Salmon Bay Estuary Synthesis Report

Including Assessment of Proposed Daylighting Wolfe Creek Project

Lake Washington, Cedar, Sammamish Watershed (WRIA 8)

January 2010

Prepared for
Lake Washington, Cedar, Sammamish
Watershed (WRIA 8)
Estuary and Nearshore Workgroup

Prepared by
Taylor Associates, Inc.
7104 Greenwood Avenue N.
Seattle, WA 98103

Acknowledgments

Taylor Associates, Inc.

- Peter Heltzel, Senior Fisheries Biologist and Project Manager
- Bill Taylor, Principal

Natural Resources Inc.

- Greg Ruggerone, Vice President

Graphic Information Services

- Kirsty Burt, GIS Specialist

J.A. Brennan Associates, PLLC

- Jim Brennan, Landscape Architect/Planner

Communication Resources Northwest

- Meg Winch, Partnering Facilitator/Editor
- Jeannie Forrest, Partnering/Research Coordinator

W.R. Consulting, Inc.

- Marian Wineman, Environmental Engineer/Toxicologist

Lake Washington, Cedar, Sammamish Watershed (WRIA 8) Estuary and Nearshore Workgroup

- Mary Jorgensen, WRIA 8 Actions and Funding Coordinator
- Hans Berge, Environmental Scientist, King County
- Michele Koehler, Aquatic Ecologist, Seattle Public Utilities
- Donna Kostka, Community Leader, Heron Habitat Helpers
- Scott Stolnack, WRIA 8 Technical Coordinator

King County, Department of Natural Resources and Parks, Water and Land Resources Division, is the Service Provider for WRIA 8

- Jean White, WRIA 8 Watershed Coordinator

Special Thanks to:

- Washington State Recreation and Conservation Office, Washington State Department of Fish and Wildlife, and the Puget Sound Partnership for the Puget Sound Acquisition and Restoration (PSAR) 5% Capacity Fund grant to the WRIA 8 Lead Entity for salmon recovery.
- The eight fishery and estuarine scientists for sharing their knowledge of Salmon Bay and salmon recovery (see Chapter 5).

Table of Contents

List of Figures

List of Tables

Glossary

acoustic studies – the use of sound in scientific investigations

delta fry – juvenile salmon that arrive in an estuary early in the season (December to April) at a small size (< 50 mm) and rear in the natal estuarine deltas for extended periods (up to ~120 days) (adapted from Fresh 2006)

epibenthic – association with the surface of bottom substrate in an estuary

exceedance – the amount by which something exceeds a standard

nearshore – extending from or occurring along a shore

lentic – pertaining to or living in still water

littoral – the region along the shoreline, between the limits of high and low tides and the extent of the sun's penetration of the water

microacoustic tag technique – the process of inserting a passive integrated transponder tag (or other transmitter type) into salmon to track movement

offshore – at a distance from the shore, on a body of water

osmoregulatory – maintenance of an optimal, constant osmotic pressure in the body of a living organism

otolith rings – rings on the otolith bone found in the middle ear of fish, the rings can be used to determine the age of fish and length of time fish spend in fresh and salt water

parr migrants – juvenile salmon that rear in river habitats for weeks or months then migrate into an estuary from approximately May through mid-July (adapted from Fresh 2006)

pelagic – living or growing at or near the surface of the ocean

polychaetes – segmented worms living in the depths of ocean, floating free near the surface, or burrowing in the mud and sand of beaches

rear – to take care of and support, nurture or raise

recycling – repeat a process from the beginning

residualizing – remaining or staying

riparian – pertaining to, situated or dwelling on the bank of a river or other body of water

softscape – shoreline that contains trees, shrubs, grasses and other vegetation

smoltification – an internal metabolic process which enables a fish to adapt from fresh to sea water

zooplankton – plankton that consists of tiny animals, such as cladocerans, rotifers, copepods, and krill

Acronyms

cfs – cubic feet per second

HSPF – Hydrological Simulation Program Fortran

MLLW – Mean Lower Low Water

mm – millimeter

PIT – Passive Integrated Transponder

ppt – parts per thousand

RM – River Mile

SBNA – Salmon Bay Natural Area

WRIA – Water Resource Inventory Area

WWHM – Western Washington Hydrologic Model

Left photo on cover by Google Earth™

Right photo on cover by Peter Kiffney, NOAA Fisheries (http://www2.seattle.gov/util/tours/CedarRiverBiodiversity/ChinookCoho/images/4-juvenile-chinook.jpg)

Executive Summary

This report was commissioned by the Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Project Subcommittee to assess the relative benefits to Chinook salmon of restoration projects in the Salmon Bay estuary[1]. It contains a review of published and unpublished literature on Chinook salmon use of estuaries including Salmon Bay, compares the relative value of four example restoration projects in the area downstream of the Hiram M. Chittenden Locks (the Locks), summarizes the results of interviews with eight local fisheries and estuarine scientists with knowledge of Salmon Bay, and recommends next steps for improving Chinook survival in the estuary.

As part of the comparison of restoration projects, the potential benefits to Chinook salmon of daylighting Wolfe Creek received additional analysis, including an investigation of the creek's possible freshwater contribution to Salmon Bay.

Literature Review

The literature review summarizes information regarding estuarine habitat in Salmon Bay and Chinook salmon use of that habitat. It includes the state of the current habitat, the extent of the freshwater lens and mixing zone below the Locks, and salinity and temperature regimes. The review also describes how both juvenile and adult Chinook typically use estuaries, and factors affecting their survival in and around Salmon Bay. Most of the literature review focuses on juveniles, due to the importance of estuarine habitats for this life history stage of Chinook.

The Salmon Bay area lacks essential functions of a natural estuary such as: 1) saltwater marshes, 2) shallow intertidal mudflats, 3) overhanging natural vegetation, and 4) a freely flowing brackish transitional zone. The lack of most estuarine characteristics and functions can be attributed to the construction of the Locks in 1916 for passage of ships. Extreme salinity, temperature, and dissolved oxygen gradients exist upstream and downstream of the Locks. The Locks have essentially truncated the estuary, creating a small freshwater lens and mixing zone immediately below the Locks. The size and depth of the lens is influenced by lockage and smolt flume operations, as well as seasonal and tidal conditions. The lens typically extends about 380 meters downstream of the Locks and seldom extends beyond the railroad bridge.

Development downstream of the Locks also contributes to the lack of natural estuarine functions. Approximately 75% of the Salmon Bay shoreline is modified by artificial structures, such as armored bulkheads and ship holding areas. The intertidal habitat has been substantially reduced and degraded.

[1] For this report, the Salmon Bay estuary is defined as the area extending from the Hiram M. Chittenden Locks westward to the nearshore and Puget Sound.

Key Findings of Literature Review

- The Locks force juvenile Chinook to make an unnaturally rapid transition from warm freshwater to cool saltwater, sometimes instantaneously.
- Juvenile Chinook from the Lake Washington system have a short residence time in the freshwater lens below the Locks and quickly move through Salmon Bay.
- Diet studies below the Locks have shown that Chinook feed and have fed upon freshwater zooplankton, which is not typical prey for estuarine salmon.
- Most juvenile Chinook from the Lake Washington system exit freshwater at considerably larger size than juvenile Chinook in other systems; because of this they appear to be less dependent upon estuarine habitat for rearing and survival. Studies suggest larger juvenile Chinook are more capable of making the abrupt change from fresh to saltwater than smaller juveniles, though delayed effects of the transition may decrease their overall survival.
- Adult Chinook salmon have a difficult transition from cold Puget Sound saltwater to very warm freshwater temperatures. These temperature challenges are often combined with delays through the Locks and water quality problems, making them susceptible to predation or stress.

Flow Analysis

The research team conducted a flow analysis to determine the potential freshwater input to Salmon Bay from Wolfe Creek's current flows. The team used a continuous simulation flow model based on the Western Washington Hydrologic Model that uses 50 years of hourly precipitation data to model flow and runoff in watersheds within Western Washington.

During the peak of juvenile Chinook migration, the analysis indicated that 99% of the time flows from Wolfe Creek would be less than 1 cubic foot per second (cfs). For comparison, the total freshwater flow from all sources at the Locks during this same time period ranges from 520 cfs to 770 cfs.

Comparison of Restoration Sites

To investigate potential benefits to Chinook salmon, four example restoration sites were compared to each other to estimate their relative merits. The team used criteria based upon typical contributing factors for restoration sites and Salmon Bay ecology to evaluate the four sites, including 1) total enhanced area, 2) upper and lower intertidal area, 3) removal of overwater structures, 4) dominant substrate type, 5) potential aquatic insect drift and freshwater input, and 6) proximity to Seattle outfalls.

Findings

Each of the restoration sites has unique characteristics that could benefit juvenile Chinook salmon. The sites are described below with their contribution given relative to all sites:

- The Wolfe Creek restoration site is a proposed short daylighted creek section flowing through Commodore Park that would empty through a small marsh area into Salmon Bay. This project could add a large restored area in Commodore Park, including a significant riparian zone, relatively small upper intertidal area, and very small quantities of freshwater input.

- The Salmon Bay Natural Area restoration has improved riparian and upland vegetation along the shoreline and removed overwater structures. Bulkhead removal, slope regrading, and more vegetation planting completed this restoration. This site adds a large restored area, including a significant riparian zone, and a relatively large area of removed overwater structures.
- The Ray's Boat House site restoration would include partial removal of the overwater dock to expose quality beach habitat. This project could add a very small restored area including a minimal riparian zone and minimal removal of overwater structures.
- The West Sheridan Street End restoration site would add a small restoration area, including a small riparian zone and small upper and lower intertidal area.

Interviews with Experts

In order to augment the literature review and better understand options surrounding restoration efforts in and around Salmon Bay, the team interviewed eight local experts involved professionally in restoration and salmon recovery efforts in the Puget Sound region.

Interview questions centered around the survival of both adult and juvenile salmon, recommendations for habitat restoration in and around Salmon Bay, and opinions regarding how to make future habitat restoration efforts more successful.

The experts agreed that future habitat restoration efforts within the Salmon Bay estuary should focus on juvenile salmon, as adult salmon do not rely on estuarine habitat for growth and development. For adult Chinook salmon they agreed that the temperature transition through the Locks and water quality concerns are the most important issues to address.

They suggested a holistic, large-scale ecosystem approach to salmon recovery as preferable to single restoration projects within Salmon Bay. Restoration planning and further research should broaden the focus beyond the estuary to the nearshore area and even to the context of the entire Puget Sound region.

The expert's opinions varied on the value, or effectiveness, of restoration in Salmon Bay due to lack of connectivity between restoration sites and the tremendous challenge to address large scale removal of overwater structures, the Locks, and overall urbanization of the estuary. However, they did agree that it is important to proceed with restoration projects if they are part of a long-term master plan for the estuary or for educational, symbolic, or community benefits such as Wolfe Creek's daylighting. Most of the experts agreed that a long-term approach to restoration would need to consider salmon life histories and a comprehensive vision for the watershed.

Recommendations

The following recommendations are based upon information gathered from the literature review, interviews, flow analysis, and comparison of values of the example restoration sites. They specifically address potential actions within Salmon Bay.

Recommendations for Future Research

Studies have been conducted on food consumption, habitat use, and to some degree, the effects of rapid transition for juvenile Chinook. Further studies should focus on:

- Diet analysis and fine scale habitat use throughout the migration period and at multiple sites within Salmon Bay, including mid-channel areas where salmon may have different size and feeding characteristics. This would help determine if Chinook are primarily feeding on freshwater prey below the Locks, or whether they are spending time and energy foraging on typical prey items found within other reaches of Salmon Bay.
- The effects of rapid transition through the Locks, i.e., immediate or delayed mortality effects, or other effects of salinity and temperature transition on Chinook.
- The effects on water quality from stormwater and combined sewer overflow outfalls in Salmon Bay.

Recommendations for Restoration and Other Actions

Restoration actions need to be prioritized and sequenced within an overall estuary and nearshore action plan. Actions that may improve the growth and survival of juvenile salmon include:

- Increase riparian vegetation along the entire shoreline.
- Remove bulkhead and riprap to soften the shoreline.
- Implement a large scale effort to remove significant amount of overwater structures.
- Significantly increase freshwater input. This may necessitate restoring a larger portion of the Wolfe Creek watershed to improve flows or incorporating Ship Canal water into a Wolfe Creek habitat restoration design to increase flows.
- Create multiple tidal marshes, large intertidal flats, and numerous habitat benches throughout Salmon Bay.
- Encourage volunteers, and other groups, to be involved in restoration design and implementation to promote understanding of salmon and their watershed and to build community action for salmon recovery.
- Include effectiveness monitoring and restoration modification in funding for habitat restoration, to ensure best use of funds.

Conclusion

The Salmon Bay estuary lacks the essential functions of a natural estuary due to urbanization and industrial development, including the construction of the H.M. Chittenden Locks in 1916. Future restoration efforts in the estuary need to be part of a clear, large-scale ecosystem approach to benefit Chinook salmon and other species that use the estuary. Future restoration actions to improve the estuarine functions of Salmon Bay should be prioritized and sequenced within the context of this larger ecosystem approach, including actions for the nearshore areas. Restoration actions need to also consider fish life-histories and design habitat accordingly that could contribute to the overall survival of WRIA 8 Chinook and other salmonid species.

For adult Chinook salmon, projects to lower water temperature above the Locks and to minimize the delay of fish passage could improve adult survival. Stormwater and other water quality issues within the estuary also influence survival. For juvenile Chinook salmon, restoration (in an ecosystem-scale context) should focus on improving fine scale habitat for growth and development, including shoreline softening, riparian plantings, and removal of overwater structures.

This report indicates that freshwater flow contributions from Wolfe Creek would have minimal measurable benefits. In addition, the daylighted channel of Wolfe Creek would most likely not be used by the majority of WRIA 8 juvenile Chinook salmon, which are larger in size. Daylighting of Wolfe Creek would have educational and community value, and may contribute to the long-term restoration of the estuary. The other three example restoration sites would also have minimal impact in the short-term due to their lack of connectivity and relatively small size. The Salmon Bay Natural Area restoration site has addressed several of the juvenile Chinook salmon habitat needs and will be monitored to guide future large-scale riparian and shoreline restoration efforts.

1.0 Introduction

Chinook salmon populations for the 692 square mile Lake Washington, Cedar, Sammamish watershed (WRIA 8) all migrate through the Salmon Bay estuary as they move from freshwater to the sea. Salmon Bay is a highly urbanized estuary just west of the Army Corps of Engineer's Hiram M. Chittenden Locks (the Locks) in the City of Seattle and is a difficult transition area for salmon. This report seeks to synthesize information from local studies, literature, and local experts and combine it with information on four sample restoration sites around Salmon Bay. In addition, there are earlier restoration projects to help salmon make the journey through the Locks and estuary that this study can build upon. The study intent is to provide an overview of the estuary area and to use this information to determine the most beneficial actions for Chinook salmon recovery.

The study idea originated when the WRIA 8 Project Subcommittee received a request from the Heron Habitat Helpers community group for funds for their Wolfe Creek daylighting project. The Project Subcommittee did not have the information on the amount of flow that would enter the Salmon Bay area, or its relative benefit, from the daylighting project. The Project Subcommittee realized that more information was needed about the estuary and nearshore as an entire ecosystem in order to make specific project funding recommendations.

This report summarizes Chinook salmon estuarine habitat needs and life history attributes in Salmon Bay through a literature review. To augment the literature review, local experts were interviewed to provide a deeper insight on restoration efforts, challenges, and opportunities within Salmon Bay. A flow duration curve for Wolfe Creek was also developed to compare the potential quantity of freshwater input from Wolfe Creek to other freshwater input areas of Salmon Bay, specifically from the Locks. This report also utilizes a restoration site cross comparison table to determine how much of an influence daylighting Wolfe Creek would have to Salmon Bay compared to other potential restoration activities within the area. The intent of this report is to determine how the proposed daylighting of Wolfe Creek and other possible projects fit into the overall goal of restoring the WRIA 8 Chinook salmon population and help establish a framework for the next steps to achieve this goal.

This study is funded by the Puget Sound Acquisition and Restoration (PSAR) 5% Capacity Funds, a state grant to the WRIA 8 Lead Entity for salmon recovery. A contract was awarded to Taylor Associates, Inc. in April 2009. An Estuary and Nearshore Workgroup was formed from members of Heron Habitat Helpers, the WRIA 8 Project Subcommittee and WRIA 8 Technical Committee to provide guidance and review of the study.

1.1 Organization of this Report

This report is organized into the following sections:

- Introduction: introduces the report, study area, and proposed Wolfe Creek Daylighting Project.
- Literature Review: discusses Chinook salmon estuarine habitat use and life history attributes within Salmon Bay and sites similar in nature to this area. Based on the review, this section also summarizes key findings and data gaps, and provides recommendations for restoration activities within Salmon Bay that could benefit Chinook salmon.
- Flow Analysis: summarizes the results from the Western Washington Hydrology Model, which was applied to Wolfe Creek.
- Cross Comparison of Restoration Sites: presents a cross comparison table estimating ecosystem contributions from four restoration sites in Salmon Bay. Visual renderings of each restoration site and maps showing Salmon Bay attributes are also presented in this section.
- Interviews of Local Experts: summarizes interviews of local experts that were asked a range of questions regarding the survival of both adult and juvenile salmon, recommendations for habitat restoration in and around Salmon Bay, and opinions relative to how to make future habitat restoration efforts more successful.
- Discussion: summarizes information gathered for this report and synthesizes opinions gathered from interviews with local experts in salmon ecology. It discusses the overall benefits to Chinook salmon from potential future daylighting of Wolfe Creek and the other potential restoration sites.
- Recommendations: recommends actions within Salmon Bay.
- Conclusion: summarizes the conclusions from this study.

1.2 Project Area

Salmon Bay

For the purposes of this project, Salmon Bay has been defined as the estuarine area west of the Locks to where it joins Puget Sound to the northwest (Figure 1). Historically, this area was a shallow water estuary with tidal influences extending to the Fremont Cut (SPU 2008). The Army Corps of Engineers constructed the H.M. Chittenden Locks in 1916 effectively changing the outlet of Lake Washington from the Black River to Salmon Bay (Goetz 1999). The Locks truncated the historical estuarine area and Salmon Bay is now characterized by an abrupt transition between fresh and saline waters. Salmon Bay shorelines are currently developed for residential and commercial use with minimal riparian vegetation.

Wolfe Creek Watershed

Wolfe Creek is located several blocks east (approximately 350 ft) of Discovery Park in the Magnolia neighborhood of Seattle, Washington (Figure 1). The proposed Wolfe Creek Daylighting project area encompasses the entire Wolfe Creek Watershed, including Kiwanis Ravine (north section of the watershed) down through Commodore Park to Salmon Bay.

Historically, Wolfe Creek drained much of the north side of Magnolia into Salmon Bay. In fact, the Duwamish Tribal name for Wolfe Creek is "Hwiwa'iq," translated "large, having lots of water." (D. Kostka, pers. comm. 10/11/09). However, over the past 100 years, drainage in the Wolfe Creek watershed has been significantly modified by residential development.

The East and West Forks were modified with fill or culverts when West Government Way was constructed. The two forks come together within Kiwanis Ravine Park (RM 0.15) and flow through the creek's main stem before reaching a culvert just south of the railroad tracks. At this culvert, Wolfe Creek enters the combined sewer system, eventually connecting to the King County sewer line, and flows to the West Point Treatment Plant. There is currently no access for adult or juvenile salmon or other fish to enter Wolfe Creek.

Figure 1. Salmon Bay Estuary Study Area and Vicinity Map with Wolfe Creek Watershed. Shown in aerial view.

2.0 Literature Review

The following literature review describes the estuarine habitat west of the Locks, which includes the freshwater lens and water quality. It also identifies local studies, programs, and projects that provide information on Chinook salmon habitat needs, conditions and use, or potential use, in the Salmon Bay estuary west of the Locks. Key factors affecting juvenile Chinook in Salmon Bay are also identified. While adult Chinook are briefly discussed, the focus of this literature review is on juvenile Chinook due to the importance of estuarine habitats for this life history stage of Chinook. This literature review concludes with a summary of the use of Salmon Bay by juvenile Chinook.

