17.4%	1.5%
Middle and Upper Issaquah	22.1	4th Order Stream	5.1%	81.3%	13.0%	0.6%
McDonald	5.1	3rd Order Stream	8.7%	71.1%	19.9%	0.3%
Fifteenmile	4.8	3rd Order Stream	3.9%	88.0%	8.1%	0.0%
East Fork Issaquah	9.4	3rd Order Stream	8.0%	80.2%	11.7%	0.1%
North Fork Issaquah	4.6	3rd Order Stream	18.2%	52.6%	27.2%	2.0%
Lower Issaquah	10.1	Multiple Drainages	9.2%	71.2%	18.3%	1.3%
Issaquah Basin	56.1	4th Order Stream	7.6%	76.6%	15.1%	0.7%
Tibbetts	5.4	3rd Order Stream	9.8%	75.8%	13.9%	0.5%
East Lake Sammamish Tribs	15.6	3rd Order Streams	15.2%	49.8%	29.2%	5.9%
West Lake Sammamish Tribs	12.1	Multiple Drainages	22.7%	36.5%	38.5%	2.3%
Lake Sammamish	7.6	Lake/Wetland	2.7%	5.3%	3.8%	88.2%
Sammamish at Weir	96.7	River	10.5%	61.6%	19.4%	8.6%
Cottage Lake	12.9	3rd Order Stream	13.4%	55.6%	28.8%	2.2%
Evans	15.2	3rd Order Stream	13.2%	56.9%	25.7%	4.2%
Upper Bear	13.4	3rd Order Stream	9.1%	68.7%	20.4%	1.8%
Lower Bear	8.2	Multiple Drainages	18.6%	44.2%	36.4%	0.7%
Big Bear Creek near Mouth	49.6	4th Order Stream	13.0%	57.7%	26.8%	2.5%
Upper Sammamish Valley	13.8	Multiple Drainages	24.9%	32.7%	42.1%	0.4%
Sammamish River at NE 136th St	160.2	River	12.5%	57.9%	23.6%	6.0%

Drainage Areas	DRAINAGE (SQ MI) AREA (SQ MI)	Stream Scale	% EIA	%FOREST	%GRASS /SHRUB	%WATER /WETLAND
Little Bear	15.0	3rd Order Stream	17.0%	51.9%	30.9%	0.2%
Upper North	13.3	3rd Order Stream	25.7%	34.1%	38.6%	1.6%
Lower North	15.2	Multiple Drainages	21.6%	41.3%	36.7%	0.3%
North at Mouth	28.5	3rd Order Stream	23.5%	37.9%	37.6%	0.9%
Upper Swamp	11.6	3rd Order Stream	25.5%	37.6%	35.7%	1.3%
Lower Swamp	12.6	Multiple Drainages	27.0%	34.0%	38.5%	0.4%
Swamp at Mouth	24.2	3rd Order Stream	26.3%	35.7%	37.2%	0.8%
Lower Sammamish Valley	12.1	Multiple Drainages	22.2%	40.4%	37.0%	0.4%
Sammamish River at Mouth	240.1	River	16.0%	52.0%	27.8%	4.2%
North Lake Washington	1.8	Small Drainage	24.1%	34.6%	40.8%	0.6%
Lyons	4.2	3rd Order Stream	23.8%	34.0%	41.6%	0.6%
McAleer	8.3	3rd Order Stream	30.5%	26.3%	40.9%	2.2%
Thornton	11.3	3rd Order Stream	31.9%	22.4%	45.0%	0.7%
Green Lake	13.2	3rd Order Stream	33.2%	18.1%	44.2%	4.4%
West Lake Washington	15.1	Multiple Drainages	32.2%	20.3%	44.9%	2.5%
East Lake Washington	21.0	Multiple Drainages	24.1%	32.7%	35.4%	7.7%
May	14.0	3rd Order Stream	13.1%	60.8%	24.2%	1.9%
Coal	6.5	3rd Order Stream	16.0%	55.1%	28.5%	0.4%
Kelsey above Richards	8.3	3rd Order Stream	27.4%	35.9%	36.2%	0.5%
Mercer Slough, Richards Ck, Lk. Bellevue	8.0	Multiple Drainages	30.4%	26.8%	35.7%	7.1%
Mercer Slough @ Mouth	16.3	3rd Order Stream	28.9%	31.4%	36.0%	3.7%
Small Un-Named	0.3	Small Drainage	27.8%	18.0%	17.5%	36.7%
Forbes	3.6	3rd Order Stream	25.7%	33.1%	40.4%	0.8%
Juanita	6.5	3rd Order Stream	26.6%	32.4%	40.6%	0.4%
Mercer Island	6.3	Multiple Drainages	20.9%	36.8%	33.9%	8.4%
Lake Washington	34.1	Lake/Wetland	3.3%	3.3%	4.1%	89.3%
Lake Union	14.0	Multiple Drainages	44.4%	10.2%	37.3%	8.1%
Ship Canal at Locks	615.9	Watershed	15.5%	51.3%	24.8%	8.4%
Marine Drainages	44.2	Multiple Drainages	32.1%	24.8%	40.3%	2.9%

Table I-2: Peak Flows

Sub-basin	Stream Scale	Drainage Area (sq mi)	% EIA	%Increase in Peak Index
Upper Cedar (above SPU diversion)	River	120.9	3.8%	1%
Walsh	3rd Order Stream	6.6	4.0%	1%
Lower Rock	3rd Order Stream	12.9	1.6%	0%
Cedar North Rural	Multiple Drainages	7.5	9.6%	20%
Cedar Main Rural	Multiple Drainages	7.0	9.6%	20%
Upper and Rural Cedar @ approx SE 209th	River	154.8	4.2%	1%
Peterson	3rd Order Stream	6.4	3.8%	1%
Cedar North Urban Tribs	Multiple Drainages	2.8	20.6%	295%
Cedar South Urban Tribs	Multiple Drainages	5.0	21.9%	365%
Cedar Main Urban	Multiple Drainages	13.9	20.9%	308%
Cedar River @ Mouth	River	182.9	6.2%	4%
				0%
Upper Issaquah	3rd Order Stream	14.9	4.0%	1%
Middle Issaquah	Multiple Drainages	7.2	7.3%	8%
Middle and Upper Issaquah	4th Order Stream	22.1	5.1%	2%
McDonald	3rd Order Stream	5.1	8.7%	14%
Fifteenmile	3rd Order Stream	4.8	3.9%	1%
East Fork Issaquah	3rd Order Stream	9.4	8.0%	11%
North Fork Issaquah	3rd Order Stream	4.6	18.2%	190%
Lower Issaquah	Multiple Drainages	10.1	9.2%	17%
Issaquah Basin	4th Order Stream	56.1	7.6%	9%
Tibbetts	3rd Order Stream	5.4	9.8%	22%
				0%
East Lake Sammamish Tribs	3rd Order Streams	15.6	15.2%	101%
West Lake Sammamish Tribs	Multiple Drainages	12.1	22.7%	417%
Lake Sammamish	Lake/Wetland	7.6	2.7%	-
Sammamish at Weir	River	96.7	10.5%	28%
Cottage Lake	3rd Order Stream	12.9	13.4%	65%
Evans	3rd Order Stream	15.2	13.2%	62%
Upper Bear	3rd Order Stream	13.4	9.1%	17%
Lower Bear	Multiple Drainages	8.2	18.6%	208%
Big Bear Creek near Mouth	4th Order Stream	49.6	13.0%	59%
Upper Sammamish Valley	Multiple Drainages	13.8	24.9%	569%
Sammamish River at NE 136th St	River	160.2	12.5%	51%
Little Bear	3rd Order Stream	15.0	17.0%	152%
Upper North	3rd Order Stream	13.3	25.7%	642%
Lower North	Multiple Drainages	15.2	21.6%	350%
North at Mouth	3rd Order Stream	28.5	23.5%	470%

Sub-basin	Stream Scale	Drainage Area (sq mi)	% EIA	%Increase in Peak Index
Upper Swamp	3rd Order Stream	11.6	25.5%	623%
Lower Swamp	Multiple Drainages	12.6	27.0%	760%
Swamp at Mouth	3rd Order Stream	24.2	26.3%	692%
Lower Sammamish Valley	Multiple Drainages	12.1	22.2%	385%
Sammamish River at Mouth	River	240.1	16.0%	121%
North Lake Washington	Small Drainage	1.8	24.1%	509%
Lyons	3rd Order Stream	4.2	23.8%	492%
McAleer	3rd Order Stream	8.3	30.5%	1167%
Thornton	3rd Order Stream	11.3	31.9%	1364%
Green Lake	3rd Order Stream	13.2	33.2%	1568%
West Lake Washington	Multiple Drainages	15.1	32.2%	1414%
East Lake Washington	Multiple Drainages	21.0	24.1%	513%
May	3rd Order Stream	14.0	13.1%	60%
Coal	3rd Order Stream	6.5	16.0%	122%
Kelsey above Richards	3rd Order Stream	8.3	27.4%	798%
Mercer Slough, Richards Ck, Lk. Bellevue	Multiple Drainages	8.0	30.4%	1153%
Mercer Slough @ Mouth	3rd Order Stream	16.3	28.9%	961%
Mercer Slough	Small Drainage	0.3	27.8%	842%
Forbes	3rd Order Stream	3.6	25.7%	642%
Juanita	3rd Order Stream	6.5	26.6%	726%
Mercer Island	Multiple Drainages	6.3	20.9%	310%
Lake Washington	Lake/Wetland	34.1	3.3%	-
Lake Union	Multiple Drainages	14.0	44.4%	4338%
Ship Canal at Locks	Watershed	615.9	15.5%	108%
Marine Drainages	Multiple Drainages	44.2	32.1%	1391%

Table I-3: Storm Volume

Sub-basin	Stream Scale	DRAINAGE AREA (SQ MI)	% EIA	Avg. Ann. I&I (IN)	STORM VOLUME INCREASE
		AREA (SQ MI)			SVCI %
Upper Cedar (above SPU diversion)	River	120.9	3.8%	0.0	14%
Walsh	3rd Order Stream	6.6	4.0%	0.0	15%
Lower Rock	3rd Order Stream	12.9	1.6%	0.0	12%
Cedar North Rural	Multiple Drainages	7.5	9.6%	0.0	39%
Cedar Main Rural	Multiple Drainages	7.0	9.6%	0.2	0.4
Upper and Rural Cedar @ approx SE 209th	River	154.8	4.2%	0.0	16%
Peterson	3rd Order Stream	6.4	3.8%	0.0	14%
Cedar North Urban Tribs	Multiple Drainages	2.8	20.6%	0.4	71%
Cedar South Urban Tribs	Multiple Drainages	5.0	21.9%	2.3	58%
Cedar Main Urban	Multiple Drainages	13.9	20.9%	0.8	0.7
Cedar River @ Mouth	River	182.9	6.2%	0.1	23%
Upper Issaquah	3rd Order Stream	14.9	4.0%	0.0	16%
Middle Issaquah	Multiple Drainages	7.2	7.3%	0.0	0.3
Middle and Upper Issaquah	4th Order Stream	22.1	5.1%	0.0	20%
McDonald	3rd Order Stream	5.1	8.7%	0.0	33%
Fifteenmile	3rd Order Stream	4.8	3.9%	0.0	15%
East Fork Issaquah	3rd Order Stream	9.4	8.0%	0.1	25%
North Fork Issaquah	3rd Order Stream	4.6	18.2%	0.6	62%
Lower Issaquah	Multiple Drainages	10.1	9.2%	0.3	0.3
Issaquah Basin	4th Order Stream	56.1	7.6%	0.2	28%
Tibbetts	3rd Order Stream	5.4	9.8%	0.3	25%
East Lake Sammamish Tribs	3rd Order Streams	15.6	15.2%	0.8	45%
West Lake Sammamish Tribs	Multiple Drainages	12.1	22.7%	1.4	63%
Lake Sammamish	Lake/Wetland	7.6	2.7%	0.0	-
Sammamish at Weir	River	96.7	10.5%	0.6	28%
Cottage Lake	3rd Order Stream	12.9	13.4%	0.2	49%
Evans	3rd Order Stream	15.2	13.2%	0.3	45%
Upper Bear	3rd Order Stream	13.4	9.1%	0.0	34%
Lower Bear	Multiple Drainages	8.2	18.6%	0.3	0.7
Big Bear Creek near Mouth	4th Order Stream	49.6	13.0%	0.4	50%
Upper Sammamish Valley	Multiple Drainages	13.8	24.9%	0.8	0.9
Sammamish River at NE 136th St	River	160.2	12.5%	0.6	41%