This review is not intended to be exhaustive, but is intended to be tool to help make future decisions about habitat restoration for Chinook in the Salmon Bay estuary.

2.1 Overview of Estuarine Habitat West of the Locks

Habitat

The saltwater area below the Locks lacks many essential functions of a natural estuary such as salt water marshes, shallow intertidal mudflats, overhanging natural vegetation, and freely moving brackish transitional zones. There are numerous bulkheads and ship-holding areas, and the intertidal habitat has been substantially reduced and degraded (NMFS 2008). The shoreline consists of private and commercial residences, some of which overhang into the wetted area during high tide (Footen 2001). Approximately 75% of the Salmon Bay shoreline is retained with artificial structures (Toft et al. 2003), and the riparian zone has largely been developed and urbanized with little remaining natural vegetation. The beaches of Salmon Bay have shallow sloping gradients ranging from 6% to 12%, with sediment compositions from silt to cobble (Footen 2001). Salmon Bay, bisected by a dredged shipping lane, has a maximum depth of 47 feet (NOAA 1984 in Footen 2001).

The Locks have drastically changed the estuarine transition between fresh and saltwater by truncating the brackish mixing zone, which is much larger in undisturbed estuaries (Goetz 1999, WR Consulting 2008). There is currently no other major freshwater input into Salmon Bay other than the input from the Locks operations. Operation of the Locks causes an exchange of fresh and saltwater. This exchange creates atypical circulation patterns resulting in a very small estuarine zone below the Locks. The presence of the Locks creates an abrupt barrier between the freshwater and saltwater environment in the estuary, limiting the ability of juvenile and adult salmonids to choose favorable temperature and salinity levels as they transition between the two areas (WR Consulting 2008).

Freshwater Lens

The size and depth of the freshwater lens and mixing area is the key influence on estuarine habitat below the Locks (NMFS 2008). The total water flow from all sources at the Locks ranges from 520 cubic feet per second (cfs) to 770 cfs from May through June and 330 cfs to 450 cfs from July through September (L. Melder, pers. comm. 1/4/10).

These are the ranges of flows that occur during juvenile Chinook salmon emigration. The size and depth of the freshwater lens is influenced by flow over the Locks, season, and tidal elevation. A surface lens comprised of water with relatively low salinity (less than 20 ppt) may occur in the area immediately downstream from the Lock complex (NMFS 2008). At volumes of 250 to 400 cfs, the surface lens generally extends into the upper 3.3 to 9.8 feet of the water column and may extend beyond the railroad bridge, depending on level of discharge at the Locks and tidal conditions (NMFS 2008). The freshwater lens does not often extend beyond the railroad bridge and is typically located in areas immediately west of the Locks, approximately 380 meters (m) downstream (Simenstad et al. 1999 in SPU 2008). The salinity gradient becomes stronger during periods of low freshwater flow (typically during summer) which limits the size and depth of the freshwater lens.

Salinity West of the Locks

Toft et al. (2005) found salinities approximately 800 feet below the Locks averaged 18.6 ppt at the surface to 24.3 ppt near the bottom during average high tides of +9.3 Mean Low Lower Water (MLLW). Footen (2001) found salinities of 12 ppt at 1 meter depth near the fish ladder when spillways were operational. The study also found that salinities increased dramatically to over 20 ppt at 1 meter depth at the railroad bridge sample locations with salinities reaching 32 ppt beyond the railroad bridge.

Temperature West of the Locks

Dramatic water temperature changes can be seen from upstream and downstream of the Locks. This is due to the warmer freshwater upstream of the Locks (east) and the cooler saline water downstream of the Locks (west). Due to minimal mixing of freshwater and saltwater through the Locks, a large temperature gradient is maintained. Summertime differences can be as high as 8.8° C (NMFS 2008). The average temperature below the Locks is 11 to 14° C during summer (NMFS 2008). In contrast, Footen (2001) found that temperatures (at 1 meter depths) reached 18° C directly adjacent to the Locks (downstream) by mid-June and 16°C at a sample location a few hundred meters downstream of the Locks. This study also found that temperatures never exceeded 14° C at a station 380 m downstream of the railroad bridge. Toft et al. (2005) found average temperatures, approximately 800 feet below the Locks, ranged from 14.5° C at the surface and 13.3° C at the bottom during average high tides of +9.3 MLLW.

2.2 Juvenile Chinook Salmon

2.2.1 Overview of Chinook Use of Estuarine Habitats

Juvenile Chinook salmon utilize estuarine habitat for rearing and growth more than other species of Pacific salmon (Healey 1982, Simenstad et al. 1982). The time of migration from freshwater and size of the fish primarily determine different ways in which each life history strategy uses the estuary and nearshore marine areas (Healey 1991, Fresh 2006). Chinook that enter the estuary at a relatively young age (~1-10 days) and small size (e.g., delta fry migrants, < ~50 mm) tend to spend the most time in estuarine habitats (weeks to months), followed by subyearling salmon (parr migrants) that rear for weeks to months in freshwater before entering the estuary and rearing for days to weeks (Beamer and Larsen 2004, Ruggerone and Volk 2004, Bottom et al. 2005, 2008, Fresh 2006). Some fry migrants may not rear in the estuary, possibly because high flows carry them downstream to marine areas. These small fish inhabit nearshore marine areas of Puget Sound, including pocket estuaries (Fresh 2006). Yearling Chinook, which are large compared with subyearling Chinook, spend the least amount of time in the estuary. After leaving the estuary, Chinook use nearshore marine areas and gradually move offshore as they grow (Duffy et al. 2005). In Puget Sound, parr migrant and delta fry are the most common life history types, although some watersheds produce primarily yearling Chinook (Fresh 2006). Wild Chinook use estuaries longer than do hatchery Chinook (Levings et al. 1986), presumably because hatchery fish are fed in the hatchery for several months before release at a larger size. Rearing and migration of subyearling Chinook in estuarine habitats is as a key phase of their life history because physiological adaptation, foraging, and refugia from predators are critical during this period (Simenstad and Cordell 2000). Estuaries often provide a range of habitat characteristics (e.g. low velocity, temperature, salinity, abundant prey, shallow water) that are favorable to small Chinook.

Estuaries typically provide salinity and temperature gradients that allow Chinook salmon to transition from freshwater to marine water. Chinook are often found in estuarine habitats having lower salinity, suggesting their need for low salinity water before entering marine habitats (Healey 1982). Studies on yearling Chinook have demonstrated that faster growth prior to seaward entry improves their adaptability to saltwater and smolt-to-adult survival (Wagner et al. 1969, Beckman et al. 1999 *in* Beamer and Larsen 2004). McCormick (1994) reviewed the salinity tolerances of many anadromous salmonids and reported that the minimum size for tolerating elevated salinity was approximately 70 mm for subyearling Chinook. Clarke and Hirano (1995) reported that tolerance of juvenile salmon to salinity is influenced by a variety of factors (e.g., size, stage of smoltification), but that sub-yearling Chinook salmon typically develop full osmoregulatory capacity within two or three months. Some fry migrants may enter nearshore marine waters with little or no rearing in fresh or brackish water, but this may occur in response to high river flows and an inability of the fish to find refuge in brackish water. The fate of these recently emerged fish is typically unknown, but presumably they experience higher mortality compared with fish that are able to rear and grow in the estuary.

Fresh (2006) noted that fry migrants may be dependent on pocket estuaries (see below) that can satisfy rearing requirements as the fry migrate along the Puget Sound nearshore. Researchers have shown that survival of marked Chinook salmon is greater when they are transferred to the upper estuary and allowed to feed and grow compared with fish transferred to marine waters just beyond the estuary (Levings et al. 1989, Levings and Bouillon 1997). Experiments such as this are rare, but provide evidence for the influence of estuarine habitat on the survival of juvenile Chinook.

Researchers have hypothesized that diverse habitat types in the estuary can support a greater diversity of Chinook salmon life history types (defined by timing, size, and residence time in the estuary), which in turn increases the resilience and stability of the salmon population to natural changes in the environment (Simenstad and Cordell 2000, Ruggerone et al. 2004). Smaller Chinook (e.g., delta fry migrants) typically use shallow, near-shore habitats, including salt marshes, tidal creeks, and intertidal flats. Larger salmon pass through estuarine habitats more quickly and are often found in relatively deeper habitats that may have somewhat higher salinity. Fresh (2006) noted that optimal conditions for delta fry migrants (<70 mm) include low gradient, shallow water, fine-grained substrates (silts and muds), low salinity, and low wave energy. The hypothesis that diverse habitats can support diverse life history types was tested in the Salmon River, OR, where historical data indicated fry migrant Chinook were not present in the estuary during a period when dikes prevented access to marsh habitat (Gray et al. 2002, Bottom et al. 2005). Following restoration of the wetland habitats, both delta fry migrants and parr migrants were observed in the marsh habitat, suggesting that the restoration of this habitat type may have contributed to the recovery of the Chinook life history type. A number of studies have examined habitat restoration and the relationship to Chinook utilization (e.g., Shreffler et al. 1990, 1992, Simenstad and Cordell 2000, Ruggerone and Jeanes 2004, Simenstad et al. 2005, 2006, Toft et al. 2007).

Pocket Estuaries

Pocket estuaries are small inundations or lagoons along the marine shoreline that provide shallow water habitat protected from waves and long-shore currents (Beamer et al. 2005). A small creek often provides freshwater input to the pocket estuary. Pocket estuaries provide important habitat for juvenile salmon migrating along the shore of Puget Sound, especially fry migrants that spend little time rearing in the river or estuary (Fresh 2006). The benefits of pocket estuaries for juvenile Chinook salmon include protection from marine predators that occupy deeper waters, relatively abundant prey, and shelter from strong shore currents (Beamer et al. 2003, 2005, 2006). Ongoing research near the Skagit River indicated that Chinook were up to five times more abundant in pocket estuaries compared with adjacent nearshore marine areas. The maximum benefit of pocket estuaries for Chinook may occur when they are in close proximity to their natal delta (Fresh 2006).

Importance of Food Sources

The ability of Chinook salmon to obtain food throughout their life is critical to growth, survival, and age-at-maturation (Bilton 1984). Ideally, salmon should be able to find adequate food throughout their migration from freshwater to marine habitats. If fish do not find adequate prey, they may continue migration until adequate resources are found (e.g., MacFarlane and Norton 2002). High growth of Chinook during early life (e.g., freshwater) has been linked to high growth in subsequent life stages (Ruggerone and Volk 2004, Ruggerone et al. 2009), indicating the importance of prey availability during early life. The estuary is a habitat where prey availability, especially epibenthic prey (supported by inputs of detritus) and terrestrial insects, can be sufficiently abundant to support rapid growth (Healey 1982, 1991). Some prey species, such as midges, are selected by Chinook salmon over other prey such as *Daphnia* (Shreffler et al. 1992). Terrestrial insects have relatively high caloric content and may be especially important to Chinook salmon compared to crustaceans (Gray 2005, Cordell et al. 2006).

A variety of habitat types in estuaries may contribute to growth efficiency of salmon. In British Columbia, recapture of marked Chinook fry indicated growth varied significantly between estuaries (3.5% to 5.5% per day), suggesting that rearing qualities vary among estuaries (Healey 1982). Other studies have documented rapid growth in estuaries, e.g.

0.67 mm per day (Bottom et al. 2005, 2008). Abundance and consumption of terrestrial prey by Chinook salmon in Puget Sound is reduced in areas with shoreline armoring and overwater structures (Toft et al. 2007). Salmon that encounter low prey availability and/or high fish densities will likely migrate and search for other suitable habitats, which may lead to greater risk of predation (Fresh 2006). For example, residence time of subyearling Chinook in Skagit Bay increased from approximately 10 days when daily growth was low (0.6 mm) to 50 days when daily growth was high (1 mm per day; Beamer and Larsen 2004). Densities of Chinook in Skagit estuarine habitats increased with greater numbers of fish moving into the estuary then leveled off with higher numbers of Chinook salmon suggesting that a carrying capacity had been reached.

Predation

Predation is typically a major source of mortality for salmon throughout all life history stages. In general, smaller salmon have a greater risk of being killed by predators because they are easier to capture. In some areas, predators may aggregate to feed on salmon fry or smolts that form dense aggregations as they migrate from one habitat to another. Chinook salmon that cannot find adequate habitat in the estuary may experience greater risk of predation as they continue to migrate and search for adequate habitat and prey (Fresh 2006). Although research on salmon predators in estuaries is not common, Footen (2001, 2003) reported that predation on salmon by cutthroat trout, sculpin, and char in Salmon Bay was low.

Simenstad et al. (1982) hypothesized that salmon may utilize habitats within estuaries, in part as a refuge from predators because some predator species may not inhabit shallow, brackish waters that support juvenile salmon. But they also noted that some predator populations can be abundant and may therefore lead to significant predation. Among fish, Simenstad et al. (1982) concluded that sea-run cutthroat trout and steelhead smolts may be the key predators on juvenile salmon that enter estuaries in Puget Sound. Locally, predation by lamprey on juvenile Chinook salmon has been observed in the Duwamish Waterway and in Elliott Bay (Ruggerone et al. 2004). Simenstad et al. (1982) noted that harbor seals and killer whales probably do not pose a significant risk to juvenile salmon, but they are predators on subadult and adult salmon. In other regions, additional predator species have been examined. For example, birds (terns, cormorants, gulls) are a major predator on salmon smolts in the Columbia River estuary (Collis et al. 2001, 2002, Roby et al. 2003) and may be important predators in Salmon Bay. River lamprey may cause exceptionally high rates of mortality of Chinook in the Fraser River plume (Beamish and Neville 1995). However, Macdonald et al. (1988) reported relatively little predation by fish on salmon near Deepwater Bay, British Columbia.

2.2.2 Juvenile Chinook Estuarine Use of Salmon Bay

Size

Most Lake Washington Chinook salmon juveniles migrate to the ocean in their first year, and are thus considered “ocean-type” fish (Celedonia et al. 2008, Kiyohara and Volkhardt 2007, 2008). Chinook from the Cedar River enter Lake Washington over an extended period from January through at least mid-July (Kiyohara and Volkhardt 2008). There is a wide variation in outmigrant size, due to various life history traits (Goetz 1999). This variation may be an artifact of Issaquah and University of Washington releasing larger hatchery fish. From January through mid-April in 2006, the weekly mean fork length of Chinook fry caught in the Cedar River fry trap averaged 41.3 mm. During screw trap operation (mid-April to mid-July), sizes ranged from 38 mm to 116 mm and averaged 82.8 mm (Kiyohara and Volkhardt 2007). The Lake Washington Chinook stock is atypical in that it experiences an extended period of lake-rearing. Based on historical information, most Chinook migrate out through the Locks and into Puget Sound later than most other river systems (Goetz 1999).

At the Locks, juvenile Chinook salmon have been caught at sizes much larger than other systems. Studies during peak migration (May-June) have shown that average lengths of Chinook caught west of the Locks ranged from 100 mm to 112.5 mm. The mean size was 110 mm (range 82 to 137 mm) in 1967 and 105 mm in 1998 (USACE 1999a *in* NMFS 2008, Warner and Fresh 1999). Footen (2001) caught Chinook with lengths of 100 mm and Toft et al. (2005) caught Chinook approximately 800 feet below the Locks (north side) with an average length of 112.5 mm. The combination of lake-rearing juveniles and delayed migration are hypothesized to be the cause of the larger Chinook smolts produced from Lake Washington (Goetz 1999, NMFS 2008). King County conducted beach seining below the Locks in May and early-June 2000, and caught small numbers of unmarked juvenile Chinook measuring approximately 70 mm in length in addition to larger marked and unmarked Chinook greater than 100 mm (H. Berge, pers. comm. 7/12/09). This indicates that although most subyearling Chinook pass through the Locks at a larger size, a small portion of the population migrate through the Locks at lengths less than 80 mm or are migrants from nearby watersheds.

Timing and Abundance

Movement of juvenile Chinook salmon into Salmon Bay through the Locks has been documented from May through September with peak passage occurring during late-May and early-June (Celedonia et al. 2008, DeVries et al. 2007). Smolts may have a higher probability of residualizing in Lake Washington as the outmigration season progresses and surface water temperatures warm as observed in lakes and reservoirs of the Columbia Basin (USACE 1999b). The Montlake Cut and Sammamish River may pose thermal barriers later in the season (July and August) with surface temperatures rising to greater than 20^{o} C. Residualized fish marked with PIT tags in WRIA 8 tend to be among the first to pass the Locks the following year(s) as noted by (DeVries et al. 2007).

While smolt outmigration at the Locks has been studied for years and relative timing is understood, counts of outmigrants are still estimates based on survival from PIT tagging stations to the PIT tag readers in the smolt flumes (DeVries et al. 2007). Hatchery production goals are 2.1 million Chinook for Issaquah Creek Hatchery and 180,000 for the University of Washington Hatchery (Celedonia et al. 2008). Estimated non-hatchery Chinook outmigrants for both the Cedar River and Bear Creek in 2006 were 35,190 smolts and 139,921 fry. Estimated outmigrants in 2007 was 27,041 smolts and 127,790 fry (Kiyohara and Volkhardt 2007, 2008). The total production of natural Chinook in the Lake Washington Basin is unclear and varies upon weather and environmental conditions, mortality, and predator interactions. A conservative estimate of approximately 100,000 natural Chinook and two million hatchery Chinook likely make their way through the Locks into Salmon Bay and Puget Sound on an average annual basis (Celedonia et al. 2008, Kiyohara and Volkhardt 2007, 2008).

Salinity and Temperature Effects

Juvenile Chinook salmon are forced to move almost instantaneously from freshwater to saline water as they pass through the Locks. In some cases they move from near zero ppt to 28 ppt in minutes or less, with a temperature difference that can reach 16° C without the benefit of a natural brackish water transition zone for physiological adaptation (NMFS 2008). The salinity directly below the smolt flumes at the Locks likely varies depending upon tide, flow of freshwater through the flumes, and weather. PIT-tagged juvenile salmon were caught below the Locks in an area where surface salinities ranged from 15 to 20 ppt, demonstrating a possible rapid osmotic transition for these fish (DeVries et al. 2001 *in* SPU 2008). Salinity tolerance increases rapidly once Puget Sound Chinook fingerlings reach a size greater than 55 mm and even direct transfer to seawater results in low mortality (NMFS 2008, Wagner et al. 1969). The large size of the Chinook caught below the Locks suggests that these fish are capable of rapid transition to saltwater (Wagner et al. 1969). Although Chinook appear to be capable of this rapid transition, additional stress and possible delayed mortality may occur. The transition from freshwater to saline water for Chinook passing through the Locks has not been thoroughly studied.

Most studies on the effects from temperature change on juvenile salmonids have focused upon sudden temperature increases, which is not the case for juvenile Chinook salmon passing through the Locks. The instantaneous transition from warm water to cold water may result in elevated stress levels, reduction in physiological activity and/or reduced feeding rates; however there is no current data to support this. The mixing zone and small freshwater lens below the smolt flumes create a small brackish area that may help Chinook salmon acclimate to both salinity and temperature.

Estuarine Residence

Studies have shown that estimated juvenile Chinook salmon (hatchery and natural) residence time within Salmon Bay ranges from less than an hour to 31.2 days (NMFS 2008, DeVries et al. 2007, 2005, Johnson et al. 2004, Simenstad et al. 2003, Footen 2001). Using PIT-tags, Footen (2001) found a mean residence time of 15 days for Chinook in Salmon Bay. Simenstad et al. (2003) found that residence times of Chinook in Salmon Bay ranged between 1.2 to 31.2 days. In another study, hatchery Chinook spent up to 3 weeks in Salmon Bay; while a small sample of natural fish were there less than 1 week (DeVries et al. 2005). Hatchery Chinook may reside longer in the inner bay below the Locks than natural origin Chinook, possibly reflecting an abundant food supply from the Lake Washington Ship Canal (DeVries et al. 2007). Although a small number of fish were sampled, acoustic studies in 2004 found that tagged Chinook and Coho salmon took 13 and 11 hours on average respectively to reach the outer Shilshole Bay receivers after passing the Locks (NMFS 2008, Johnson et al. 2004).