Sub-basin	Stream Scale	DRAINAGE AREA (SQ MI)	% EIA	Avg. Ann. I&I (IN)	STORM VOLUME INCREASE
		AREA (SQ MI)			SVCI %
Little Bear	3rd Order Stream	15.0	17.0%	0.3	61%
Upper North	3rd Order Stream	13.3	25.7%	0.5	84%
Lower North	Multiple Drainages	15.2	21.6%	1.4	72%
North at Mouth	3rd Order Stream	28.5	23.5%	1.2	78%
Upper Swamp	3rd Order Stream	11.6	25.5%	0.7	76%
Lower Swamp	Multiple Drainages	12.6	27.0%	1.2	87%
Swamp at Mouth	3rd Order Stream	24.2	26.3%	1.0	82%
Lower Sammamish Valley	Multiple Drainages	12.1	22.2%	1.4	71%
Sammamish River at Mouth	River	240.1	16.0%	0.8	48%
North Lake Washington	Small Drainage	1.8	24.1%	2.0	71%
Lyons	3rd Order Stream	4.2	23.8%	3.5	59%
McAleer	3rd Order Stream	8.3	30.5%	2.8	83%
Thornton	3rd Order Stream	11.3	31.9%	6.2	59%
Green Lake	3rd Order Stream	13.2	33.2%	7.2	50%
West Lake Washington	Multiple Drainages	15.1	32.2%	7.2	49%
East Lake Washington	Multiple Drainages	21.0	24.1%	4.5	41%
May	3rd Order Stream	14.0	13.1%	0.6	43%
Coal	3rd Order Stream	6.5	16.0%	1.2	46%
Kelsey above Richards	3rd Order Stream	8.3	27.4%	1.7	84%
Mercer Slough, Richards Ck, Lk. Bellevue	Multiple Drainages	8.0	30.4%	3.5	0.7
Mercer Slough @ Mouth	3rd Order Stream	16.3	28.9%	1.9	89%
Mercer Slough	Small Drainage	0.3	27.8%	1.6	80%
Forbes	3rd Order Stream	3.6	25.7%	6.5	77%
Juanita	3rd Order Stream	6.5	26.6%	8.4	83%
Mercer Island	Multiple Drainages	6.3	20.9%	4.6	27%
Lake Washington	Lake/Wetland	34.1	3.3%	0.0	-
Lake Union	Multiple Drainages	14.0	44.4%	9.0	59%
Ship Canal at Locks	Watershed	615.9	15.5%	1.4	38%
Marine Drainages	Multiple Drainages	44.2	32.1%	?	?

Table I-4: Base Flow

Stream Scale	DA (SQ MI)	% EIA	BASE Q LOSS-RECHARGE (CFS)	BASE Q LOSS-WATER MGMT (CFS)	Total Net Loss (CFS)	Est. Natural Base Q (CFS)	Loss as % of Natural Base Flow
River	120.9	3.8%	3.4	-56.0	-52.6	289.0	-18%
3rd Order Stream	6.6	4.0%	0.1	0.1	0.2	3.8	5%
3rd Order Stream	12.9	1.6%	-0.5	6.1	5.6	9.8	57%
Multiple Drainages	7.5	9.6%	0.4	-0.2	0.2	4.5	5%
Multiple Drainages	7.0	9.6%	0.2	0.0	0.1	5.2	3%
River	154.8	4.2%	3.7	146.0	149.7	320.6	47%
3rd Order Stream	6.4	3.8%	0.2	-0.2	0.0	3.4	1%
Multiple Drainages	2.8	20.6%	0.4	-0.4	0.0	1.4	0%
Multiple Drainages	5.0	21.9%	0.8	-0.6	0.2	2.8	7%
Multiple Drainages	13.9	20.9%	1.5	12.4	13.9	9.3	>100%
River	182.9	6.2%	6.8	157.3	164.0	347.2	47%
3rd Order Stream	14.9	4.0%	0.3	0.0	0.3	8.6	3%
Multiple Drainages	7.2	7.3%	0.2	0.5	0.7	4.5	15%
4th Order Stream	22.1	5.1%	0.5	0.5	1.0	14.2	7%
3rd Order Stream	5.1	8.7%	0.2	-0.1	0.1	3.0	5%
3rd Order Stream	4.8	3.9%	0.1	0.0	0.1	3.1	4%
3rd Order Stream	9.4	8.0%	0.4	0.9	1.3	5.3	24%
3rd Order Stream	4.6	18.2%	0.4	4.0	4.4	2.6	>100%
Multiple Drainages	10.1	9.2%	0.4	1.0	1.4	7.0	20%
4th Order Stream	56.1	7.6%	2.0	6.4	8.4	35.4	24%
3rd Order Stream	5.4	9.8%	0.3	0.1	0.4	2.9	12%
					0.0	0.0	
3rd Order Streams	15.6	15.2%	1.3	3.0	4.3	7.9	54%
Multiple Drainages	12.1	22.7%	1.9	-0.5	1.4	7.0	19%
Lake/Wetland	7.6	2.7%	0.2		0.2	1.6	-
River	96.7	10.5%	5.6	9.0	14.5	103.5	14%
3rd Order Stream	12.9	13.4%	1.1	-1.5	-0.4	8.2	-5%
3rd Order Stream	15.2	13.2%	1.0	5.9	7.0	9.5	74%
3rd Order Stream	13.4	9.1%	0.8	0.9	1.7	8.5	21%
Multiple Drainages	8.2	18.6%	0.8	3.6	4.4	4.9	88%
4th Order Stream	49.6	13.0%	3.7	8.9	12.6	32.2	39%
Multiple Drainages	13.8	24.9%	1.9	2.4	4.3	8.0	54%
River	160.2	12.5%	11.2	20.3	31.5	107.4	29%
3rd Order Stream	15.0	17.0%	1.7	-1.6	0.0	7.4	0%

Stream Scale	DA (SQ MI)	% EIA	BASE Q LOSS-RECHARGE (CFS)	BASE Q LOSS-WATER MGMT (CFS)	Total Net Loss (CFS)	Est. Natural Base Q (CFS)	Loss as % of Natural Base Flow
					0.0		
3rd Order Stream	13.3	25.7%	2.4	-2.1	0.3	7.2	4%
Multiple Drainages	15.2	21.6%	1.7	-3.6	-1.9	10.7	-17%
3rd Order Stream	28.5	23.5%	4.2	-5.7	-1.5	17.9	-9%
3rd Order Stream	11.6	25.5%	2.3	-1.5	0.8	6.1	13%
Multiple Drainages	12.6	27.0%	2.2	-4.3	-2.1	7.9	-27%
3rd Order Stream	24.2	26.3%	4.5	-5.8	-1.3	13.9	-9%
Multiple Drainages	12.1	22.2%	1.6	1.6	3.2	8.1	39%
River	240.1	16.0%	23.1	8.7	31.9	153.6	21%
						136.0	0%
Small Drainage	1.8	24.1%	0.3	0.1	0.3	1.1	32%
3rd Order Stream	4.2	23.8%	0.6	-0.7	-0.1	2.7	-4%
3rd Order Stream	8.3	30.5%	1.6	-0.6	1.0	4.8	20%
3rd Order Stream	11.3	31.9%	2.4	3.3	5.7	6.9	83%
3rd Order Stream	13.2	33.2%	3.1	3.9	7.0	7.5	93%
Multiple Drainages	15.1	32.2%	3.5	5.5	9.0	9.3	97%
Multiple Drainages	21.0	24.1%	3.2	5.6	8.8	13.5	65%
3rd Order Stream	14.0	13.1%	1.2	-0.7	0.5	9.8	5%
3rd Order Stream	6.5	16.0%	0.8	0.2	1.0	3.5	29%
					0.0		
3rd Order Stream	8.3	27.4%	1.4	0.7	2.1	4.6	46%
Multiple Drainages	8.0	30.4%	1.6	0.0	1.6	4.5	36%
3rd Order Stream	16.3	28.9%	3.0	0.7	3.7	10.8	35%
Small Drainage	0.3	27.8%	0.1	0.0	0.1	0.1	83%
3rd Order Stream	3.6	25.7%	0.6	0.0	0.6	3.1	21%
3rd Order Stream	6.5	26.6%	1.0	-0.7	0.3	4.3	7%
Multiple Drainages	6.3	20.9%	1.0	1.2	2.2	3.7	60%
Lake/Wetland	34.1	3.3%	0.8	0.0	0.8	7.9	-
Multiple Drainages	14.0	44.4%	4.4	3.5	7.9	11.8	67%
Watershed	615.9	15.5%	55.9	182.1	242.2	595.2	41%
Multiple Drainages	44.2	32.1%	9.8	?	>9.8	16.5	?

Table I – 5: Ranking by Scale

Stream Flow Site	Scale	DRAINAGE AREA (SQ MI)	% INCREASE PEAK	% INCREASE STORM VOLUME	% DECREASE SUMMER BASE FLOW	Relative Ranking of Change		
						Peak	*Storm Volume*	*Base Flow*
Ship Canal at Locks	Watershed	615.9	110%	38%	41%	-	-	HIGH
Upper Cedar (above SPU diversion)	River	120.9	1%	14%	-18%	LOW	LOW	LOW
Upper and Rural Cedar @ approx SE 209th	River	154.8	1%	16%	47%	LOW	LOW	HIGH
Cedar River @ Mouth	River	182.9	4%	23%	47%	LOW	LOW	HIGH
Sammamish at Weir	River	96.7	28%	28%	14%	MEDIUM	MEDIUM	MEDIUM
Sammamish River at NE 136th St	River	160.2	52%	41%	29%	HIGH	MEDIUM	HIGH
Sammamish River at Mouth	River	240.1	124%	48%	21%	EXTREME	MEDIUM	MEDIUM
Middle and Upper Issaquah	4th Order Stream	22.1	2%	20%	7%	LOW	LOW	LOW
Issaquah Creek nr Mouth	4th Order Stream	56.1	9%	28%	24%	MEDIUM	MEDIUM	MEDIUM
Big Bear Creek near Mouth	4th Order Stream	49.6	61%	50%	39%	HIGH	HIGH	HIGH
Lower Rock	3rd Order Stream	12.9	0%	12%	57%	LOW	LOW	EXTREME
Peterson	3rd Order Stream	6.4	1%	14%	1%	LOW	LOW	LOW
Fifteenmile	3rd Order Stream	4.8	1%	15%	4%	LOW	LOW	LOW
Walsh	3rd Order Stream	6.6	1%	15%	5%	LOW	LOW	LOW
Upper Issaquah	3rd Order Stream	14.9	1%	16%	3%	LOW	LOW	LOW
East Fork Issaquah	3rd Order Stream	9.4	11%	25%	24%	MEDIUM	LOW	MEDIUM
McDonald	3rd Order Stream	5.1	15%	33%	5%	MEDIUM	MEDIUM	LOW
North Fork Issaquah	3rd Order Stream	4.6	194%	62%	>100%	EXTREME	HIGH	EXTREME
Tibbetts	3rd Order Stream	5.4	23%	25%	12%	MEDIUM	LOW	MEDIUM
East Lake Sammamish Tribs	3rd Order	15.6	103%	45%	54%	EXTREME	MEDIUM	EXTREME

Stream Flow Site	Scale	DRAINAGE AREA (SQ MI)	% INCREASE PEAK	% INCREASE STORM VOLUME	% DECREASE SUMMER BASE FLOW	Relative Ranking of Change		
						Peak	*Storm Volume*	*Base Flow*
	Streams							
Cottage Lake	3rd Order Stream	12.9	66%	49%	-5%	HIGH	MEDIUM	LOW
Evans	3rd Order Stream	15.2	63%	45%	74%	HIGH	MEDIUM	EXTREME
Upper Bear	3rd Order Stream	13.4	17%	34%	21%	MEDIUM	MEDIUM	MEDIUM
Little Bear	3rd Order Stream	15.0	155%	61%	0%	EXTREME	HIGH	LOW
Upper North	3rd Order Stream	13.3	655%	84%	4%	EXTREME	EXTREME	LOW
North at Mouth	3rd Order Stream	28.5	470%	78%	-9%	EXTREME	EXTREME	LOW
Upper Swamp	3rd Order Stream	11.6	623%	76%	13%	EXTREME	EXTREME	MEDIUM
Swamp at Mouth	3rd Order Stream	24.2	692%	82%	-9%	EXTREME	EXTREME	LOW
Lyons	3rd Order Stream	4.2	502%	59%	-4%	EXTREME	HIGH	LOW
McAleer	3rd Order Stream	8.3	1191%	83%	20%	EXTREME	EXTREME	MEDIUM
Thornton	3rd Order Stream	11.3	1392%	59%	83%	EXTREME	HIGH	EXTREME
Green Lake	3rd Order Stream	13.2	1601%	50%	93%	EXTREME	MEDIUM	EXTREME
May	3rd Order Stream	14.0	61%	43%	5%	HIGH	MEDIUM	LOW
Coal	3rd Order Stream	6.5	124%	46%	29%	EXTREME	MEDIUM	HIGH
Kelsey above Richards Ck	3rd Order Stream	8.3	815%	84%	46%	EXTREME	EXTREME	HIGH
Mercer Slough @ Mouth	3rd Order Stream	16.3	982%	89%	35%	EXTREME	EXTREME	HIGH
Forbes	3rd Order Stream	3.6	656%	77%	21%	EXTREME	EXTREME	MEDIUM
Juanita	3rd Order	6.5	741%	83%	>100%	EXTREME	EXTREME	LOW