PIT-tag data suggest that juvenile Chinook spend relatively little time in the lower salinity lens below the Lock complex before making the transition to higher salinity water (NMFS 2008). This is supported by data from DeVries et al. (2005) that suggests that natural origin smolts of all species spend about 12 hours or less in the lower salinity lens below the Locks. Simenstad et al. (2003) found during a three day "blitz" sampling event (June 18-20), a rapidly declining residence time for PIT-tagged Chinook from the Lake

Washington system in inner Salmon Bay suggesting only approximately 1-3 day residence time.

Recycling

A small portion of salmon smolts recycle through the Locks (DeVries et al. 2007). Recycling occurs when these fish pass through the Locks and re-enter the Ship Canal. Hatchery Chinook salmon smolts released directly into the flumes as part of calibration testing and those from the UW Hatchery were found to recycle the most (DeVries et al. 2005). A weaker recycling behavior was found for natural origin fish. However, some natural origin Chinook and Coho salmon have been observed to recycle more than twice. Recycling may indicate extended rearing times near the Locks and/or the need for further acclimization to saltwater (DeVries et al. 2007).

Habitat Use in Salmon Bay

Specific habitat use within Salmon Bay by juvenile Chinook salmon has not been extensively studied. Simenstad et al. (2003) found during May and June that most catches of all species of juvenile salmon were concentrated in inner to mid-Salmon Bay (typically between the Locks and a sampling site approximately 950 m below the Locks on the north shore) (Figure 2). After June, catches tended to be distributed more evenly around Salmon Bay creating an evident gradient in juvenile salmon density along the estuarine gradient, from beach seine sites immediately below the Locks to the outer bay with increased catches near the Locks (Simenstad et al. 2003). This appeared to be most influenced by a trend in decreasing hatchery Chinook at increasing distances from the Locks (Simenstad et al. 2003).

Footen (2001) found that the southwest corner of Salmon Bay yielded the greatest catch of hatchery and natural origin Chinook (Figure 2). Hatchery Chinook were caught at all locations within Salmon Bay (three sample sites were located on both the west and east side of Salmon Bay), and wild Chinook were caught at all locations except for the Statue sites (northeast corner of Salmon Bay). Footen (2001) also reported that Chinook had a slight preference for large cobble substrate, no preference for small cobble, no preference for sand, and a high preference for silt substrate. However, the sample size in this study was relatively small and not representative of Salmon Bay as a whole. Substrate preferences for Chinook in Salmon Bay have not been thoroughly studied.

A smaller scale habitat use study was conducted in the Salmon Bay Natural Area (SBNA) by Toft et al. (2005). The study focused on monitoring the before-restoration biological attributes related to juvenile salmonid utilization of the SBNA (Figure 2). Results showed that although snorkel observations of juvenile Chinook salmon were greater at a reference site compared to a site with overwater structures, these differences were not significant (Toft et al. 2005). They also found that overwater structures appear to affect salmonid movements, as juvenile salmonids were never observed underneath either the overwater structure or the floating dock at the site (Toft et al. 2005).

Figure 2. Sample locations for habitat use by juvenile Chinook salmon.

2.2.3 Key Factors Affecting Juvenile Chinook in Salmon Bay West of the Locks

Factors that constrain productivity of juvenile Chinook salmon include factors that cause immediate death or injury to individual fish and factors that lead to greater risk of mortality at a later time period. The key natural factor that may cause immediate death of salmon is predation. Other sources of immediate mortality may involve passage of juvenile salmon through the plumbing system of the Locks (SPU 2008). Factors that may potentially constrain productivity of juvenile salmon in Salmon Bay west of the Locks include habitat quantity and quality, food sources and supply, and osmoregulation during smoltification. These factors are discussed below.

It is noteworthy that the survival rate (release to recovery in fisheries and hatcheries) of tagged subyearling Chinook salmon produced by hatcheries in Puget Sound is typically low, averaging approximately 0.4% during 1984-1997 (Ruggerone and Goetz 2004). Survival of subyearling hatchery Chinook released into the Lake Washington drainage (only three years of data) was similar to the average survival for hatchery Chinook salmon in Puget Sound (Ruggerone and Goetz 2004).

Predation

In the Salmon Bay area, potential predators of Chinook salmon include marine mammals, birds, and fishes. Relatively little data has been collected on predation rates on juvenile Chinook migrating through Salmon Bay west of the Locks. Some predation on Chinook in Salmon Bay is to be expected, but there is no evidence that predation on Chinook is unusually high. Within the Locks, gulls consumed approximately 7% of the estimated juvenile salmon population during one year of study (Weitkamp and Ruggerone 2000). Gulls and fishes may also consume smolts immediately downstream from the Locks where salmon may be disoriented after passing through the Locks or spillways. Seattle's largest nesting colony of Great Blue Herons (located in Kiwanis Ravine) may also contribute to predation on Chinook below the Locks (D. Kostka, pers. comm. 10/11/09).

Footen (2001, 2003) examined predation on salmon by fishes collected by beach seine in Salmon Bay during 2000. Sea run cutthroat (*Oncorhynchus clarki*), followed by staghorn sculpin (*Leptocottus armatus*) and char (*Salvelinus spp.*) were the primary predators in Salmon Bay. Consumption of juvenile Chinook salmon by these predators was low, possibly because smaller prey such as sandlance (*Ammodytes hexapterus*) and juvenile chum (*O. keta*) were more abundant. Predation by fishes in deeper offshore areas of Salmon Bay has not been examined. Lamprey marks have been detected on juvenile Chinook in the Locks, apparently from interactions in Lake Washington (Warner and Fresh 1999), but lamprey predation in Salmon Bay west of the Locks has not been examined.

Habitat

The effect of habitat quality and quantity on Chinook salmon survival is difficult to predict because habitat does not directly cause mortality. Instead, Chinook will likely continue their migration along the Puget Sound nearshore until they find sufficient prey and habitat, while attempting to avoid predators. Fresh (2006) hypothesized that shoreline armoring and overwater structures may reduce prey availability and/or lead to greater predation risk for Chinook. Available data suggests that most tagged hatchery Chinook salmon spend approximately 10-20 days in Salmon Bay (Johnson et al. 2004, DeVries et al. 2005). Few natural Chinook were tagged and recaptured, but few captured natural salmon spent less time in Salmon Bay compared with hatchery Chinook. Compared to other undisturbed estuaries where Chinook smolts may spend up to 90 days (Levings et al. 1986) in nearshore habitat, the time period that Chinook appear to spend in Salmon Bay is brief (Footen 2001). Rapid movement through Salmon Bay may be related, in part, to the relatively large size of the subyearling Chinook entering Salmon Bay (Footen 2001). Few fry migrant or delta fry life history forms (i.e. small fish) emigrate from the Lake Washington watershed. These fish experience high prey availability and rapid growth in Lake Washington (Koehler et al. 2006). Therefore, the ability of juvenile Chinook to grow rapidly in Lake Washington prior to reaching Salmon Bay may reduce the dependency of these fish on estuarine habitats compared to Chinook in other watersheds.

Nevertheless, the lack of estuarine habitat in Salmon Bay may also contribute to the rapid movement of fish through Salmon Bay. In comparison, residence time of natural parr migrants in the industrial Duwamish Waterway was approximately 15-28 days and approximately 10 days less for hatchery parr migrants based on strontium levels in daily otolith rings (Ruggerone and Volk 2004). These salmon likely spent most of their time in the transition zone (Turning Basin), a productive salmon habitat where freshwater initially mixes with marine water and where shallow mudflat habitat and limited tidal channels are available. This type of transition zone is missing from Salmon Bay. Lake Washington Chinook salmon (avg. ~100-110 mm; Footen 2001) are bigger than Duwamish salmon (avg. 71 mm; range: 40-100 mm) at the time they encounter brackish water (Ruggerone et al. 2006), and this size difference may contribute to differential residence time in the brackish marine areas. Conceivably, the rapid growth of Chinook in Lake Washington and the lack of estuarine habitats in Salmon Bay contribute to the lack of delta fry migrants passing into Salmon Bay.

Interestingly, juvenile chum salmon, a species that is not produced in the Lake Washington watershed, is the most abundant species of salmon in Salmon Bay (Footen 2001, Simenstad et al. 2003). Chum salmon are highly dependent on nearshore marine habitats in Puget Sound (Fresh 2006).

Food Resources

Available data indicate that prey abundance for Chinook salmon is relatively high within Salmon Bay, although most prey production originates from Lake Washington rather than from within Salmon Bay. Prey for Chinook in Salmon Bay is dominated by zooplankton originating from freshwater areas above the Locks (Simenstad et al. 2003). Densities of zooplankton in Salmon Bay (mostly *Daphnia* sp.), based on vertical plankton hauls, were approximately 60% of those above the Locks, but they were approximately 1.7 times greater than densities in nearby Puget Sound where zooplankton were almost entirely estuarine and marine taxa. Potential epibenthic prey (e.g. harpacticoid copepods, gammarid amphipods) were considerably more abundant in nearby Puget Sound compared with Salmon Bay.

Juvenile Chinook salmon sampled by beach seine in Salmon Bay primarily consumed freshwater zooplankton and to a lesser degree pelagic marine/estuarine zooplankton

(Simenstad et al. 2003). Insects, epibenthic crustaceans, and polychaete worms were more prominent in the diets of juvenile salmon from other nearby nearshore Puget Sound areas. These prey items were also slightly more numerous in unmarked (naturally-produced Chinook) than hatchery Chinook salmon. Simenstad et al. (2003) concluded that neither littoral production of epibenthic prey within Salmon Bay nor input of riparian insects appear to play a large role in supporting juvenile salmonids in Salmon Bay, although these sources may be more important in nearby nearshore Puget Sound areas. Simenstad et al. (2003) noted that Salmon Bay is unique in that Chinook salmon in other estuaries typically consume locally-produced prey (e.g., epibenthic crustaceans and insects) rather than freshwater zooplankton originating from upstream areas.

Freshwater/Marine Transitions

Juvenile Chinook salmon experience an abrupt change in salinity and temperature as they pass from the Locks into Salmon Bay. Size of Chinook is a key factor that influences their ability to tolerate and acclimate to marine water. Average size of Chinook entering Salmon Bay is relatively large (~100-110 mm) and most fish appear to be greater than 80 mm (Warner and Fresh 1999, Footen 2001, Toft et al. 2005, DeVries et al. 2007, USACE 1999a in NMFS 2008). The large size at which most Chinook enter Salmon Bay suggests Chinook are not directly killed by this transition, but researchers have raised the question of whether these large subyearling salmon may experience elevated stress. Some Chinook have been observed to recycle through the Locks, possibly in response to the abrupt change in water quality (DeVries et al. 2005, 2007). Most Chinook appear to pass through the low salinity lens immediately below the Locks relatively quickly, but this could be in response to the lack of suitable habitat in this area. The abrupt decline in temperature experienced by juvenile salmon would alter the rate in which they process food, and it could cause a change in feeding behavior, although diet studies suggest Chinook salmon are feeding in Salmon Bay (Simenstad et al. 2003).

2.3 Adult Chinook Salmon

Estuary Use and Timing

Adult Chinook salmon typically utilize estuaries for migration corridors freely moving up and down the channel selecting preferable temperatures, salinities, and current velocities. Adults may hold in estuaries until river flows are adequate for upstream migration and/or until they attain the proper maturation stage (Healey 1991). Fresh and saltwater gradients with adequate temperatures and dissolved oxygen (DO) levels are significant characteristics of estuaries for immigrating adult salmon (Healey 1991). However, Lake Washington Chinook must negotiate passage through the Locks while encountering large temperature, salinity, and DO gradients as they migrate from the ocean to their spawning grounds.

Peak returns of adult Chinook salmon occur in mid-August and 80% of the return typically passes through the Locks between July 25 and September 12, corresponding to the period of highest Lake Washington surface water temperatures (NMFS 2008). As Chinook swim toward the Locks in Shilshole Bay, they occupy less saline, warmer surface waters during night and morning hours, moving during mid-afternoon to deeper waters where temperature is lower and salinity is relatively higher (USACE 1999c).

Returning adult Chinook salmon hold in Salmon Bay for unknown periods of time (likely varying with discharge from Locks) while acclimating to changes in salinity and temperature associated with discharge of freshwater from the Locks (G. Ruggerone, pers. comm. 11/09/09). Research indicates that as many as 30 percent of tagged adult Chinook salmon that passed through the fish ladder move back downstream below the Locks to return to the cooler more saline water (Fresh et al. 1999, unpublished).

Adult Chinook salmon encounter an abrupt change in temperature and salinity as they pass from the relatively cool, saline waters of Salmon Bay to the warm, fresh water immediately upstream of the Locks. During 1998, when surface water temperatures above the Locks were exceptionally warm (22-23°C), Chinook salmon held in the Locks forebay for an average of 19 days (range: 1.9-45.9 days) (Fresh et al. 1999, unpublished). Some adult Chinook salmon appear to seek out an area upstream of the Locks where water is cooler and more saline even though DO content is low (Timko et al. 2000).

Predation

The only known predation risk to adult salmon in Salmon Bay is from marine mammals downstream of the Locks (SPU 2008). California sea lions, which are known to kill adult steelhead in Salmon Bay, typically arrive in the area after most adult Chinook salmon pass through the Locks (USACE 2001 *in* NMFS 2008). Harbor seals are present in Puget Sound year-round and are more abundant than sea lions. They commonly prey on salmon, but predation by harbor seals at the Locks has been observed infrequently (NMFS 2008). Although one or more adults can be seen on an irregular basis by the fish ladder, the number of adult Chinook taken by harbor seals is believed to be a small percentage of the run (USACE 2001 *in* NMFS 2008).

2.4 Summary

Salmon Bay appears to be a transitory habitat for juvenile salmonids of both Lake Washington and Puget Sound origins (Simenstad et al. 2003), while Lake Washington and the Ship Canal (upstream of the Locks) appear to act as a pseudo-estuarine environment prior to juvenile salmon emigration (Celedonia et al. 2008). This is supported by the consumption of freshwater zooplankton, short residence time in the freshwater lens, and somewhat rapid movement by juvenile Chinook through Salmon Bay.

Rapid movement of juvenile Chinook salmon through Salmon Bay may be due to the absence of natural estuary elements in addition to their large size as they transit through the habitat. Salmon Bay lacks key estuarine habitat features such as pocket beaches, salt marshes, tidal creeks, and large intertidal flats. Furthermore, shoreline habitat in Salmon Bay has been significantly altered by bulkheads, rip-rap, and overwater structures. Shoreline vegetation has also been influenced by buildings and roads. Except for the broadening of the channel (south side) immediately west of the railroad bridge, there is little shallow water habitat in Salmon Bay to support juvenile Chinook foraging.

The estuarine portion of Salmon Bay is limited by the extent of the freshwater lens below the Locks. The freshwater lens typically extends to an average depth of seven feet and does not often extend past the railroad bridge below the Locks (NMFS 2008). This small area of freshwater lens and the lack of associated shallow intertidal habitat in this zone may accelerate passage through this area, leading to reduced opportunity for growth prior to entering Puget Sound (Footen 2001). The reduction of this important habitat feature may also be inducing stress and delayed mortality through a rapid transition from warmer freshwater to cooler saline water. However, there are no data to support an increase in mortality to Chinook smolts below the Locks as a result of an insignificant freshwater lens (NMFS 2008).

Although studies have been conducted on food consumption, habitat use, and, to some degree, the effects of rapid transition for juvenile Chinook, further studies are needed to understand the utilization of Salmon Bay by Chinook. We suggest conducting studies that include:

- Research on the effects of rapid transition through the Locks to Salmon Bay, specifically whether or not there is any delayed mortality and the effects of salinity and temperature transition on osmoregulation for Chinook.
- Fine scale habitat use by Chinook within Salmon Bay.
- Diet analyses throughout the migration period and at multiple sites within Salmon Bay, including mid-channel areas where salmon may have different size and feeding characteristics. This would help determine if Chinook are primarily foraging on freshwater prey below the Locks, or whether they are spending time and energy foraging on typical estuarine prey items found within other reaches of Salmon Bay.

The Ship Canal, Locks, and Salmon Bay represent highly modified habitat. Creation of "natural" estuarine habitat in Salmon Bay while focusing upon life history processes and needs of Chinook salmon could be beneficial for Chinook (Toft et al. 2005). Based on this literature review, we suggest the following actions within Salmon Bay that would improve Chinook habitat below the Locks:

- a large increase in freshwater input
- creation of multiple tidal marshes and intertidal flats
- large scale removal of overwater structures
- increasing riparian vegetation across the entire shoreline

Habitat restoration projects that include these elements should improve the linkage between shoreline habitat and Chinook utilization of Salmon Bay. Salmon Bay lacks natural estuarine elements, and based on this literature review we suggest habitat restoration or enhancement projects that:

- improve food production
- improve refuge functions
- improve rearing opportunities

These actions could benefit the growth and survival of Lake Washington juvenile Chinook salmon. While such habitats would be beneficial, it is worthwhile to note that such benefits may be less for the relatively large parr migrant Chinook that presently enter Salmon Bay from Lake Washington compared with smaller delta fry and parr migrants that enter other Puget Sound estuaries. However, restoration projects west of the Locks may benefit Chinook that exit the Locks at a smaller size (albeit in smaller numbers), as well as other Puget Sound juvenile salmonids known to utilize Salmon Bay. Further analysis of the specific benefits of daylighting Wolfe Creek to Chinook are discussed in Chapter 6.

3.0 Flow Analysis

One aspect of this report is to analyze the benefits to Chinook salmon from the freshwater input to Salmon Bay that would result from the proposed daylighting of Wolfe Creek. In order to analyze the potential flow contribution a continuous simulation flow modeling was performed utilizing Hydrologic Simulation Program Fortran (HSPF) and the Western Washington Hydrologic Model version 3 (WWHM3). This model uses 50 years of hourly precipitation data to model flow and runoff in watersheds within western Washington.

The current Wolfe Creek watershed is composed of approximately 87 acres of residential, park, and forested areas along the West Fork primarily. After reviewing previous data for Wolfe Creek, as well as verification with a site visit, it was concluded that approximately 43 acres of basin area west of 36th Avenue West no longer contribute surface flows to Wolfe Creek. This area is composed of predominantly open fields and forests, with some scattered roads and buildings. Surface runoff from this area gets intercepted by storm drainage west of 36th Avenue, and is redirected north into a different drainage basin. However, subsurface flow, including groundwater flows, continues to flow east into the current basin. This area is referred to as the "upper basin". The remaining 44 acres of the Wolfe Creek watershed east of 36th Avenue West and north of West Thurman Street flows entirely to Wolfe Creek and is composed of urban residential and forested areas. This area is referred to as the "lower basin" (Figure 1).

Two separate scenarios were analyzed for this project. The first included surface flows from only the lower basin and subsurface flows from both the lower and upper basin. This first scenario represents the existing drainage basin. The second scenario included all flows from both the lower and upper basins. The two scenarios were analyzed to determine the potential additional flow from the inclusion of surface flows from the upper basin back into the lower.

The drainage area was divided into smaller subbasins to facilitate calculating areas and flow directions (Appendix A-Flow Model Information). The subbasins were then subdivided into land use types: forest, pasture, residential impervious (rooftops and roads), and residential pervious (lawns). The residential areas were divided at a ratio of 60% impervious / 40% pervious. This ratio was verified with a check of several of the subbasin residential areas. The land was also separated by soil types. The majority of the basin is well draining Esperance Sand/Silt. However, the forested portion and surrounding areas of the creek ravine in the north section of the basin is poorly draining Lawton Clay (Appendix A).

The extent of the analysis was limited to the months of March through July, with each month being analyzed separately. This time range represents the primary juvenile salmonid migration period, with the peak of juvenile Chinook occurring in May and June. Original results can be found in Appendix A.

The potential differences in the March through July flows between the two scenarios can be best seen during periods of high flow. The maximum flows that the creek can produce during this time period, including only the "lower basin" analysis, is approximately 11.5 cfs (Figure 3). Flows from the both the upper and lower drainage area can produce approximately 15.4 cfs maximum. This corresponds to a 25% increase in peak flows with the inclusion of the surface flow from the upper basin. When only low flow periods are observed, the surface flow from the upper basin only adds a minimal amount of flow to the creek.