Stream Flow Site	Scale	DRAINAGE AREA (SQ MI)	% INCREASE PEAK	% INCREASE STORM VOLUME	% DECREASE SUMMER BASE FLOW	Relative Ranking of Change		
						Peak	*Storm Volume*	*Base Flow*
	Stream							
Cedar North Rural	Multiple Drainages	7.5	20%	39%	5%	MEDIUM	MEDIUM	LOW
Cedar Main Rural	Multiple Drainages	7.0	20%	40%	3%	MEDIUM	MEDIUM	LOW
Cedar North Urban Tribs	Multiple Drainages	2.8	295%	71%	0%	EXTREME	HIGH	LOW
Cedar South Urban Tribs	Multiple Drainages	5.0	365%	58%	7%	EXTREME	HIGH	LOW
Cedar Main Urban	Multiple Drainages	13.9	308%	70%	149%	EXTREME	HIGH	EXTREME
Middle Issaquah	Multiple Drainages	7.2	8%	28%	15%	MEDIUM	MEDIUM	MEDIUM
Lower Issaquah	Multiple Drainages	10.1	17%	30%	20%	MEDIUM	MEDIUM	MEDIUM
West Lake Sammamish Tribs	Multiple Drainages	12.1	417%	63%	19%	EXTREME	HIGH	MEDIUM
Lower Bear	Multiple Drainages	8.2	208%	71%	88%	EXTREME	HIGH	EXTREME
Upper Sammamish Valley	Multiple Drainages	13.8	569%	87%	54%	EXTREME	EXTREME	EXTREME
Lower North	Multiple Drainages	15.2	350%	72%	-17%	EXTREME	HIGH	LOW
Lower Swamp	Multiple Drainages	12.6	760%	87%	-27%	EXTREME	EXTREME	LOW
Lower Sammamish Valley	Multiple Drainages	12.1	385%	71%	39%	EXTREME	HIGH	HIGH
West Lake Washington	Multiple Drainages	15.1	1414%	49%	97%	EXTREME	MEDIUM	EXTREME
East Lake Washington	Multiple Drainages	21.0	513%	41%	65%	EXTREME	MEDIUM	EXTREME
Mercer Slough, Richards Ck, Lk. Bellevue	Multiple Drainages	8.0	1153%	70%	36%	EXTREME	HIGH	HIGH
Mercer Island	Multiple Drainages	6.3	310%	27%	60%	EXTREME	MEDIUM	EXTREME
Lake Union	Multiple	14.0	4338%	59%	67%	EXTREME	HIGH	EXTREME

Stream Flow Site	Scale	DRAINAGE AREA (SQ MI)	% INCREASE PEAK	% INCREASE STORM VOLUME	% DECREASE SUMMER BASE FLOW	Relative Ranking of Change		
						Peak	*Storm Volume*	*Base Flow*
	Drainages							
Marine Drainages	Multiple Drainages	44.2	1391%	?	?	EXTREME	?	?
North Lake Washington	Small Drainage	1.8	520%	71%	32%	EXTREME	HIGH	HIGH
Small Un-named	Small Drainage	0.3	860%	80%	83%	EXTREME	EXTREME	EXTREME
Lake Sammamish	Lake/Wetland	7.6	-	-	-	-	-	-
Lake Washington	Lake/Wetland	34.1	-	-	-	-	-	-

Appendix 2. WRIA 8 STREAM FLOW ASSESSMENT STRATEGY

INTRODUCTION

This document describes a strategy to do detailed flow assessment to determine the hydrologic status of streams and rivers within the watershed with respect to conservation and recovery of salmonids. The underlying concept behind the proposed strategy is that the natural flow regime generally provides the best general template for ecologically functional conditions and that departures from natural flow characteristics indicate potential ecosystem problems.

FLOW ANALYSIS POINT (FAP) CLASSIFICATION

For purposes of this study, flow analysis is conceived as taking place at specific geographic points within the drainage network of the watershed. Both as a practical matter of workload and from the perspective salmonid conservation and recovery, not all points within the watershed are of equal importance. Consequently, its is proposed to apply different levels of effort to the analysis of different classes of locations within the watershed that are defined both in terms of spatial scale and in terms of prominence with regard to conservation and recovery of the primary salmonid species of interest.

Class-1. Major Rivers- FAPs located at mouth of major rivers and optionally at additional upstream river locations. Propose two FAPs for the Cedar River and one for the Sammamish River. Cedar River FAPs expected to reflect and distinguish both basin land use and effects of water supply facilities and operations.
Class-2. Significant Chinook Streams- FAPS at mouths of streams with currently or historically significant chinook productivity. Does not include streams located in the Seattle Watershed because flow regime of these streams is assumed to be and remain relatively un-impacted by current or future human activites.
Class-3. Larger Streams- FAPs at mouths of all third or higher order streams that are not included in classes 1 or 2. Third order FAP locations are at the boundary between third and fourth order in the drainage system.
Class-4. Smaller Streams- FAPs at the mouth of all second order streams that do not drain to stream segments with a Class-3 FAP. This creates an FAP at the mouth of second order stream basins that drain directly to fourth order streams, major lakes, or Puget Sound. It assures that FAPs will be well-distributed throughout the entire WRIA 8 drainage network (excluding the Seattle Watershed).

DEFINITION OF ANALYSIS LEVELS

All levels of flow analysis have a common purpose- to characterize the departure of current and projected future flow regimes at a stream location from the flow regime under natural conditions prior to urbanization, dam construction, water diversion, and other human impacts that affect flow. As a practical matter, the most comprehensive flow

regime analysis methods can not be applied to all mapped stream segments within the watershed. Therefore, several levels of analysis are proposed to be applied to stream and river locations commensurate with their significance for salmon conservation and recovery. Analysis levels differ in the number of parameters and complexity of analytic tools utilized to characterize the departures from natural conditions.

Level-1. Applies full IHA-RTV analysis as originally developed by Richter et al (1996, 1997) and modified by King County (2000). This consists of comparisons of inter-annual distributions of 34 yearly flow statistics calculated from mean daily flow data. The statistics describe include monthly means, annual high and low flow extremes, high and low flow durations, timing of peaks and minima, and measures of flow volatility. Statistics and their distributions are calculated for natural, pristine conditions. The values and distributions for natural conditions are used as a basis for comparison with values representative of current conditions and future flow scenarios.

- 12 monthly means
- Minimum 1, 3, 7, 30, 90-day flows
- Maximum 1, 3, 7, 30, 90-day flows
- Count of daily low flow excursions below low-flow threshold (use long term, average, natural, 7-day minimum flow)
- Count of hourly high flow excursions above high-flow threshold (use forested 1.5-year hourly flow)
- Julian Date of 1-day min
- Julian Date of 1-day max
- Duration in days below low-flow threshold
- Duration in hours above high-flow threshold
- Average annual size of daily rises of more than 10% (cfs)
- Average annual size of daily falls of more than 10 (cfs)
- Number of days flows rise by more than 10%
- Number of days flows fall by more than 10%

Level-3. Applies IHA-RTV methods using nine statistics

Maximum annual hourly flow
7-day minimum annual flow
90-day minimum annual flow
90-day maximum annual flow
Count of high flow excursions (hourly data) above high-flow threshold
(use forested 1.5-year hourly flow)
Duration in days below low-flow threshold
Duration in hours above high-flow threshold
Average annual difference between maximum and minimum daily hourly flow
Number of days daily max minus daily min exceeds 10% of daily max

Level-4. Applies IHA-RTV methods using four statistics
Maximum annual hourly flow
7-day minimum annual flow

Duration in days below low-flow threshold
Duration in hours above high-flow threshold

FLOW TIME SERIES SOURCES AND SYNTHESIS STRATEGIES

Historical stream flow data within the watershed represents an important source of information for performing the proposed flow assessment. However, in applying these data within the proposed analysis scheme, it is important to recognize several limitations including the following:

1. Limitations in the number of historical flow gaging sites
2. Uneven record lengths
3. Lack of stationarity in available data

Items 1) and 2) relate to gaps in spatial and temporal coverage of the available data. Item 3) relates to the fact that generally existing flow records represent both natural variability related to climate and human-influenced caused by such activities as land cover change, water extraction, channel engineering, and dam operations.

To conduct the proposed flow analysis, decades-long, stationary natural, stationary current, or stationary proposed flow records are needed at defined flow analysis points. This requires a tool that can essentially overcome the deficiencies in the historical data- i.e. a technique is needed to spatially extrapolate records for ungaged flow points, extend record length to obtain adequate samples to estimate flow parameters, estimate basin response under stationary basin conditions. These are all possible to do by leveraging existing data with distributed hydrologic simulation modeling.

Table 1. FLOW ANALYSIS POINTS

STREAM	ANALYSIS LOCATION	ANALYSIS LEVEL	COMMENT
CEDAR RIVER	RENTON GAGE SITE (USGS 12119000)	1	USGS gage site near mouth of Cedar River. Flow regime reflects integration of all anthropogenic effects within the river basis including major and minor flow diversions.
CEDAR RIVER	ABOVE LANDSBURG GAGE SITE (USGS 12117500)	1	USGS gage site above SPU diversion. Current flow regime reflects Seattle net effect of dam presence and operations with minimal influence from land use change.
SAMMAMISH RIVER	NR WOODINVILLE (USGS 12125200)	1	Location is downstream of Big Bear Creek. Flow data could be adjusted using tributary data and simulation modeling to reposition the location of analysis- e.g. upstream to the outlet of Lake Sammamish or downstream to the mouth of the river below Swamp Creek.
ISSAQUAH CREEK	GAGE SITE NR MOUTH (USGS 12121600)	2	
BEAR CREEK	NR MOUTH (KC GAGE SITE 02A, FORMER USGS 12124500)	2	
COTTAGE LAKE CREEK	NR MOUTH (FORMER USGS GAGE SITES 12123100 & 12123101)	2	10 year USGS flow record at 12113000 from 1955-1965
ROCK CREEK	ROCK CREEK NR MAPLE VALLEY (FORMER USGS GAGE SITE 12118500 AND CURRENT KC GAGE 31L	2	Increasingly affected by City of Kent diversions in the last 20 years.
BOEING CREEK	NR MOUTH	3	
PIPERS CREEK	NR MOUTH	3	
THORNTON CREEK	NR MOUTH	3	
MCALEER CREEK	NR MOUTH	3	
JUANITA CREEK	NR MOUTH	3	
FORBES CREEK	NR MOUTH	3	
KELSEYCREEK-MERCER SLOUGH	NR MOUTH	3	
COAL CREEK	NR MOUTH	3	
MAY CREEK	NR MOUTH	3	

STREAM	ANALYSIS LOCATION	ANALYSIS LEVEL	COMMENT
SWAMP CREEK	NR MOUTH	3	
NORTH CREEK	NR MOUTH	3	
LITTLE BEAR CREEK	NR MOUTH	3	
UPPER BEAR CREEK	NR NE 133 ST (FORMER USGS GAGE SITE 12122500, CURRENT KC GAGE 02E)	3	Above confluence with Cottage Lake Creek. Approx. 13.9 sq mi drainage basin.
EVANS CREEK	NR MOUTH IN REDMOND , FORMER USGS GAGE SITE 12124000, CURRENT KC GAGE 18A)	3	22 years of usgs of date from 1955-1976.
W. LK. SAMMAMISH TRIB 0162	MOUTH	3	
GEORGE DAVIS CREEK	MOUTH	3	
PINE LAKE CREEK	MOUTH	3	
LAUGHING JACOBS CREEK	MOUTH	3	
TIBBETTS CREEK	MOUTH	3	
NORTH FORK ISSAQUAH CREEK	NR MOUTH (KC GAGE SITE 46A)	3	
EAST FORK ISSAQUAH CREEK	NR MOUTH (KC GAGE SITE 14A)	3	
FIFTEEN MILE CREEK	MOUTH	3	
ISSAQUAH CREEK	JUST ABOVE MCDONALD CREEK CONFLUENCE	3	
MCDONALD CREEK	MOUTH	3	
HOLDER CREEK	MOUTH	3	
TAYLOR CREEK	MOUTH	3	
PETERSON CREEK	MOUTH	3	
WALSH LAKE DIVERSION	MOUTH	3	