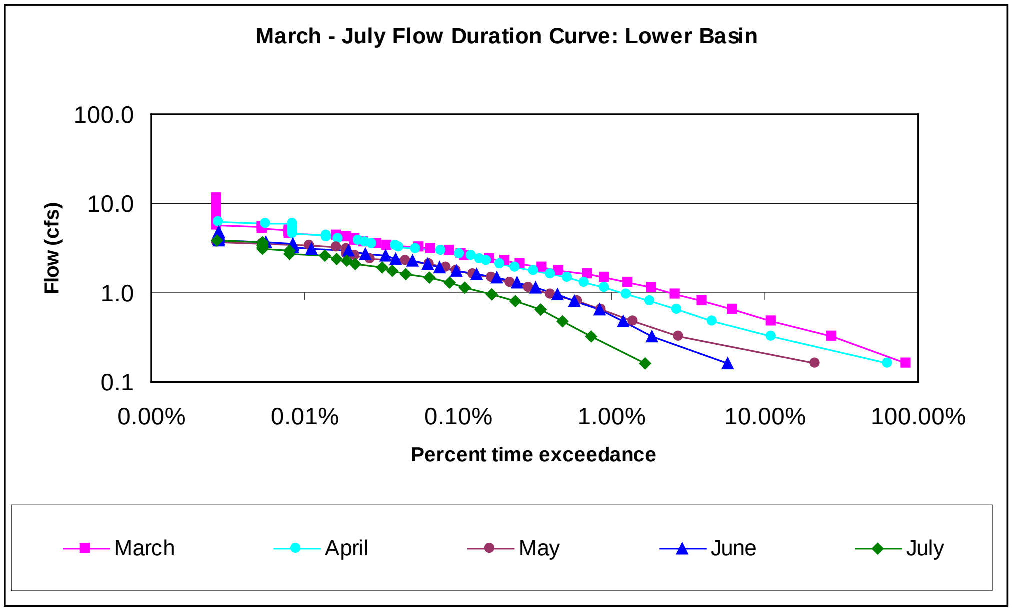


Figure 3. Flow duration Curve for Lower Basin Scenario.

The values for 1% exceedance, which defines the flows occurring 99% of the time, range from approximately 2 cfs in March to 0.2 cfs in July for the lower basin scenario. This means that flows of 0.2 to 2 cfs will be seen 99% of the time during March to July. With the inclusion of flows from the upper basin, 1% exceedance flows range from approximately 2 cfs in March to 0.4 cfs in July (Figure 4.). In May and June, flows are approximately 0.8 cfs and 1.0 cfs for the lower and upper basins, respectively. This indicates that during the months of May and June, flows within Wolfe Creek do not exceed 1cfs more than 1% of the time. Additionally, when the flow rates corresponding to 10% exceedance are noted for May and June, the months of particular significance to salmonid migration, the creek has approximately 0.1 to 0.2 cfs of flow in either scenario. The difference in flows between the lower and upper basins scenarios during the peak Chinook emigration period of May and June is minimal (0.2 cfs).

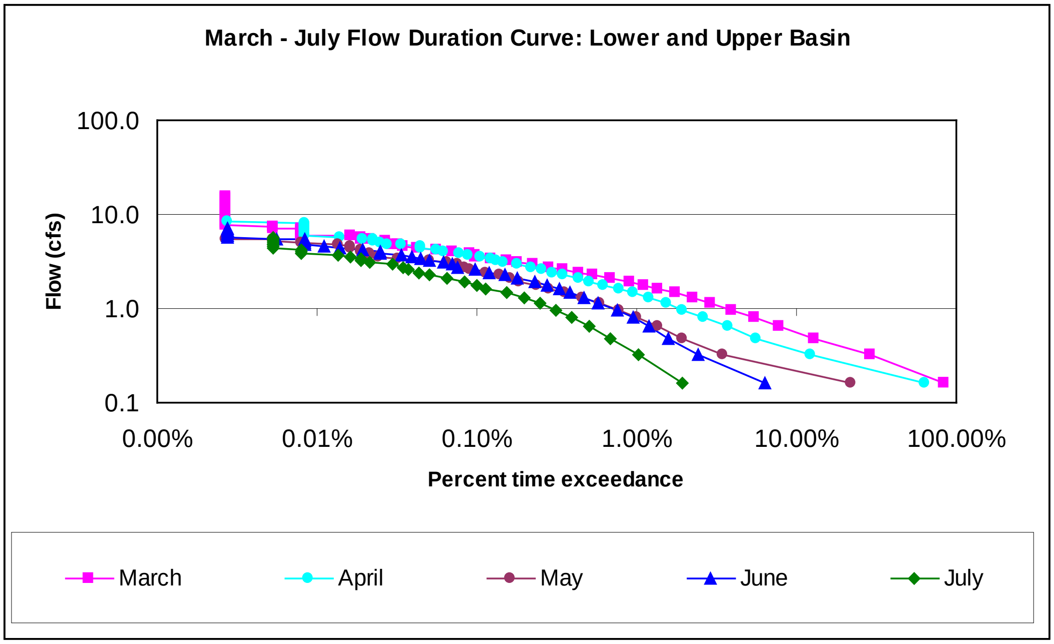


Figure 4. Flow Duration Curve for Lower and Upper Basin Scenario.

4.0 Cross Comparison of Restoration Sites

Four potential restoration sites are presented in this section. The sites were compared in order to determine how much of an influence each site would have on Salmon Bay relative to each other. Restoration sites that are used for comparison include Wolfe Creek, Salmon Bay Natural Area (SBNA), Ray's Boat House, and West Sheridan Street End. Figure 5 shows the proximity of the four restoration sites to each other and relative positions within Salmon Bay. Restoration sites were chosen based on available habitat within Salmon Bay in conjunction with these habitats residing on public land. These sites were also identified as potential restoration opportunities in the Greater Salmon Bay Concept Plan (Brennan 2006). It should be noted that three of the restoration sites are hypothetical sites, while restoration at the SBNA is complete. These restoration sites have not been fully analyzed for ecological contributions, but are specifically used to compare possible benefits to Chinook salmon.

4.1 Wolfe Creek

A number of studies and concept designs have been developed for the proposed daylighting of Wolfe Creek (WR Consulting 2008). Based on this review, the research team used a concept design for Wolfe Creek that included a short daylighted section flowing through Commodore Park that emptied into a small marsh area (Figure 6). The influx of freshwater into the marsh has potential to create a small estuarine mixing zone at the mouth of Wolfe Creek (Figure 7). For this study, the specific location of the daylighted portion of Wolfe Creek was determined primarily by the topography of the site (Figure 8). Other options were considered in Brennan (2006), but this was the most realistic option for this analysis.

4.1.1 General Benefits of Daylighting Wolfe Creek

Daylighting Wolfe Creek would create new upland riparian and instream habitat, reconnect the creek to the saltwater of Salmon Bay, and create a localized marsh environment at the mouth of the creek. Creating new instream and upland riparian habitat would increase the availability of terrestrial food sources, as well as increase the recruitment of wood and detritus. Riparian habitat would also create cover for migrating juvenile salmonids.

The functional values of creating an open channel are important benefits. Exposure to sunlight, air, and soil can allow growth of aquatic and riparian vegetation that can improve water quality by taking up organic and inorganic pollutants, and support development of an instream food web including invertebrate prey organisms (Pinkham 2000).

Daylighting would also remove water from the combined sewer system which Wolfe Creek currently enters. However, peak flows during winter or storm events is insignificant in comparison to the total flow the King County wastewater system receives (J. White, pers. comm. 8/13/09). Other daylighting benefits include increased

Figure 5. Location of Wolfe Creek Daylighting compared to three example restoration sites in Salmon Bay.

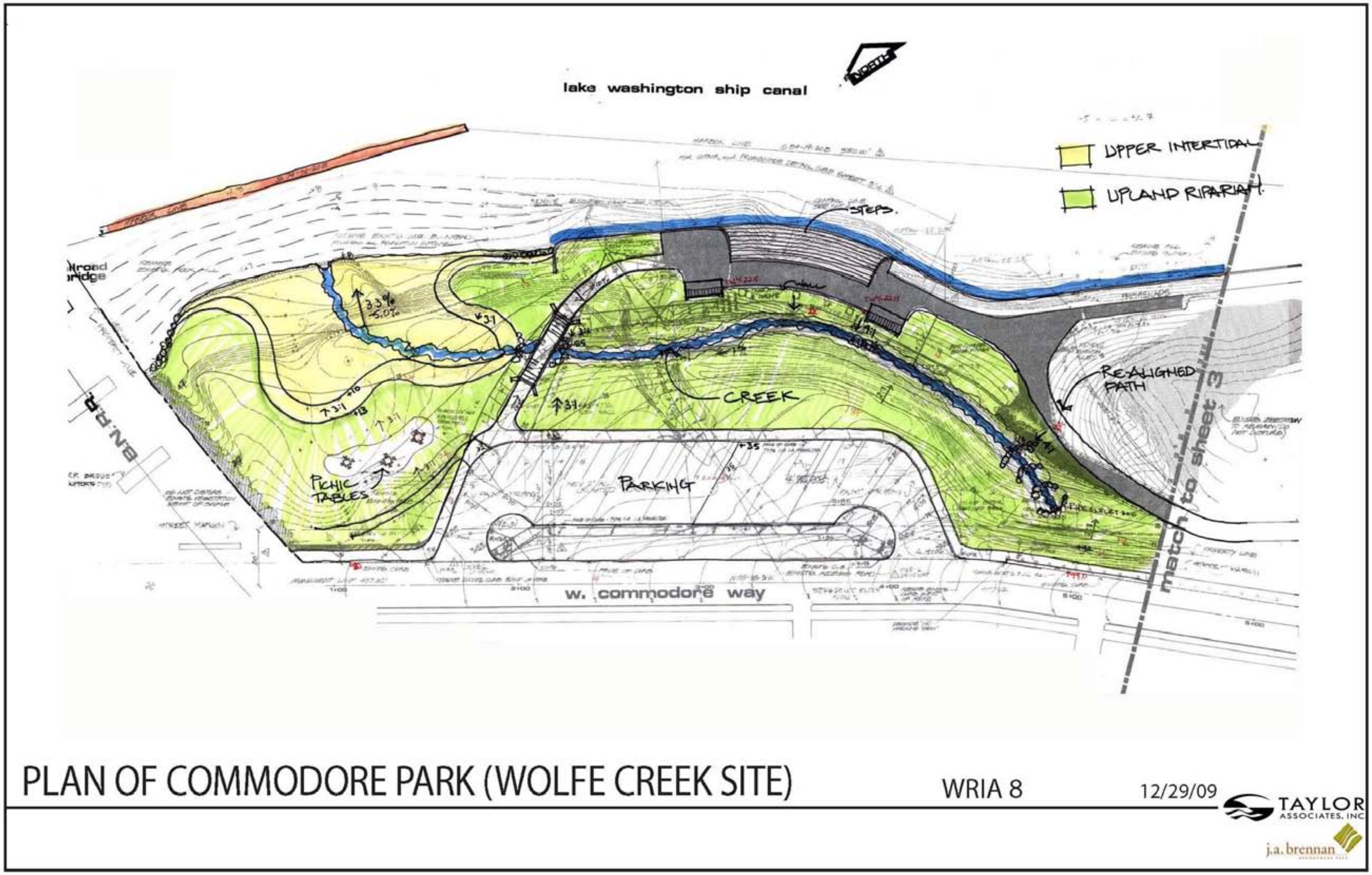


Figure 6. Visual rendering of Wolfe Creek restoration site.

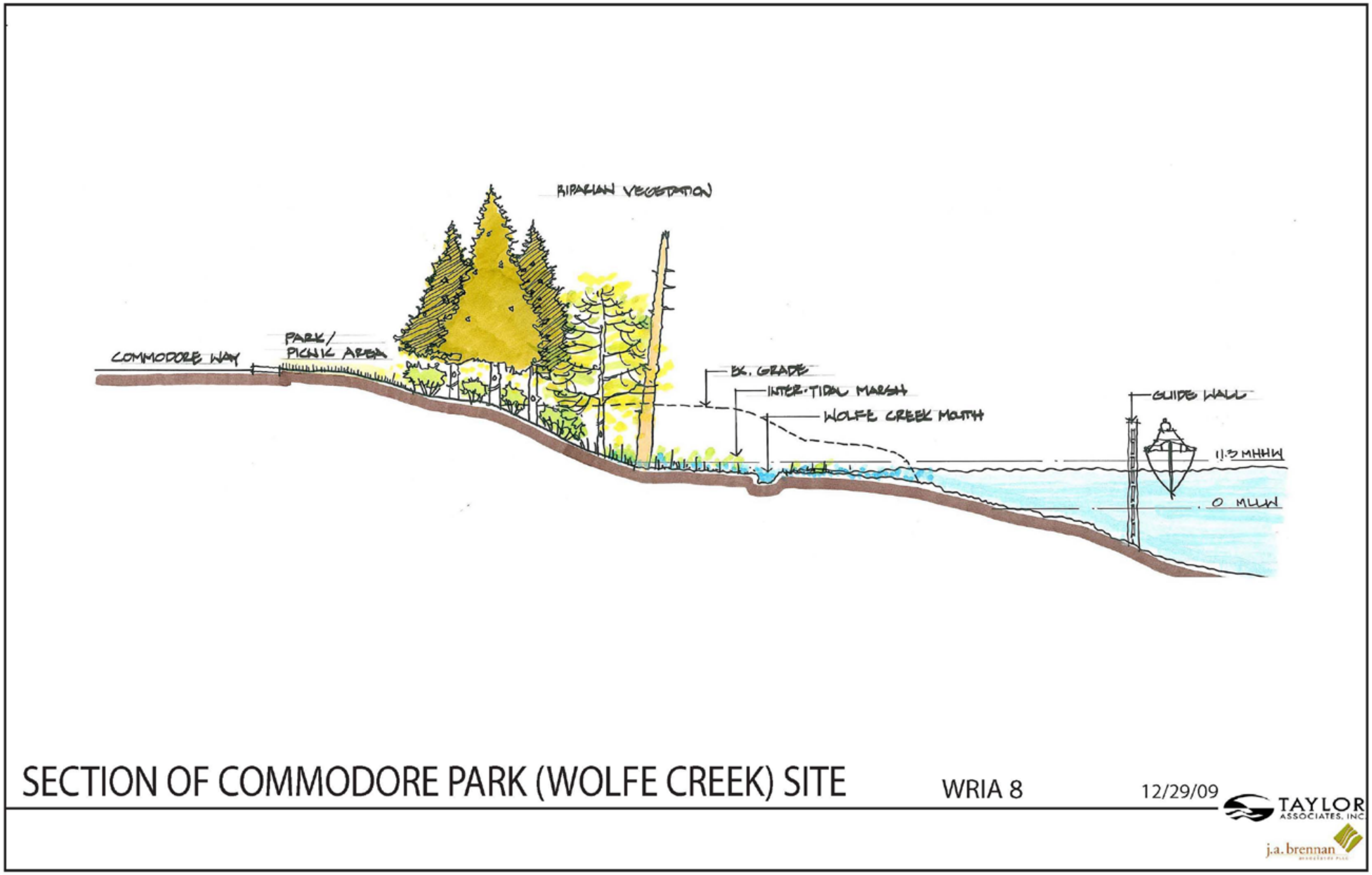


Figure 7. Cross sectional view of Wolfe Creek restoration site.

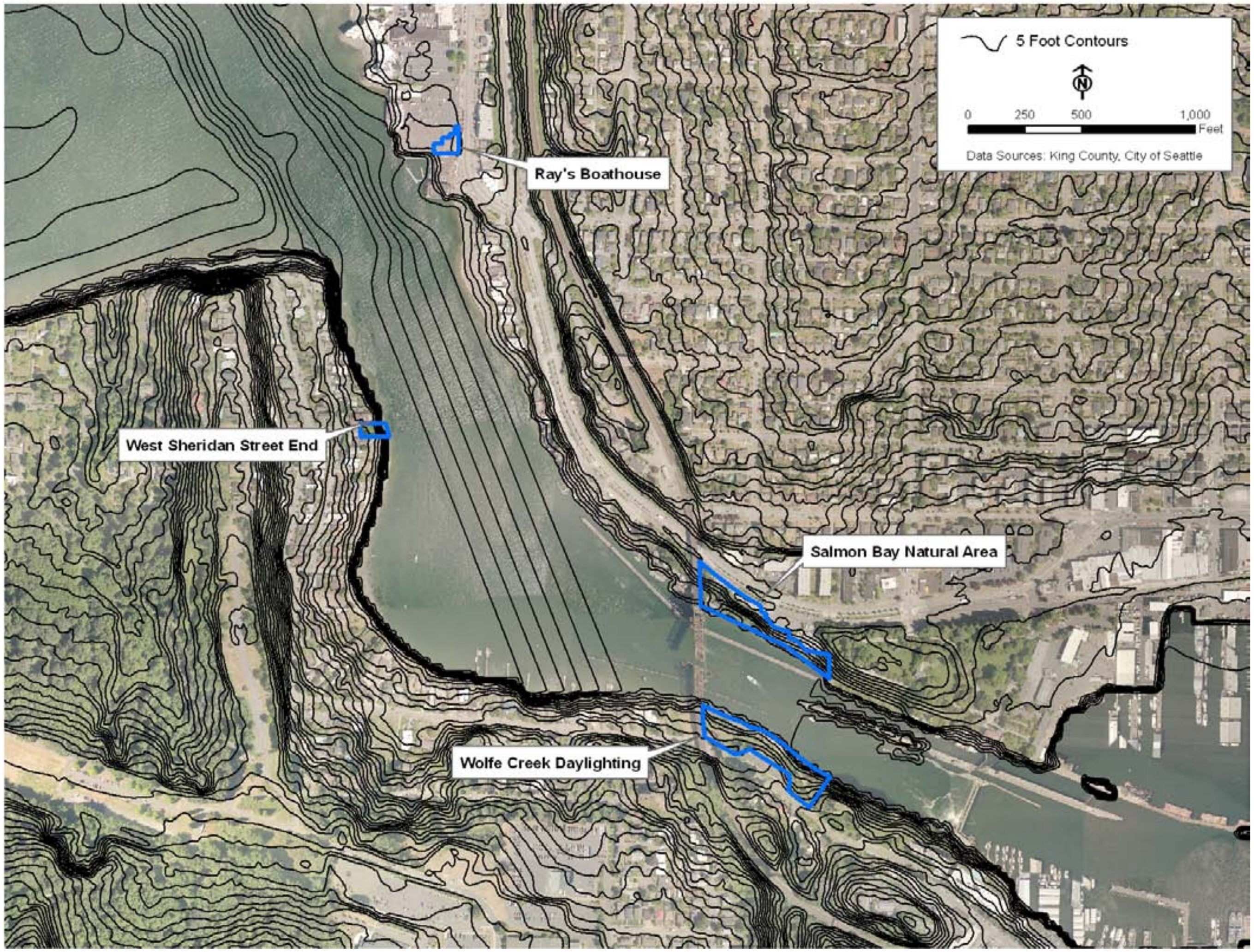


Figure 8. Topography of Salmon Bay area and restoration site locations.

educational value of Salmon Bay and reconnecting people to nature. The aesthetic and amenity value of water is quite high, and daylighting projects can revitalize surrounding neighborhoods by providing these new amenities.

Reconnecting Wolfe Creek to the saltwater habitat of Salmon Bay has the potential to create a localized brackish environment and intertidal delta. These shallow littoral habitats are absent below the Locks, and provide both foraging opportunities and protection from predators for juvenile salmonids. A section of culvert, however, would remain between the daylighted section of the creek and the portion of Wolfe Creek that is in Kiwanis Ravine Park. That section of culvert would continue to prevent fish passage because of its length and angle (W.R. Consulting 2008).