Fig 1. Cedar-Lake Washington Sub-basins

Fig. 2. Percent Effective Impervious

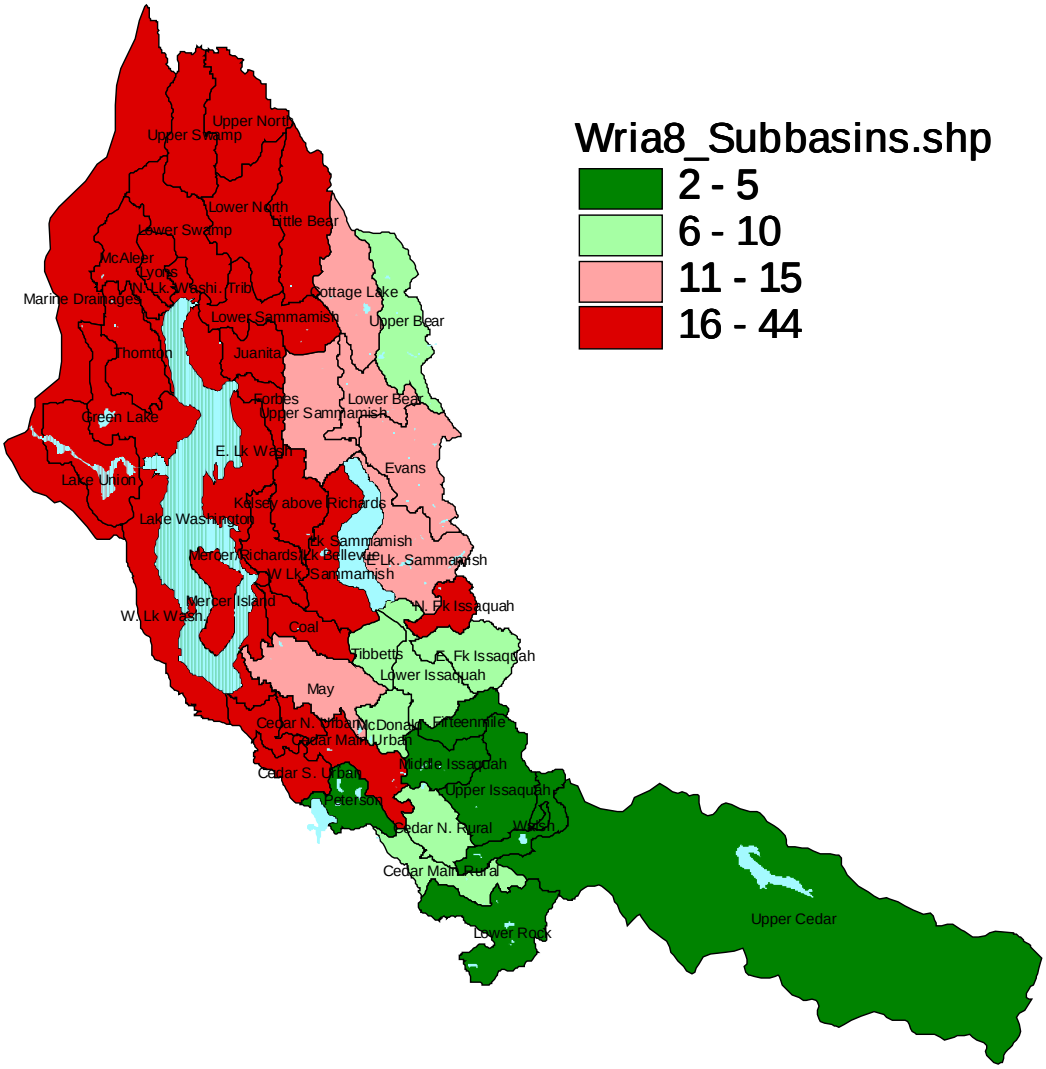


Fig 3. Relative Increase in Peak Flow

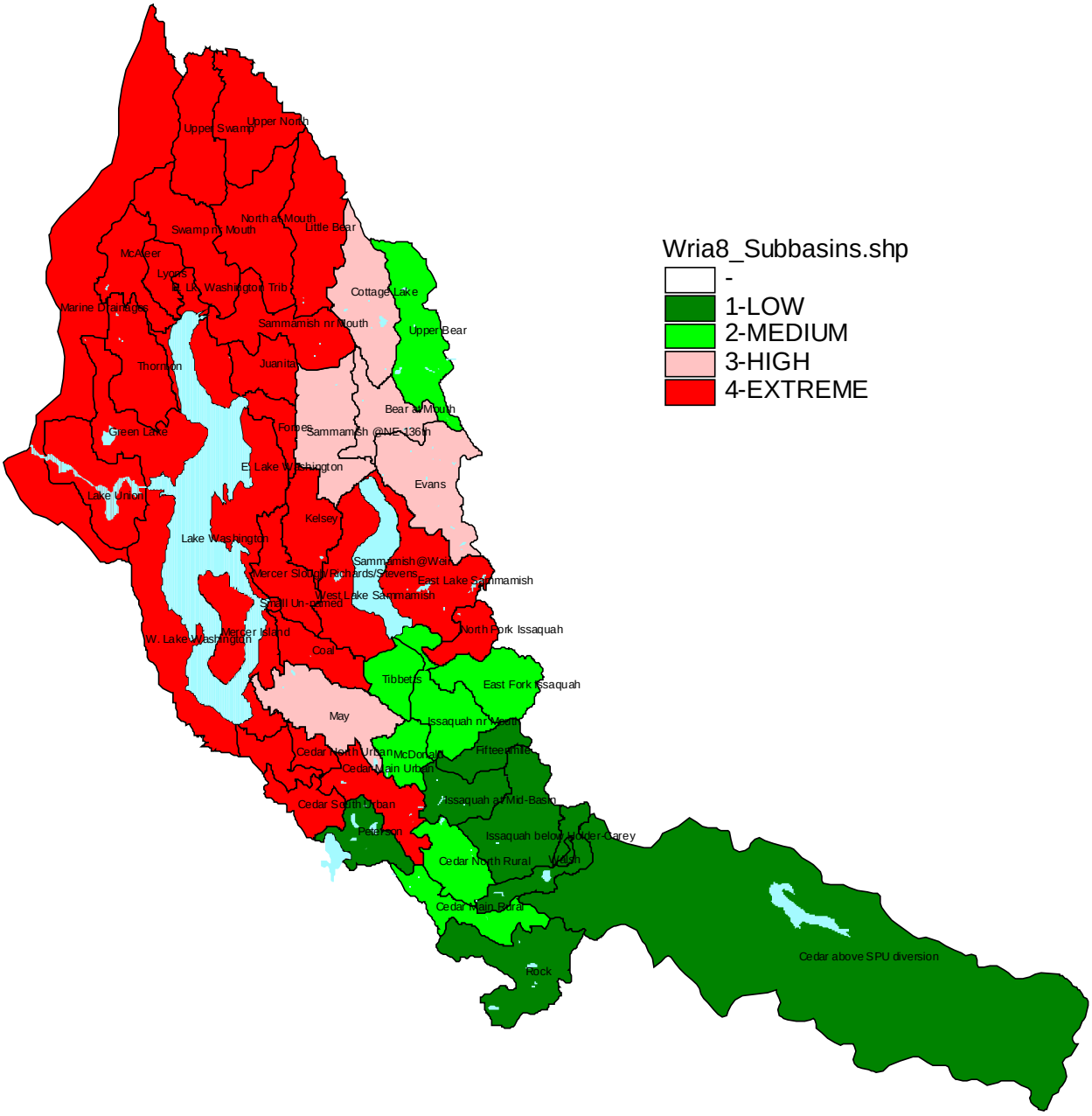