4.2 Salmon Bay Natural Area

For this report, we used visual renderings of the Salmon Bay Natural Area from the Greater Salmon Bay Concept Plan (Brennan 2006). This site has been implemented by improving riparian and upland vegetation along the shoreline as well as demolition of the over-water structures on site (Figures 9 and 10). Bulkhead removal, slope regrading, and more vegetation planting completed this restoration.

4.2.1 General Benefits of Salmon Bay Natural Area

Upland and riparian vegetation provides habitat and detritus as a food supply for invertebrates, which are in turn preyed upon by juvenile fish. The overhanging vegetation also provides refuge from predators (Toft et al. 2005). Vegetation also provides terrestrial organisms as juvenile Chinook salmon prey. Removal of overwater structures is beneficial to juvenile salmonids because structures prevent light penetration (Simenstad et al. 1999 *in* Toft et al. 2005), reducing primary productivity and some types of invertebrate production. Overwater structures may also provide refuge habitat for larger fish that could prey on juvenile salmon, may affect movement patterns of juvenile salmon if they avoid dark areas underneath structures, and cause habitat disturbance when floating structures rest on the substrate during low tides (Toft et al. 2005).

4.3 Ray's Boat House

For the purpose of this report, we used the visual rendering of Ray's Boat House from the Greater Salmon Bay Concept Plan (2006). Restoration at Ray's Boat House would include partial removal of the overwater dock to expose quality beach habitat and improve upland and riparian vegetation along the shoreline (Figure 11).

4.3.1 General Benefits of Ray's Boat House

Improvements to upland and riparian vegetation will have benefits similar to Wolfe Creek and the Salmon Bay Natural Area by providing a terrestrial insect food source and shallow water refuge from predators for juvenile salmonids. Partial removal of the dock to expose quality beach habitat currently covered by overwater structures could help encourage shoreline habitat use by juvenile salmonids in this area.

4.4 West Sheridan Street End

After conducting an on-site visit, this site was chosen for its public land and potential for restoring waterfront habitat. This site is located at the end of West Sheridan Street on the western side of Salmon Bay. The water's edge is currently choked by blackberry and non-native vegetation atop a concrete debris revetment. Restoration at this site would include improving upland and riparian vegetation, re-grading and enhancement of the intertidal substrate, and adding large woody debris along the shoreline (Figures 12 and 13).

4.4.1 General Benefits of West Sheridan Street End

Improvements to upland and riparian vegetation will have benefits similar to Wolfe Creek and Salmon Bay Natural Area by providing a terrestrial insect food source and shallow water refuge from predators for juvenile salmonids. The addition of large woody debris would create additional refuge for juvenile salmonids and serve as a natural retaining structure. Re-grading the shoreline to a more natural slope and enhancing the intertidal substrate would provide invertebrate prey habitat, while not providing hiding/ambush opportunities for predatory fish (Toft et al. 2005).

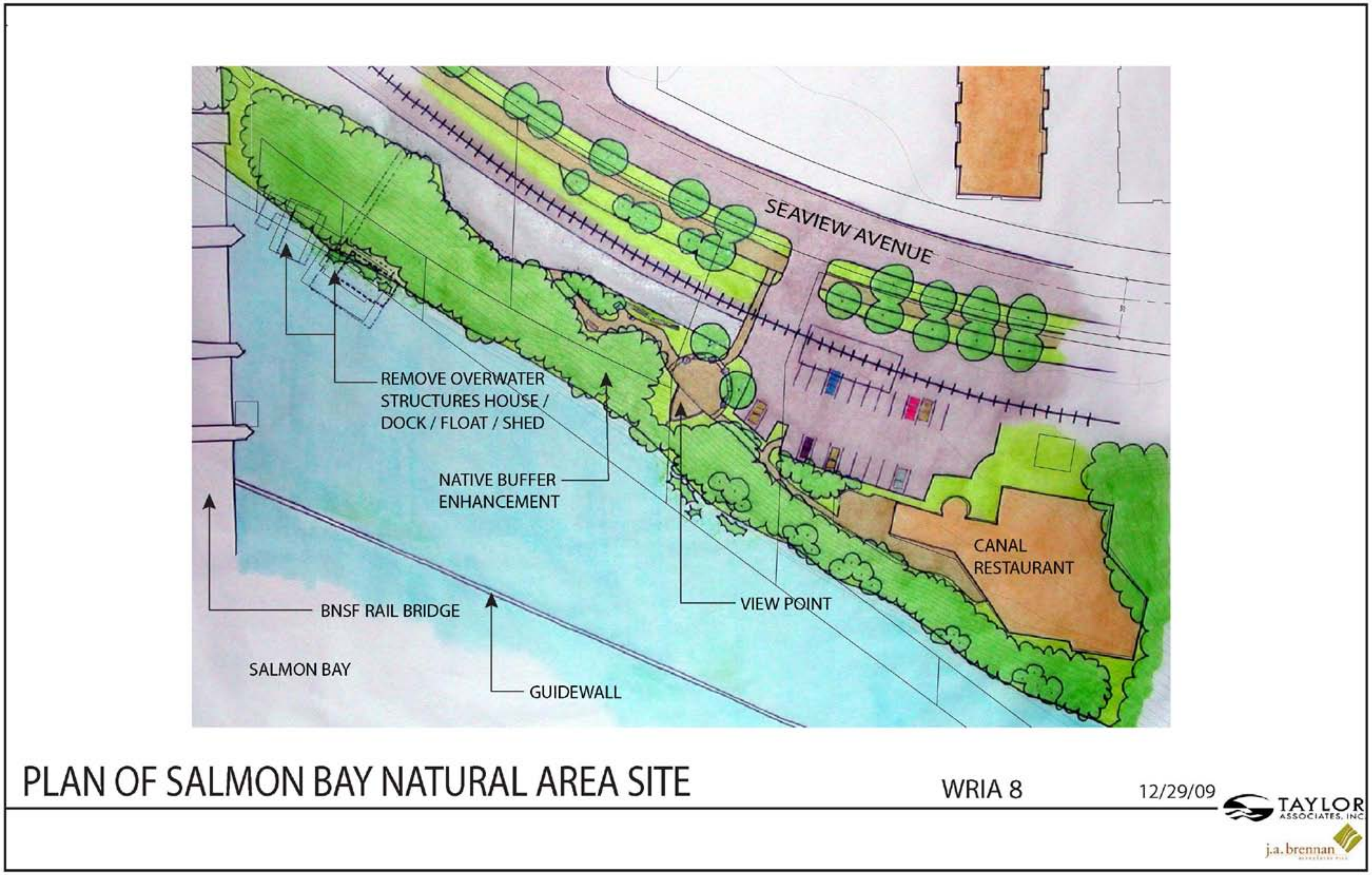


Figure 9. Visual rendering of Salmon Bay Natural Area restoration site.

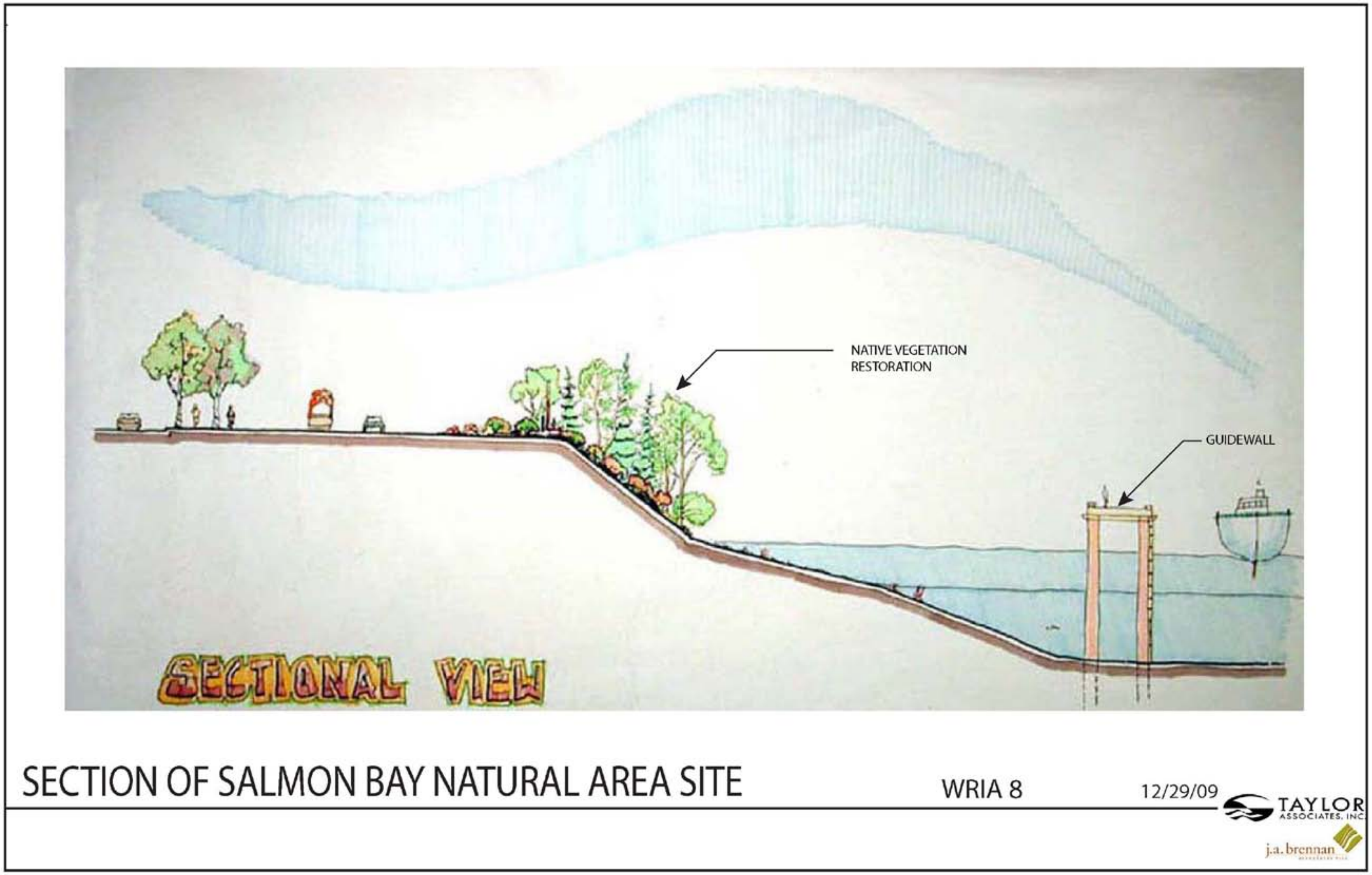


Figure 10. Cross sectional view of Salmon Bay Natural Area restoration site.

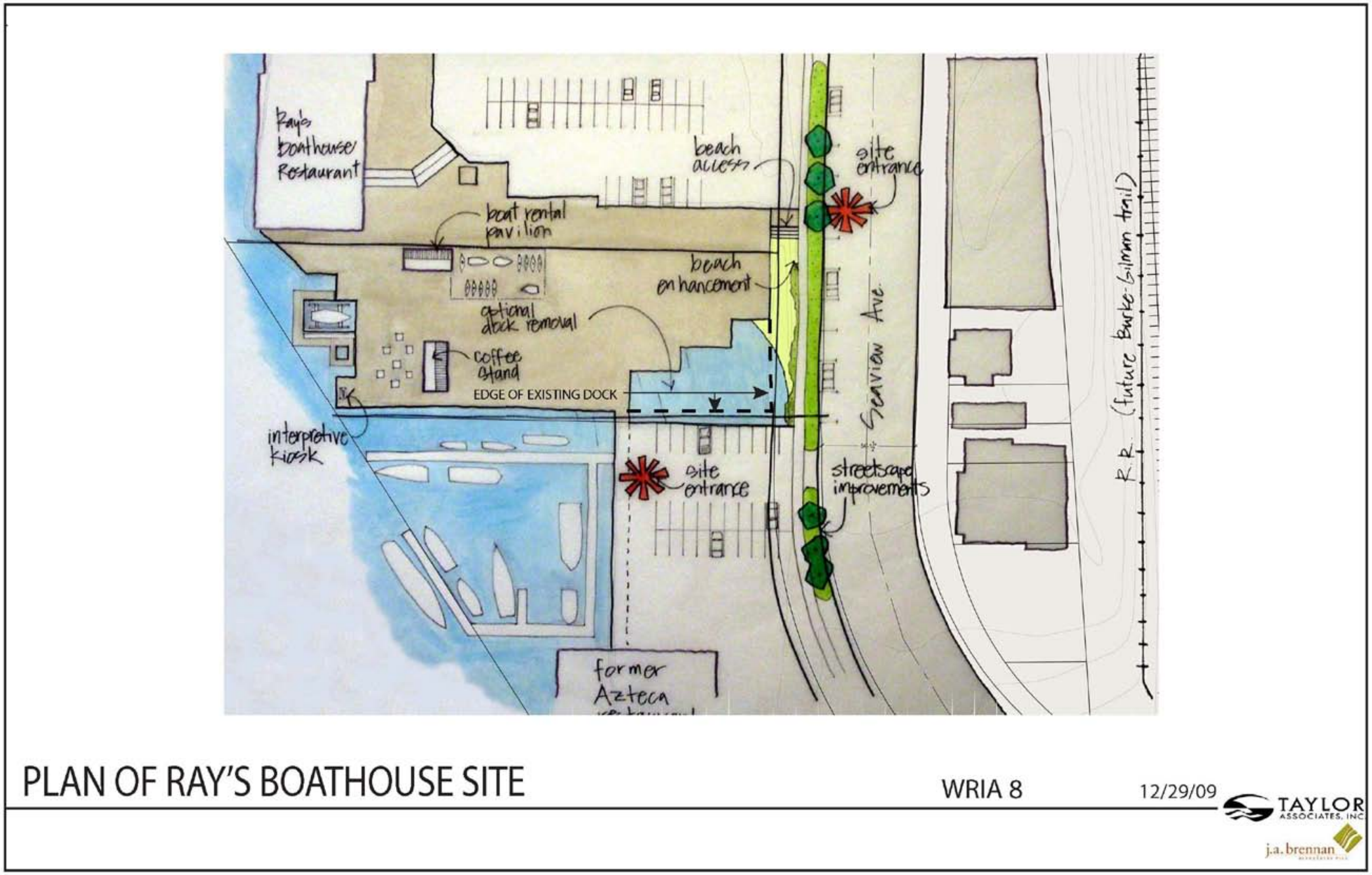


Figure 11. Visual rendering of Ray's Boat House restoration site.

Figure 12. Visual rendering of West Sheridan Street End restoration site.

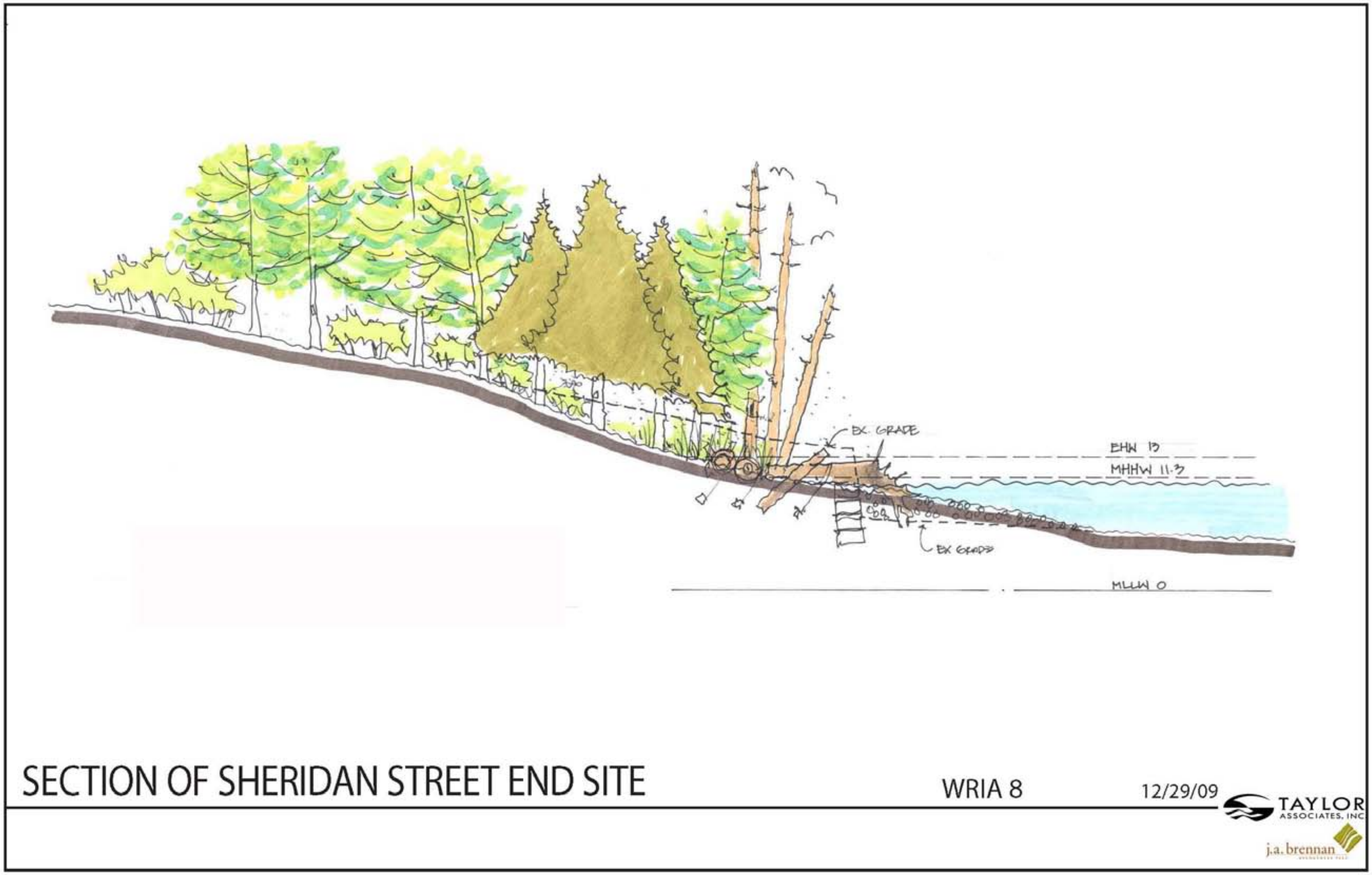


Figure 13. Cross sectional view of West Sheridan Street End restoration site.

4.5 Comparison of Restoration Sites

One specific objective within this synthesis report is to estimate ecosystem contributions from daylighting Wolfe Creek and its freshwater input into Salmon Bay. Estimating the potential contributions of other restoration activities within Salmon Bay allows for a comparison between all these areas and to develop perspective on potential Chinook salmon benefits from the various restoration options.

Specific criteria for ecosystem contributions were developed and included in a cross comparison table containing all four restoration sites (Table 2 top row). These criteria were chosen based upon typical contributing factors for restoration sites and Salmon Bay ecology and then discussed by the WRIA 8 Estuary and Nearshore Workgroup, Taylor Associates, Inc. and the sub-consultants. Table 2 shows estimated ecological contributions for the four restoration sites. All areas (square feet) are calculated from the visual renderings and are based only upon newly restored attributes.

Total Enhanced Area

Total enhanced area is greatest for Wolfe Creek (44,866 sq ft), followed by the Salmon Bay Natural Area (32,102 sq ft). Ray's Boat House and the West Sheridan Street End show much smaller total enhanced areas (3,755 sq ft and 4,679 sq ft, respectively). It has been found that larger sites are better able to become self sustaining than smaller sites (Dean et al. 2001). Other benefits of size include increased diversity of plant and animal species, greater ability to hold up against outside pressures such as pollution and invasive species, and the ability to be self-buffering against disturbances such as noise and light (Dean et al. 2001).

Upland Riparian Area

Upland riparian areas show a similar trend with Wolfe Creek (35,935 sq ft) and the Salmon Bay Natural Area (29,039 sq ft) having the greatest areas. The West Sheridan Street End and Ray's Boat House show much smaller areas (3,896 sq ft and 620 sq ft, respectively). Upland riparian areas play an important role in producing terrestrial insect prey for juvenile salmonids (Brennan and Culverwell 2004). Shoreline vegetation reduces shade and large woody debris, which affects the supply of terrestrial insects and epibenthic prey resources (Brennan and Culverwell 2004).

Upper and Lower Intertidal Areas

The Upper Intertidal can only be restored at two sites. These include Wolfe Creek (8,931 sq ft) and the West Sheridan Street End (620 sq ft), with Wolfe Creek showing approximately 14 times the amount of upper intertidal area. Only the West Sheridan Street End includes restoring the lower intertidal area, albeit with a small area of 162 sq ft. Upper and lower intertidal areas serve as important corridors for migration, refuge, prey production, and feeding by juvenile salmonids (Brennan et al. 2004). Restoring degraded intertidal areas increases the amount of available habitat that could be used by juvenile salmonids.

Removal of Overwater Structures

Removal of overwater structures can only be restored at two sites. These include Ray's Boat House (3,135 sq ft) and the Salmon Bay Natural Area (2,300 sq ft). It has been found that juvenile salmonids avoid swimming beneath overwater structures (Toft et al. 2007). Removal of structures could encourage juvenile salmonids to utilize shoreline habitat not previously accessible.

Dominant Substrate Types

Dominant substrate types are similar for all four sites with silt and sand being the most dominant types. There is no discernable difference between these sites in regards to substrate composition.

Potential Aquatic Insect Drift Quantities/Freshwater Input

Wolfe Creek is the only identified restoration site that could include freshwater input and subsequent aquatic insect drift production. Although potential aquatic insect drift was not quantified for this report, Wolfe Creek would likely deliver aquatic insect prey in a mass that is generally proportional to the basin area or flow rate (range of 0.2 to 0.8 cfs in May-June), both of which are small.

Nearness to Outfalls

Outfalls are numerous in Salmon Bay (Table 2 and Figure 14). Proximity to outfalls could decrease the effectiveness of a restoration site by introducing pollutants at the site. Salmonids may avoid areas of decreased water quality and invertebrate prey sources may not inhabit these areas due to poor sediment quality. The closest outfall to Wolfe Creek is 1,750 feet (ft) along the linear shoreline west. However, there is an outfall directly across Salmon Bay (approximately 300 ft) located at the Salmon Bay Natural Area. The West Sheridan Street End and Ray's Boat House have outfalls 600 ft. south and 250 ft. south, respectively. The Salmon Bay Natural Area contains an outfall at the site.

Site Connectivity to Other Habitats

Qualitatively assessing the nearness of beneficial or degraded habitat to each restoration site is useful in determining overall benefits of these sites. Contributions from adjacent upland habitats or lack thereof, are important factors in determining locations and effectiveness of restoration sites. Close connectivity to upland habitat can contribute terrestrial food sources to surrounding aquatic habitats through wind. The Wolfe Creek site is bordered by the Kiwanis Wildlife Corridor to south and southwest, while the area directly west is interspersed with residential land. The H.M. Chittenden Botanical Garden (east) is directly adjacent to the Salmon Bay Natural Area, while to the north and west, residential and commercial areas are in close proximity. Ray's Boat House is surrounded by large docks, residential areas, and commercial areas, with little to no upland habitat. West Sheridan Street End is surrounded by residential areas with extensive upland habitat of Discovery Park located further to the west.

The Salmon Bay estuary is conspicuous by its almost complete development and virtually 100% armoring (Figure 15). Wolfe Creek and the Salmon Bay Natural Area are the only two areas currently containing a significant amount of unarmored shoreline on site. However, both of these sites are bordered by armoring in either direction along the shoreline. The Ray's Boat House site has armoring in both directions along the shoreline, with no areas in proximity that are unarmored. Similarly, the West Sheridan Street End site has shoreline armoring in both directions. However, there is one small area 200 ft to the south that is unarmored.

Each one the restoration sites have their own unique combination of contributions that could benefit Chinook salmon. Compared to the other sites, Wolfe Creek could add a large restored area including a significant upland riparian zone, upper intertidal area, and freshwater input (albeit in very small quantities) (Table 2). The Salmon Bay Natural Area adds a large restored area including a significant upland riparian zone and removal of overwater structures. Bulkhead removal, slope regrading, and more vegetation planting also contributes to this restoration site. Ray's Boat House could add a small restored area including a minimal upland riparian zone and removal of overwater structures. West Sheridan Street End could add a small restoration area including a small upland riparian zone and small upper and lower intertidal areas.

	Total Enhanced Area (sq ft)	Upland Riparian Area (sq ft)	Upper Intertidal Area +8 to +13 (sq ft)	Lower Intertidal Area -4 to +8 (sq ft)	Removal of Overwater Structure (sq ft)	Dominant Substrate Types	Potential Aquatic Insect Drift Quantities	Freshwater Input (average cfs)	Nearness to Outfalls (ft) (Figure 14)
Wolfe Creek	44,866	35,935[2]	8,931	N/A	N/A	Silt, sand, and cobble (Footen 2001)	Wolfe Creek would deliver aquatic insect prey organisms in a mass that is generally proportional to the basin area or flow rate, both of which are small	10% exceedance = **0.1 to 0.2 cfs** (May-Jun) 1% exceedance = **0.8 cfs** (May-June)	1,750 ft along shoreline west, 300 ft north across Salmon Bay
Salmon Bay Natural Area	32,102	29,039	N/A	N/A	2,300	Sand, gravel (Toft et al. 2005)	Terrestrial insect delivery will likely occur, however no aquatic insect delivery will occur due to absence of freshwater input	None	Outfall located on site
Ray's Boat House	3,755	620	N/A	N/A	3,135	Sand (J.Brennan, pers. comm.)	None, no freshwater input	None	250 ft south
West Sheridan Street End	4,679	3,896	620	163	N/A	Sand, mud, small cobble	None, no freshwater input	None	600 ft south along shoreline

Table 1. Cross comparison criteria for four Salmon Bay restoration sites.

[2] Upland Riparian area excludes 16 acres of Kiwanis Ravine in the Wolfe Creek Watershed.

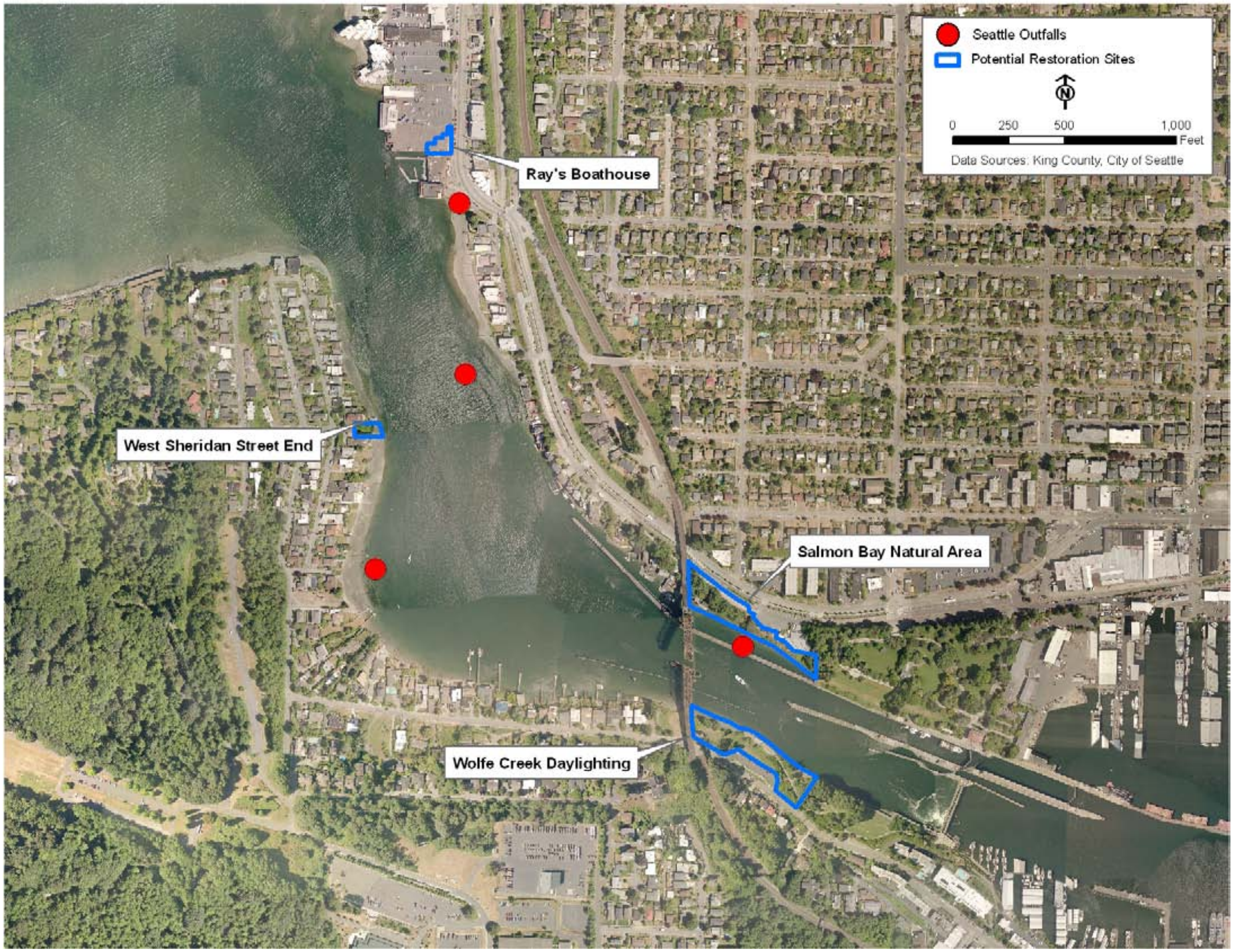


Figure 14. Seattle outfalls in Salmon Bay and proximity to restoration sites.

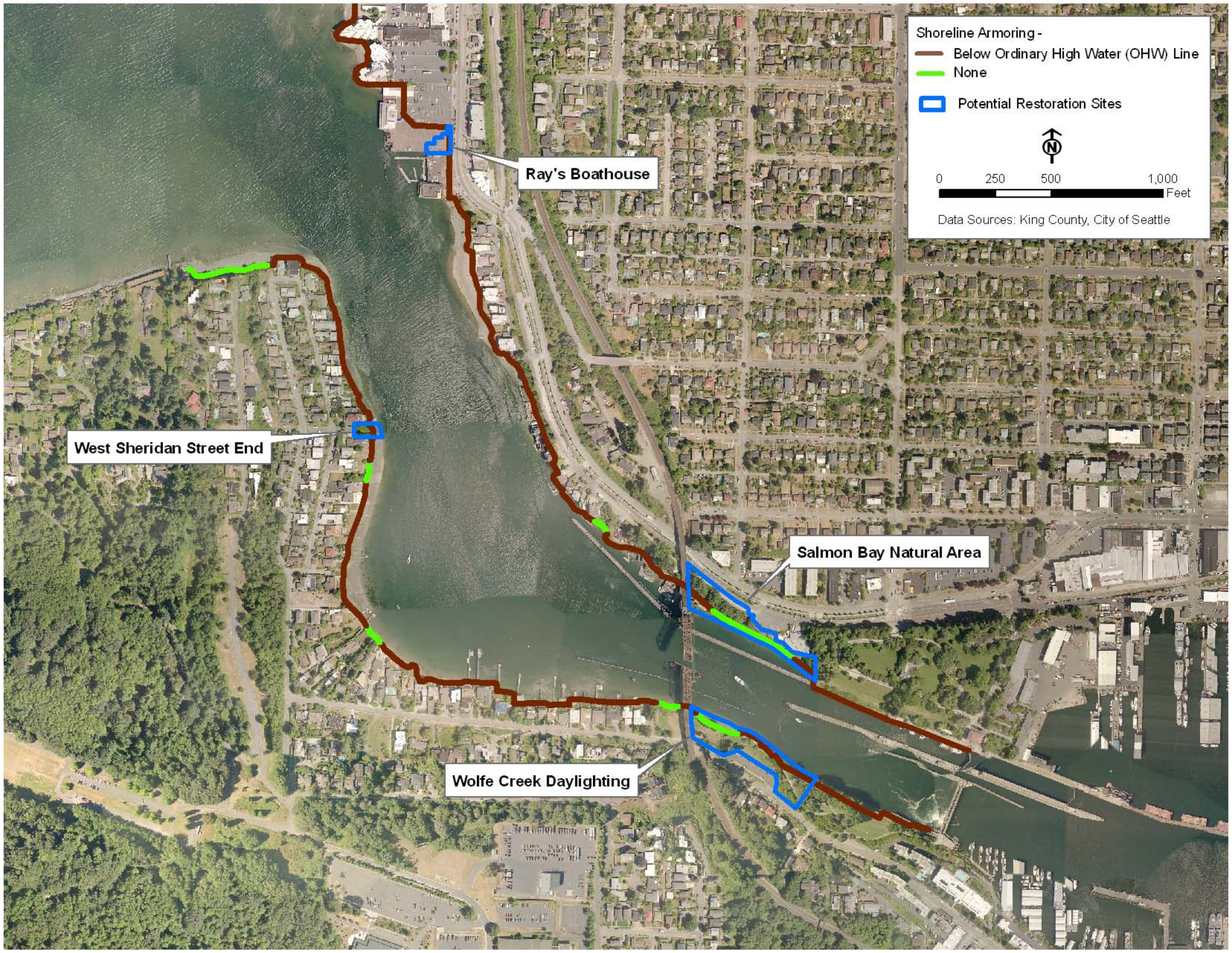


Figure 15. Shoreline armoring in Salmon Bay and proximity to restoration sites.

5.0 Summary of Interviews

To better understand the benefits to Chinook salmon of potential restoration efforts in and around the Salmon Bay Estuary, the team elected to interview eight individuals with expertise in restoration and salmon recovery efforts in the Puget Sound region.

5.1 Methodology

The team developed a short interview guide to focus the interviews and provide consistency. A cross section of experts were asked questions regarding the survival of both adult and juvenile salmon, recommendations for habitat restoration in and around Salmon Bay, and opinions relative to how to make future habitat restoration efforts more successful. Table 3 lists the complete text of the interview guide. The interviewer used the guide loosely, asking all questions, but enabling subjects to expand on issues of interest and to provide information outside the guide as well.

In your view, what are the greatest influences on the survival of Chinook salmon in the Salmon Bay Estuary (west of the Locks)? How does this differ for juvenile vs. adult salmon?
After reviewing the map of the four restoration sites, in your view, what types of restoration activities in and around the Salmon Bay Estuary have the most promise for improving survival of Chinook salmon?
What might be the best strategies to maximize the effectiveness of future restoration efforts?
What do you think are the greatest barriers to successful habitat restoration efforts in and around the estuary?
How should we measure the effectiveness of restoration efforts?
What additional information do we need to know in order to make solid restoration decisions for restoration in the estuary area west of the Locks?
What's overall (?) driving your recommendations?
Do you know anyone else who I should talk to about salmon habitat restoration in Salmon Bay (west of Locks)?

Table 2. Complete text of the interview guide.

5.1.1 Interview Subjects

The selected Chinook salmon experts came from a range of agencies across the Puget Sound, some with direct knowledge of the Salmon Bay Estuary and others with more general knowledge about salmon recovery and fish survival. The experts interviewed included:

- Eric Beamer, Skagit River System
- Jeff Cordell, University of Washington
- Kurt Fresh, National Marine Fisheries Service/Northwest Fisheries Science Center

- Casey Rice, National Oceanic Atmospheric Administration
- Dave Seiler, Washington Department of Fish and Wildlife (retired)
- Ron Thom, Pacific Northwest Laboratories
- Eric Warner, Muckleshoot Tribe
- Charles Ebel, U.S. Army Corps of Engineers

While the interviewed experts were fairly consistent about the value of habitat restoration efforts regionally, they differed significantly in their opinions relative to the value of restoration efforts at the identified sites in and around Salmon Bay. The following paragraphs summarize the feedback from all of the interviews.

5.2 Characteristics of the Salmon Bay Estuary

The interviewed experts agree that the Salmon Bay Estuary is a highly-developed, urban estuary with little shallow water refuge for juvenile fish. The Locks create a salinity problem for juvenile fish by limiting the flow of freshwater into the estuary. Several stated that Salmon Bay is limited to being an urban estuary due to the extensive development and associated water quality challenges in and around the estuary.

5.2.1 Characteristics of the estuary given by the experts include:

- Freshwater flow issues due to the barrier of the Locks, which limits Salmon Bay's ability to function like a natural estuary – there is not a lot of freshwater.
- The sudden change in salinity as fish move through the Locks creates a difficult transition for juvenile salmon as they osmoregulate and can increase juvenile mortality.
- Water quality issues are problematic with increased pollution from development and stormwater.
- The shoreline is extremely built up with few softscape features to provide habitat or refuge for juvenile salmon.
- The extent of development around the estuary creates significant problems for future restoration relative to the lack of connectivity between sites and the influences of impervious surface on both water temperature and quality.
- Development of the area creates habitat for predators that feed on juvenile salmon.
- Overwater structures limit estuary functionality.

5.2.2 Juvenile and Adult Chinook

All of the experts agreed that the estuary needs of adult salmon are very different from juveniles. The primary issue for adult salmon is poor water quality in the estuary. Juvenile salmon, however, require:

- Shallow habitat with finer grained substrate
- Ability to make the salinity transfer
- Refuge from birds and other predators
- Overwater vegetation for cooling and food production

All of the experts agreed that habitat quality and quantity were the most important concerns for juvenile fish. One expert noted, regardless of whether one has the ability to measure future habitat restoration success, that creating new habitat would be beneficial to improve water quality, influence water temperature, and provide refuge for juvenile fish. As he noted, "It's a slam dunk – just do it!"

Several of the experts noted a "Lake Effect" in which the size of juvenile salmon migrating through the Locks may actually be larger due to the time they spend in Lake Washington. Thus, these experts believe that the juvenile salmon are migrating through the estuary at a larger size and may have both less need for traditional habitat and may have an easier time handling salt water adaptation. Most of the experts agreed that more research is needed to determine the actual use of the estuary by different salmon life history types.

Several of the experts suggested that juvenile salmon are much more unpredictable; some spend a longer time in Lake Washington; others move back and forth between freshwater and saltwater. Future work cannot assume a straight migration path from Lake Washington through the Locks. One expert, however, did note that in recent small studies, smaller juveniles do spend time in and around the estuary, rearing as might be expected in a more natural environment.

All of the researchers agreed that the focus on future restoration efforts in and around Salmon Bay should be on juvenile fish. Several suggested more thought should go into the fish diversity objectives for the future. One expert noted that in the highest return year for Chinook, of the 30,000 fish that returned through the Locks, 900 of them were wild Chinook. Another expert noted the fact that most of the fish in the system are likely hatchery fish, which will certainly influence the success of restoration efforts because hatchery fish tend to be larger than wild fish, making them less likely to use restored habitats in the area.

5.3 Habitat Recommendations

Many of the experts suggested a broader focus than just the Salmon Bay estuary – that future efforts should consider a more holistic approach, broadening the focus beyond the estuary to the WRIA 8 nearshore and even the Puget Sound region.

A more holistic approach, restoring for 50 to 100 years, fish diversity, and habitat connectivity, would make any individual restoration efforts more effective. Interviewed experts disagreed as to the value of the individual Salmon Bay estuary restoration examples, with most suggesting that such a limited focus would not have significant impacts on fish survival in the estuary.

Several of the experts felt restoration efforts would have limited impact unless the effect of the Locks on the ecosystem was addressed as an issue.

Several suggested that habitat restoration projects need to consider the life history types and fish characteristics such as hatchery verses wild salmon that will certainly influence the use of habitat types.

Any restoration effort should consider long-term maintenance and the ability of the environment to self heal to limit future maintenance.

Future restoration efforts should seek to restore process and not just function of the habitat.

One expert suggested that we need to take a more holistic approach to ensure we aren't restoring with one hand and destroying with the other.

A whole series of restoration efforts, focused on quality of habitat and connectivity would be more effective than isolated restoration projects in and around Salmon Bay.

While most of the experts agreed in the value of restoration projects, most suggested that the effectiveness of the restoration projects proposed would be limited due to their lack of connectivity, inability to address overwater structures, the Locks related issues, and the overall urbanization of the estuary.