Fig 4. Relative Increase in Storm Volume

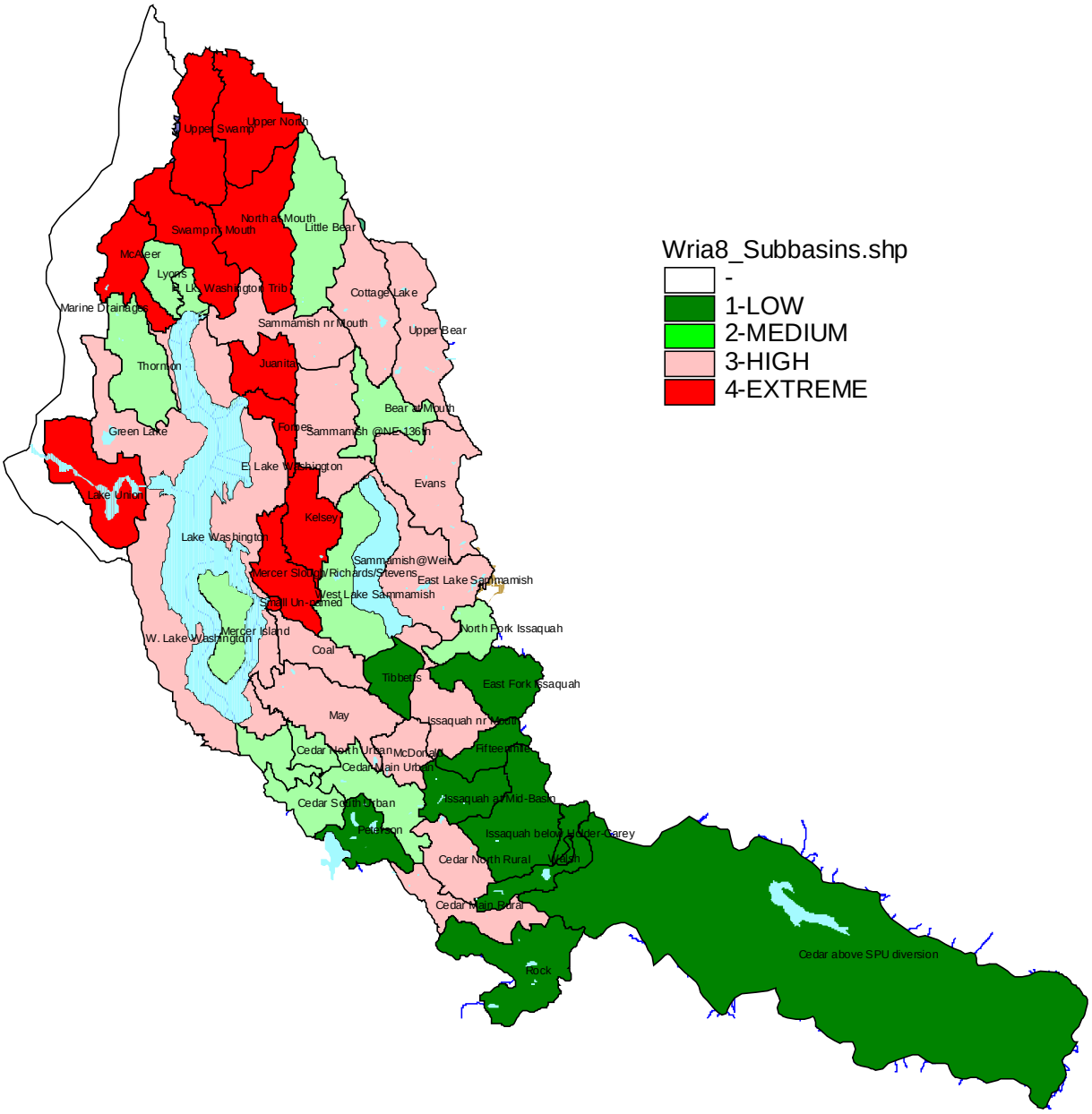
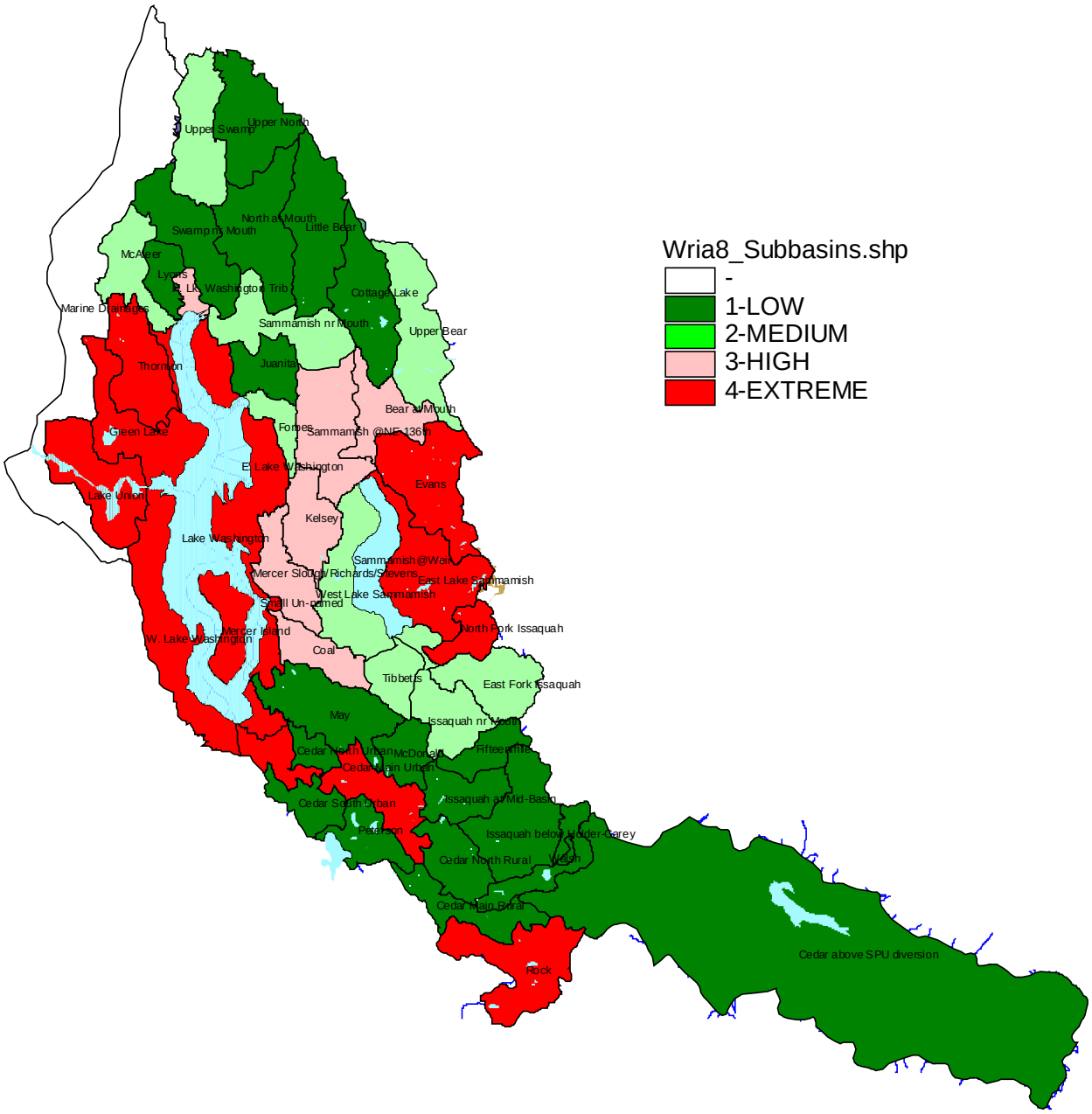



Fig 5. Relative Decrease in Base Flow