Currently, the experts agreed, that significant shallow refuge habitat does not exist for juvenile salmon in and around the estuary. One emphasized the importance of any restoration efforts, with particular emphasis on the importance of Wolfe Creek for shallow water habitat.

Some common recommendations include:

- Bigger habitat restoration areas are generally better than smaller ones.
- Higher connectivity increases the value of the habitat to juvenile salmon.
- Habitat should include overwater vegetation for food production and temperature control.
- Juvenile fish like finer grain substrate.
- Juvenile fish like embayments and little marshes for refuge from prey.

Recommendations for Future Work/Research

All of the experts agreed that additional research needs to be done on the quantity and life history of fish that use Salmon Bay. Several suggested research needs to go beyond Chinook salmon to other fish. Several also suggested that research on water quality and temperature needs to continue as these factors will have the greatest impact overall on fish survival.

Future Restoration Effectiveness

Interviewed experts differed in their opinions relative to the potential effectiveness of future restoration efforts. Several of the experts suggested the following for improving the effectiveness of restoration efforts in the long term:

- Continue to monitor the movement of salmon through Salmon Bay to see how they are using habitat.
- Consider future vision for fish diversity and design habitat accordingly.
- Develop habitat in areas that can be self sustaining.
- Ensure monitoring and modification are part of the overall budgets for habitat restoration.
- Utilize the efforts of volunteers and other groups to augment habitat restoration budgets.
- Develop a strategic, less opportunistic approach to habitat restoration – seek a regional effort rather than spot projects throughout a single area.

Specific to Wolfe Creek, one expert noted that any future restoration needs to improve the habitat quality at the discharge point to the estuary, making sure to improve areas for refuge and food sources with woody debris, overwater vegetation, shallow bank, and small substrate. This, he believes, would be much more valuable than "a discharge pipe into the waterway."

5.4 Metrics

Experts expressed significant differences in how the effectiveness of habitat restoration projects should be measured. Several, in fact, suggested that true measurement would be impossible due to the transient nature of the fish and the diversity of when and how the fish use the habitat as they pass through the estuary.

Some of the suggestions include:

- Growth of fish using the habitat
- Food production within the restored habitat
- Carrying capacity
- Inclusion of salinity refuges
- Presence of fish in the habitat
- Presence of desirable attributes for fish (e.g., refuge, food, overhanging vegetation)

5.5 Final Thoughts

While the majority of the interviewed experts agreed that due to the challenges of an urban estuary and the lack of size and connectivity across the potential restoration sites, all agreed as to the importance of proceeding with restoration projects if only for educational or symbolic reasons. Most also agreed that habitat restoration is inherently of value, but that a more holistic, connected, long-term approach is required that considers fish life-histories and the long-term restoration vision for the watershed.

6.0 Discussion

The discussion below synthesizes the information from the literature review, the comparison of the four example restoration sites, the interview comments of local fisheries and estuarine scientists with knowledge of Salmon Bay, and the freshwater contribution analysis for Wolfe Creek.

6.1 Chinook Salmon Use of Salmon Bay Estuary

Adult Chinook salmon estuary use and run-timing is generally determined by environmental conditions such as temperature and flow. Information gathered from the literature review and interviews showed that temperature, salinity, and access through the Locks are the determining factors for adult Chinook in Salmon Bay. The physiological transition from Salmon Bay to freshwater above the Locks is difficult for adult Chinook salmon and is mostly influenced by the presence and operation of the Locks. Increased freshwater through the Locks, specifically for the fish ladder, could help migrating adult Chinook.

Adult Chinook salmon utilize estuarine habitats differently than juveniles, as they do not use fine scale habitats within estuaries for growth and development. Any changes to the physical habitat of the shoreline or improving riparian vegetation would therefore have negligible impacts to adult Chinook survival.

Based on the literature review, most juvenile Chinook salmon exit the Locks into Salmon Bay at a large size (100+ mm). In contrast, their residence time within Salmon Bay is relatively short. This detail is important when determining benefits to WRIA 8 juvenile Chinook from restored habitat sites. Some of the local experts stated that the larger the smolt, the less likely it would be that they would utilize a slough or marsh environment at that point in their migration. One interviewed expert noted that the riskiest thing about the Wolfe Creek site is that if there are not the life history types (delta fry/parr) to colonize the restoration, then this restoration site, and perhaps other sites, would not be used. Very few small Chinook (80 mm or less) exit the Locks; these fish have been identified as the life history stage that may utilize restored habitat at the example restoration sites. The restoration sites may benefit this small portion of fish by providing additional prey resources and refuge, and thereby could conceivably contribute in a small way to improving Chinook life history diversity of the population. However, it is unclear what percentage of these small numbers of fish would actually find and utilize Wolfe Creek because flow is negligible compared with the large freshwater input from the Locks. Similarly, it is unlikely that these small numbers would have an impact on overall population dynamics in the watershed.

The freshwater lens formed below the Locks, as a result of smolt flume operation and lockages, is relatively small compared to a natural estuary. Juvenile Chinook have been found to utilize the lens for a short period of time after passing through the Locks. Studies show that they feed upon freshwater zooplankton originating upstream. Prior to this report, freshwater input from Wolfe Creek was hypothesized to help increase the freshwater habitat below the Locks and create a small localized estuarine mixing zone. These attributes in turn, would increase typical invertebrate prey sources and assist juvenile Chinook in their sharp transition from freshwater to saline water. However, flow model results indicate that flows entering Salmon Bay from Wolfe Creek would be less than 1 cfs during the peak juvenile migration (May through June). This flow is negligible compared to the freshwater input from the Locks (520 to 770 cfs) during the same time period. Flows of less than 1 cfs would likely quickly dissipate into the much higher flows from the Locks. Although not quantitatively studied, such low flows are likely not strong enough to sustain a brackish environment at the mouth of Wolfe Creek due to salt water intrusion during tidal cycles.

6.2 Restoration in Salmon Bay

The interviewed experts concurred that an ecosystem approach would be more beneficial to Chinook and other species than a piecemeal or opportunistic approach. A broader restoration plan would include Shilshole, part of Magnolia, and Salmon Bay at a minimum. Restoring more ecosystem components and functions would make the whole system resilient and help more species. For example, as currently designed the Wolfe Creek daylighting project addresses only a small portion of the Salmon Bay ecosystem and would provide minimal benefit to juvenile Chinook.

All four of the example restoration sites in Salmon Bay would not make a significant difference to the ecosystem if restored because they are not close enough to each other to create a cumulative effect. Sites that are far apart benefit fewer fish. The benefit of restoring these sites would only be as part of a broad scale, long-term restoration plan. The completed Salmon Bay Natural Area project accomplished some beneficial actions, such as removal of overwater structures, improvement of the shoreline, and riparian plantings, but the area is small in scale and isolated at this time.

Some of the local experts thought that the most beneficial types of restoration in Salmon Bay would include large scale riparian greenbelts and dramatic changes such as converting the shoreline from armoring to softer substrates. A large scale effort to remove overwater structures would also benefit juvenile Chinook salmon. However, other opinions were not as optimistic, and thought Salmon Bay would be limited as an urban estuary and that little could be done because of land use issues and human features already in place. Other experts suggested that long-term habitat restoration work should consider fish diversity, such as wild versus hatchery and increasing life history diversity, and design habitat accordingly. In addition, habitats should be restored in areas that can be self sustaining.

7.0 Recommendations

The following recommendations are based upon information gathered from the literature review, interviews, flow analysis, and comparison of values of the example restoration sites. They specifically address potential actions within Salmon Bay.

Recommendations for Future Research

Studies have been conducted on food consumption, habitat use, and to some degree, the effects of rapid transition for juvenile Chinook. Further studies should focus on:

- Diet analysis and fine scale habitat use throughout the migration period and at multiple sites within Salmon Bay, including mid-channel areas where salmon may have different size and feeding characteristics. This would help determine if Chinook are primarily feeding on freshwater prey below the Locks, or whether they are spending time and energy foraging on typical prey items found within other reaches of Salmon Bay.
- The effects of rapid transition through the Locks, i.e., immediate or delayed mortality effects, or other effects of salinity and temperature transition on Chinook.
- The effects on water quality from stormwater and combined sewer overflow outfalls in Salmon Bay.

Recommendations for Restoration and Other Actions

Restoration actions need to be prioritized and sequenced within an overall estuary and nearshore action plan. Actions that may improve the growth and survival of juvenile salmon include:

- Increase riparian vegetation along the entire shoreline.
- Remove bulkhead and riprap to soften the shoreline.
- Implement a large scale effort to remove significant amount of overwater structures.
- Significantly increase freshwater input. This may necessitate restoring a larger portion of the Wolfe Creek watershed to improve flows or incorporating Ship Canal water into a Wolfe Creek habitat restoration design to increase flows.
- Create multiple tidal marshes, large intertidal flats, and numerous habitat benches throughout Salmon Bay.
- Encourage volunteers, and other groups, to be involved in restoration design and implementation to promote understanding of salmon and their watershed and to build community action for salmon recovery.
- Include effectiveness monitoring and restoration modification in funding for habitat restoration, to ensure best use of funds.

8.0 Conclusion

The Salmon Bay estuary lacks the essential functions of a natural estuary due to urbanization and industrial development, including the construction of the H.M. Chittenden Locks in 1916. Future restoration efforts in the estuary need to be part of a clear, large-scale ecosystem approach to benefit Chinook salmon and other species that use the estuary. Future restoration actions to improve the estuarine functions of Salmon Bay should be prioritized and sequenced within the context of this larger ecosystem approach, including actions for the nearshore areas. Restoration actions need to also consider fish life-histories and design habitat accordingly that could contribute to the overall survival of WRIA 8 Chinook and other salmonid species.

For adult Chinook salmon, projects to lower water temperature above the Locks and to minimize the delay of fish passage could improve adult survival. Stormwater and other water quality issues within the estuary also influence survival. For juvenile Chinook salmon, restoration (in an ecosystem-scale context) should focus on improving fine scale habitat for growth and development, including shoreline softening, riparian plantings, and removal of overwater structures.

This report indicates that freshwater flow contributions from Wolfe Creek would have minimal measurable benefits. In addition, the daylighted channel of Wolfe Creek would most likely not be used by the majority of WRIA 8 juvenile Chinook salmon, which are larger in size. Daylighting of Wolfe Creek would have educational and community value, and may contribute to the long-term restoration of the estuary. The other three example restoration sites would also have minimal impact in the short-term due to their lack of connectivity and relatively small size. The Salmon Bay Natural Area restoration site has addressed several of the juvenile Chinook salmon habitat needs and will be monitored to guide future large-scale riparian and shoreline restoration efforts.

9.0 Literature Cited

Beamer, E.M., A. McBride, R. Henderson, and K. Wolf. 2003. The importance of non-natal pocket estuaries in Skagit Bay to wild Chinook salmon: An emerging priority for restoration. Skagit River System Cooperative. LaConner, WA. Available at www.skagitcoop.org.

Beamer, E.M., and K. Larsen. 2004. The importance of Skagit delta habitat on the growth of wild ocean-type Chinook in Skagit Bay: implications for delta restoration. Skagit River System Cooperative research report. Available at www.skagitcoop.org.

Beamer, E.M., A. McBride, C. Greene, R. Henderson, G. Hood, K. Wolf, K. Larson, C. Rice, and K. Fresh. 2005. Delta and nearshore restoration for the recovery of wild Skagit River Chinook salmon: Linking estuary restoration to wild Chinook salmon populations. Skagit River System Cooperative. LaConner, WA. Available at www.skagitcoop.org.

Beamer, E.M., A. McBride, R. Henderson, J. Griffith, K. Fresh, T. Zackey, R. Barsh, T. Wyllie-Echeverria, and K. Wolf. 2006. Habitat and fish use of pocket estuaries in the Whidbey Basin and north Skagit County bays, 2004 and 2005. Skagit River System Cooperative. LaConner, WA. Available at www.skagitcoop.org.

Beamish, J.R., and C.M Neville. 1995. Pacific salmon and Pacific herring mortalities in the Fraser River plume caused by river lamprey (*Lampetra ayresi*). Can. J. Fish. Aquat. Sci. 52: 644-650.

Beckman, B.R., W.W. Dickhoff, W.S. Zaugg, C. Sharpe, S. Hirtzel, R. Schrock, D.A. Larsen, R.D. Ewing, A. Palmisano, C.B. Schreck, and C.V.W. Mahnken. 1999. Growth, smoltification, and smolt-to-adult return of spring Chinook salmon (*Oncorhynchus tshawytscha*) from hatcheries on the Deschutes River, Oregon. Trans. of the Am. Fish. Soc. 128: 1125-1150.

Bilton, H.T. 1984. Returns of Chinook salmon in relation to juvenile size at release. Canadian Technical Report of Fisheries and Aquatic Sciences 1245:1-33.

Bottom, D.L., K.K. Jones, T.J. Cornwell, A. Gray, and C.A. Simenstad. 2005. Patterns of Chinook salmon migration and residency in the Salmon River Estuary (Oregon). Est. Coastal Shelf Sci. 1:79-93.

Bottom, D.L., G. Anderson, A. Baptista, J. Burke, M. Burla, M. Bhuthimethee, L. Campbell, E. Casillas, S. Hinton, K. Jacobson, D. Jay, R. McNatt, P. Moran, G.C. Roegner, C.A. Simenstad, V. Stamatiou, D. Teel, and J.E. Zamon. 2008. Salmon Life Histories, Habitat, and Food Webs in the Columbia River Estuary: An Overview of Research Results, 2002-2006. Rep. Res., Fish Ecol. Conserv. Biol. Div., NW Fish. Sci. Center, Natl. Mar. Fish. Serv., Natl. Oceanic Atmos. Admin., Seattle, WA. 45 pp.

Brennan, J.A. 2006. Greater Salmon Bay Concept Plan. June 2006. Prepared for Groundswell Northwest. 14 pp.

Brennan, J.S., and H. Culverwell. 2004. Marine Riparian: An Assessment of Riparian Functions in Marine Ecosystems. Published by Washington Sea Grant Program Copyright 2005, UW Board of Regents, Seattle, WA. 34 pp.

Brennan, J.S., K.F. Higgins, J.R. Cordell, and V.A. Stamatiou. 2004. Juvenile Salmon Composition, Timing, Distribution, and Diet in Marine Nearshore Waters of Central Puget Sound in 2001-2002. King County Department of Natural Resources and Parks, Seattle, WA. 164 pp.

Celedonia, M.T., R.A. Tabor, S. Sanders, D.W. Lantz, and I. Grettenberger. Movement and Habitat Use of Chinook Salmon Smolts and Two Predatory Fishes in Lake Washington and the Lake Washington Ship Canal. 2008. 2004-2005 Acoustic Tracking Studies. Final Report to Seattle Public Utilities. U.S. Fish and Wildlife Service, Lacey, Washington. 116 pp.

Clarke, W.C. and T. Hirano. 1995. Osmoregulation. Pp. 317-378 *in* Physiological Ecology of Pacific Salmon (C. Groot, L. Margolis, W.C. Clarke, eds). UBC Press, Vancouver.

Collis, K., D.D. Roby, D.P. Craig, B.A. Ryan, and R.D. Ledgerwood. 2001. Colonial waterbird predation on juvenile salmonids tagged with Passive Integrated Transponders in the Columbia River Estuary: Vulnerability of different species, stocks, and rearing types. Transactions of the American Fisheries Society 130:385–396.

Collis, K., D.D. Roby, D.P. Craig, S. Adamany, J. Adkins, and D.E. Lyons. 2002. Colony size and diet composition of piscivorous waterbirds on the lower Columbia River: Implications for losses of juvenile salmonids to avian predation. Transactions of the American Fisheries Society 131:537–550.

Cordell, J., J. Toft, M. Coosey, and A. Gray. 2006. Fish assemblages and patterns of Chinook salmon abundance, diet, and growth at restored sites in the Duwamish River. Prepared by University of Washington for the King Conservation District and Salmon Recovery Funding Board. ftp://dnr.metrokc.gov/dnr/library/2006/kcr1953.pdf

Dean, T., Z. Ferdana, and J. White. 2001. Identifying and Prioritizing Sites for Potential Estuarine Habitat Restoration in Puget Sound's Skagit River Delta. Puget Sound Restoration 2001. 12 pp.

DeVries, P., and 18 others. 2005. PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fourth Year (2003) Pilot Study Results and Synopsis of 2000-2003 Findings. Prepared for U.S. Army Corps of Engineers. Contract Number DACW57-00-D-003. R2 Resource Consultants, Inc., Redmond, Washington.

DeVries, P., and 14 others. 2007. PIT Tagging of Juvenile Salmon Smolts in the Lake Washington Basin: Fifth and Six Year (2004-2005) Pilot Study Results. Prepared for U.S. Army Corps of Engineers. Contract Numbers DACW67-02-D-1013, W912DW-05-D-1001, and ROO-34-12. R2 Resource Consultants, Inc., Redmond, Washington.

Duffy, E.J., D.A. Beauchamp and R.M. Buckley. 2005. Early marine life history of juvenile Pacific salmon in two regions of Puget Sound. Estuarine, Coastal, and Shelf Science 64:94-107.

Footen, B. 2001. Impacts of piscivorous predation on juvenile Chinook (*Oncorhynchus tshawytscha*) and other salmonids in Salmon and Shilshole Bays of Puget Sound, King Co., WA. Master's Thesis, Evergreen State College, Olympia, WA.

Footen, B. 2003. Piscivorous Impacts on Chinook (*Oncorhynchus tshawytscha*) in the Salmon Bay Estuary, the Lake Washington Ship Canal and Lake Sammamish. 2003 Greater Lake Washington Chinook Workshop. Seattle, WA.

Fresh, K.L. 2006. Juvenile Pacific Salmon in Puget Sound. Puget Sound Nearshore Partnership Report No. 2006-06. Published by Seattle District, U.S. Army Corps of Engineers, Seattle, WA.

Goetz, F. 1999. Smolt Passage Restoration Project – Lake Washington Ship Canal Section 1135. Draft Biological Assessment. U.S. Army Corps of Engineers, Seattle District. CENWS-EC-TB-ER.

Gray, A., C.A. Simenstad, D.L. Bottom and T.J. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River Estuary, Oregon, U.S.A. Restoration Ecology 10:514-526.

Gray, A. 2005. The Salmon River estuary: restoring tidal inundation and tracking ecosystem response. Doctoral dissertation. University of Washington, Seattle.

Healey, M.C. 1982. Juvenile Pacific salmon in estuaries: the life support system. Pages 315-341 *in* V. S. Kennedy, editor. Estuarine Comparisons. Academic Publishers, New York.

Healey, M.C. 1991. Life history of Chinook salmon (*Oncorhynchus tshawytscha*). Pp 312-391 *in* C. Groot and L. Margolis (eds.). Pacific salmon life histories. University of British Columbia Press, Vancouver, British Columbia.

Johnson, P.N., D. Faber, K. Bouchard, F.A. Goetz, and C.J. Ebel. 2004. Juvenile salmon outmigrant behavior in the Lake Washington Ship Canal and into Shilshole Bay in 2003. Draft Technical Report to the U.S. Army Corps of Engineers, Seattle District, Seattle, WA.

Kiyohara, K., and G. Volkhardt. 2007. Evaluation of Downstream Migrant Salmon Production in 2006 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife, Olympia, Washington. FPA 07-02. 79 pp. (http://wdfw.wa.gov/fish/wild_salmon_monitor/publications/lakewa2006_final.htm)

Kiyohara, K. and G. Volkhardt. 2008. Evaluation of Downstream Migrant Salmon Production in 2007 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife, Olympia, Washington. 72 pp. (http://wdfw.wa.gov/fish/wild_salmon_monitor/publications/lake_wa07_rpt.htm)

Koehler, M.E., K.L. Fresh, D.A. Beauchamp, J.R. Cordell, C.A. Simenstad, D.E. Deiler. 2006. Diet and bioenergetics of lake rearing juvenile Chinook salmon in Lake Washington. Transactions of the American Fisheries Society 135:1580-1591.

Levings, C.D., C.D. McAllister, and B.D. Chang. 1986. Differential use of Campbell River estuary, British Columbia, by wild and hatchery-reared juvenile Chinook salmon. Can J. Fish. Aquat. Sci. 43: 1386-1397.

Levings, C.D., C.D. McAllister, J.S. Macdonald, T.J. Brown, M.S. Kotyk, and B. Kask. 1989. Chinook salmon (*Oncorhynchus tshawytscha*) and estuarine habitat: a transfer experiment can help evaluate estuary dependency. Canadian Special Publication in Fisheries and Aquatic Sciences 105: 116-122.

Levings, C.D. and D. Bouillon. 1997. Criteria for evaluating the survival value of estuaries for salmonids in Emmett, R.L., and M.H. Schiewe (editors), Estuarine and Ocean Survival of Northeastern Pacific salmon: Proceedings of the workshop. U.S. Dep. Commer., NOAA Tech. Memo. NMFS-NWFSC-29.

Macdonald, J.S. C.D. Levings, C.D. McAllister, U.H. Fagerlund, and J.R. McBride. 1988. A field experiment to test the importance of estuaries for Chinook salmon survival: short term results. Can. J. Fish. Aquat. Sci. 45:1366-1377.

MacFarlane, R.B., and E.C. Norton. 2002. Physiological Ecology of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fishery Bulletin 100:244-257.

McCormick, S.D. 1994. Ontogeny and evolution of salinity tolerance in anadromous salmonids: hormones and heterochrony. Estuaries 17:26-33.

National Marine Fisheries Service. 2008. Biological Opinion – Operation and Maintenance of the Lake Washington Ship Canal. King County, Washington. NMFS No:2001-01298.

NOAA 1984. Charts of Puget Sound. National Oceanic and Atmospheric Administration. Seattle, WA.

Pinkham, R. 2000. Daylighting: New Life for Buried Streams. Rocky Mountain Institute, Snowmass, Colorado. September 2000. 73 pp.

Roby, D.D., D.E. Lyons, D.P. Craig, K. Collis, and G.H. Visser. 2003. Quantifying the effects of predators on endangered species using a bioenergetics approach: Caspian terns and juvenile salmonids in the Columbia River estuary. Canadian Journal of Zoology 81:250–265.

Ruggerone, G.T and E. Jeanes. 2004. Salmon utilization of restored off-channel habitats in the Duwamish Estuary, 2003. Prepared for Environmental Resource Section, U.S. Army Corps of Engineers, Seattle District. Prepared by Natural Resources Consultants, Inc. and R2 Consultants, Inc. Seattle, WA.

Ruggerone, G.T. and F. Goetz. 2004. Survival of Puget Sound Chinook salmon (*Oncorhynchus tshawytscha*) in response to climate-induced competition with pink salmon (*O. gorbuscha*). Can. J. Fish. Aquat. Sci. 61:1756-1770.

Ruggerone, G.T. and E.C. Volk. 2004. Residence time and growth of natural and hatchery Chinook salmon in the Duwamish Estuary and Elliott Bay, Washington: an application of otolith chemical and structural attributes. Prepared for U.S. Army Corps of Engineers, Seattle District, and Port of Seattle. Prepared by Natural Resources Consultants, Inc. and Washington Dept. Fish and Wildlife. Seattle, WA.

Ruggerone, G.T., D. Weitkamp, and WRIA 9 Technical Committee. 2004. WRIA 9 Chinook Salmon Research Framework: Identifying Key Research Questions about Chinook Salmon Life Histories and Habitat Use in the Middle and Lower Green River, Duwamish Waterway, and Marine Nearshore Areas. Prepared for WRIA 9 Steering Committee. Prepared by Natural Resources Consultants, Inc., Parametrix, Inc., and the WRIA 9 Technical Committee. Seattle, WA. (ftp://dnr.metrokc.gov/dnr/library/2004/kcr1613.pdf)

Ruggerone, G.T., T. Nelson, J. Hall, and E. Jeanes. 2006. Habitat utilization, migration timing, growth, and diet of juvenile Chinook salmon in the Duwamish River and estuary. Prepared by Natural Resources Consultants, Inc. for the King Conservation District and Salmon Recovery Funding Board. (ftp://dnr.metrokc.gov/dnr/library/2006/kcr1953.pdf)

Ruggerone, G.T., J.L. Nielsen, and B.A. Agler. 2009. Linking marine and freshwater growth in western Alaska Chinook salmon, *Oncorhynchus tshawytscha*. Journal of Fish Biology. In press.

Seattle Public Utilities. 2008. Synthesis of Salmon Research and Monitoring – Investigations Conducted in the Western Lake Washington Basin. City of Seattle. 133 pp.

Shreffler, D.K., C.A. Simenstad, and R.M. Thom. 1990. Temporary residence by juvenile salmon in a restored estuarine wetland. Can. J. Fish. Aquat. Sci. 47: 2079-2084.

Shreffler, D. K., C. A. Simenstad, and R. M. Thom. 1992. Juvenile salmon foraging in a restored estuarine wetland. Estuaries 15:204-213.

Simenstad, C.A., K.L. Fresh and E.O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. Pages 343-364 *in* V.S. Kennedy (ed.). Estuarine Comparisons. Academic Press, New York.

Simenstad, C.A., 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.

Simenstad, C. A., and J. R. Cordell. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecol. Engineering 15:283-302.

Simenstad, C., J. Toft, M. Haas, M. Koehler, J. Cordell, and K. Fresh. 2003. Investigations of Juvenile Salmon Passage and Habitat Utilization, Lake Washington Ship Canal-Hiram Chittenden Locks-Shilshole Bay. Final Report of 2001 Investigations. Prepared for U.S. Army Corps of Engineers-Seattle District, Contract Number: DACW67-00-D-1011. 45 pp.

Simenstad, C., C. Tanner, C. Crandell, J. White, J. Cordell. 2005. Challenges of habitat restoration in a heavily urbanized estuary: evaluating the investment. J. Coast. Res. 40:6-23.

Simenstad, C.A., M. Logsdon, K. Fresh, H. Shipman, M. Dethier and J. Newton. 2006. Conceptual model for assessing restoration of Puget Sound nearshore ecosystems. Puget Sound Nearshore Partnership Report No. 2006-03. Published by Washington Sea Grant, University of Washington, Seattle. Available online: www.pugetsoundnearshore.org.

Timko, M.A., S.V. Johnson, P.A. Nealson. 2000. Using acoustic tags for monitoring adult chinook salmon behavior at the Hiram M. Chittenden Locks, summer 2000. Draft report by Hydroacoustic Technology, Inc. Prepared for U.S. Army Corps of Engineers, Seattle District.

Toft, J.D., C.A. Simenstad, C. Young, and L. Stamatiou. 2003. Inventory and mapping of City of Seattle shorelines along Lake Washington, the Ship Canal, and Shilshole Bay. Technical Report SAFS-UW-0302, School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. Prepared for Seattle Public Utilities, City of Seattle. 33 pp.

Toft, J., J. Cordell, B Starkhouse. 2005. Salmon Bay Natural Area Pre-Restoration Monitoring 2004. Technical Report SAFS-UW-0503, School of Aquatic and Fishery Sciences, University of Washington, Seattle, Washington. Prepared for Seattle Public Utilities, City of Seattle. 28 pp.

Toft, J.D., J.R.Cordell, C.A. Simenstad, L.A. Stamatiou. 2007. Fish Distribution, Abundance, and Behavior along City Shoreline Types in Puget Sound. North American Journal of Fisheries Management. 27:465-480.

USACE. 1999a. Ecosystem restoration report/environmental assessment: Lake Washington Ship Canal smolt passage. Section 1135 restoration project. U.S. Army Corps of Engineers, Seattle District, Seattle, WA.

USACE. 1999b. Lower Snake River Juvenile Salmon Migration Feasibility Report/Environmental Impact Statement. Appendix M. Fish and Wildlife Coordination Act Report. December 1999. 283 pp.

USACE. 1999c. Methods and results for analysis of data from tagging study of adult Chinook at the Ballard Locks, summer 1999. Draft report. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

USACE. 2001. Reference biological assessment: Continued operation and maintenance of the Lake Washington Ship Canal. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington.

W.R. Consulting. 2008. Wolfe Creek Daylighting Concept Feasibility Study. Technical Summary Memorandum. May 2008. 40 pp.

Wagner, H.H., F.P. Conte, and J.L. Fessler. 1969. Development of osmotic and ionic regulation in two races of Chinook salmon (*Oncorhynchus tshawytscha*). Comparative Biochemistry and Physiology 29:325-341.

Warner, E. and K. Fresh. 1999. Draft: Lake Washington Chinook salmon (*Oncorhynchus tshawytscha*) recovery plan. March 25, 1999 draft prepared by Muckleshoot Indian Tribe Fisheries Department, Washington Department of Fish and Wildlife, and Suquamish Indian Tribe Fisheries Department. Auburn, WA.

Weitkamp, D. and G.T. Ruggerone. 2000. Factors influencing Chinook salmon populations in proximity to the City of Seattle. Prepared for the City of Seattle by Parametrix, Natural Resources Consultants, and Cedar River Associates. 224 p.

Personal Communications and Unpublished Data

Berge, H., Environmental Scientist, King County

DeVries et al. 2001, Unpublished, R2 Consultants, Redmond, WA

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 Report. Washington Dept. Fish and Wildlife. Olympia, Washington.

Kostka, D., Community Leader, Heron Habitat Helpers

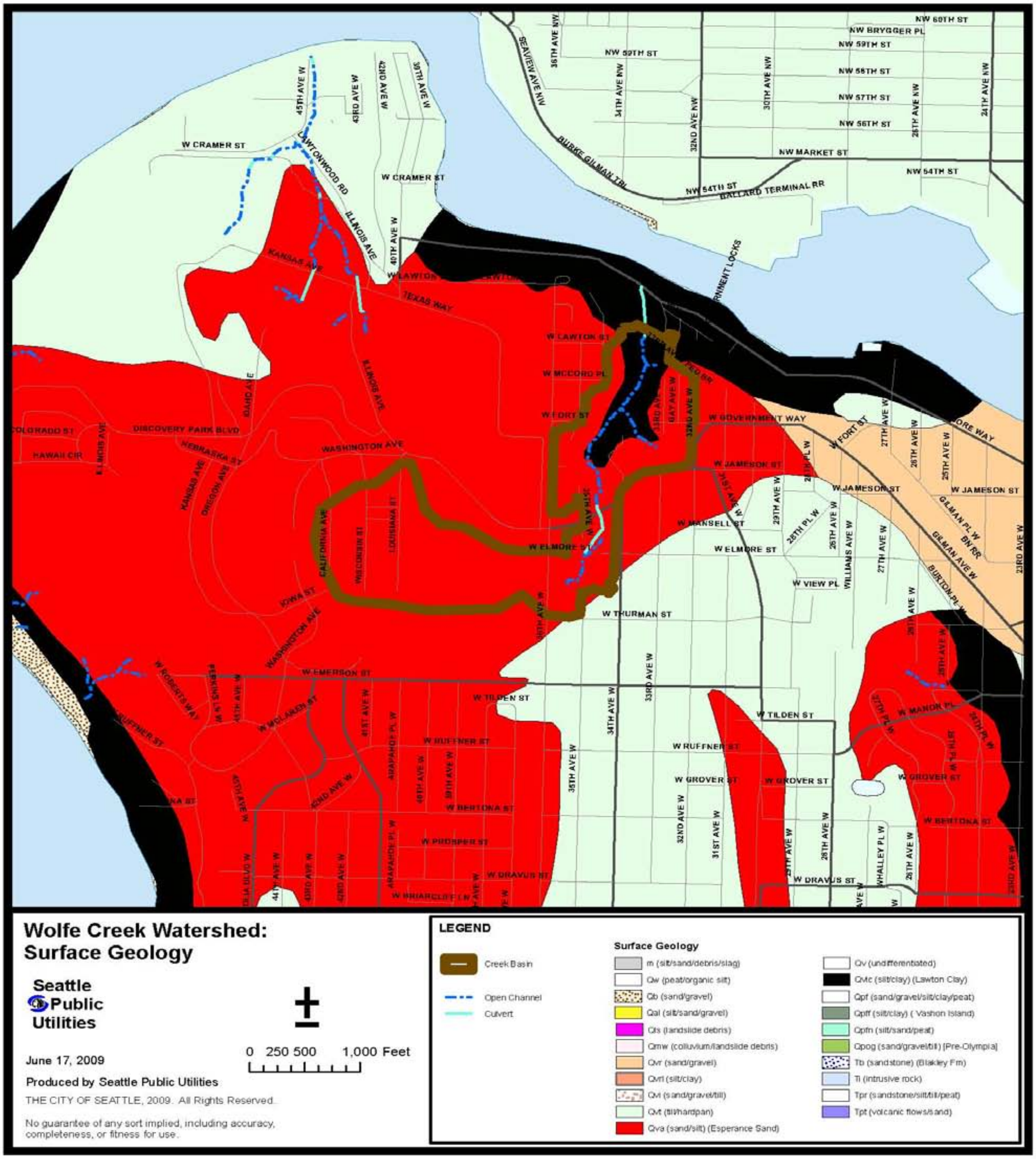
Melder, L., Hydraulic Engineer, U.S. Army Corps of Engineers

Ruggerone, G., Vice President, Natural Resources, Inc.

White, J., WRIA 8 Watershed Coordinator, King County Water and Land Resources

APPENDIX A

Flow Model Information


Wolfe Creek Watershed:
Surface Geology
Seattle Public Utilities
June 17, 2009
0 250 500 1,000 Feet
Produced by Seattle Public Utilities
THE CITY OF SEATTLE, 2009. All Rights Reserved.
No guarantee of any sort implied, including accuracy, completeness, or fitness for use.
LEGEND
Creek Basin
Open Channel
Culvert
Surface Geology
m (silt/sand/debris/slag)
Qw (peat/organic silt)
Qb (sand/gravel)
Qal (silt/sand/gravel)
Qls (landslide debris)
Qmw (colluvium/landslide debris)
Qvr (sand/gravel)
Qvrl (silt/clay)
Qvi (sand/gravel/till)
Qvt (till/hardpan)
Qva (sand/silt) (Esperance Sand)
Qv (undifferentiated)
Qvlc (silt/clay) (Lawton Clay)
Qpf (sand/gravel/silt/clay/peat)
Qpff (silt/clay) (Vashon Island)
Qpfn (silt/sand/peat)
Qpog (sand/gravel/till) [Pre-Olympia]
Tb (sandstone) (Blakley Fm)
Ti (intrusive rock)
Tpr (sandstone/silt/till/peat)
Tpt (volcanic flows/sand)
W CRAMER ST
NW MARKET ST
NW 54TH ST
W LAWTON ST
W GOVERNMENT WAY
W JAMESON ST
W EMERSON ST
W THURMAN ST
W TILDEN ST
W RUFFNER ST
W GROVER ST
W BERTONA ST
W DRAVUS ST

WWHM3 Results Data

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions
6/18/2009 Doug Beyerlein

Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
0.000	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%	100.000%
0.162	83.029%	82.840%	63.669%	63.319%	22.059%	21.481%	6.278%	5.775%	1.944%	1.640%
0.323	28.761%	27.609%	12.211%	11.039%	3.473%	2.750%	2.403%	1.844%	1.024%	0.747%
0.485	12.849%	11.100%	5.642%	4.581%	1.930%	1.379%	1.586%	1.186%	0.683%	0.478%
0.647	7.821%	6.165%	3.706%	2.675%	1.352%	0.866%	1.200%	0.836%	0.503%	0.341%
0.808	5.420%	3.889%	2.589%	1.781%	1.008%	0.597%	0.939%	0.572%	0.392%	0.234%
0.970	3.897%	2.590%	1.933%	1.264%	0.769%	0.398%	0.758%	0.442%	0.312%	0.167%
1.131	2.908%	1.817%	1.525%	0.911%	0.594%	0.288%	0.567%	0.319%	0.247%	0.110%
1.293	2.249%	1.302%	1.197%	0.675%	0.452%	0.218%	0.472%	0.242%	0.196%	0.089%
1.455	1.763%	0.912%	0.944%	0.519%	0.358%	0.164%	0.383%	0.181%	0.153%	0.065%
1.616	1.360%	0.696%	0.772%	0.400%	0.280%	0.126%	0.328%	0.133%	0.113%	0.046%
1.778	1.112%	0.461%	0.617%	0.308%	0.234%	0.097%	0.275%	0.097%	0.099%	0.038%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions
6/18/2009 Doug Beyerlein

Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
1.939	0.902%	0.357%	0.506%	0.236%	0.185%	0.083%	0.231%	0.075%	0.083%	0.032%
2.101	0.686%	0.256%	0.431%	0.186%	0.161%	0.065%	0.181%	0.064%	0.065%	0.022%
2.263	0.536%	0.203%	0.347%	0.153%	0.140%	0.046%	0.150%	0.050%	0.051%	0.019%
2.424	0.429%	0.160%	0.297%	0.139%	0.113%	0.027%	0.119%	0.039%	0.043%	0.016%
2.586	0.349%	0.112%	0.256%	0.122%	0.091%	0.022%	0.097%	0.033%	0.038%	0.013%
2.748	0.280%	0.104%	0.219%	0.103%	0.083%	0.019%	0.075%	0.025%	0.035%	0.008%
2.909	0.224%	0.088%	0.178%	0.078%	0.075%	0.019%	0.069%	0.019%	0.030%	0.008%
3.071	0.179%	0.067%	0.144%	0.053%	0.065%	0.019%	0.061%	0.011%	0.022%	0.005%
3.232	0.155%	0.056%	0.131%	0.042%	0.051%	0.016%	0.050%	0.008%	0.019%	0.005%
3.394	0.123%	0.035%	0.122%	0.039%	0.032%	0.011%	0.044%	0.008%	0.019%	0.005%
3.556	0.099%	0.029%	0.106%	0.028%	0.024%	0.005%	0.039%	0.008%	0.016%	0.005%
3.717	0.099%	0.024%	0.089%	0.025%	0.022%	0.003%	0.033%	0.006%	0.013%	0.005%
3.879	0.091%	0.021%	0.078%	0.022%	0.022%	0.000%	0.025%	0.003%	0.008%	0.003%

TAYLOR ASSOCIATES, INC.

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions 6/18/2009 Doug Beyerlein										
Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
4.040	0.069%	0.021%	0.061%	0.017%	0.019%	0.000%	0.025%	0.003%	0.008%	0.000%
4.202	0.056%	0.019%	0.056%	0.014%	0.019%	0.000%	0.019%	0.003%	0.008%	0.000%
4.364	0.043%	0.016%	0.044%	0.014%	0.016%	0.000%	0.014%	0.003%	0.005%	0.000%
4.525	0.035%	0.008%	0.044%	0.008%	0.016%	0.000%	0.011%	0.003%	0.005%	0.000%
4.687	0.032%	0.008%	0.033%	0.008%	0.013%	0.000%	0.008%	0.003%	0.005%	0.000%
4.849	0.029%	0.008%	0.028%	0.008%	0.013%	0.000%	0.008%	0.003%	0.005%	0.000%
5.010	0.027%	0.008%	0.025%	0.008%	0.008%	0.000%	0.008%	0.000%	0.005%	0.000%
5.172	0.027%	0.005%	0.022%	0.008%	0.005%	0.000%	0.008%	0.000%	0.005%	0.000%
5.333	0.021%	0.005%	0.022%	0.008%	0.005%	0.000%	0.008%	0.000%	0.005%	0.000%
5.495	0.019%	0.005%	0.019%	0.008%	0.003%	0.000%	0.006%	0.000%	0.005%	0.000%
5.657	0.019%	0.003%	0.014%	0.008%	0.000%	0.000%	0.003%	0.000%	0.005%	0.000%
5.818	0.016%	0.003%	0.008%	0.008%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
5.980	0.008%	0.003%	0.008%	0.006%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions
6/18/2009 Doug Beyerlein

Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
6.141	0.008%	0.003%	0.008%	0.003%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
6.303	0.008%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
6.465	0.008%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
6.626	0.008%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
6.788	0.008%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
6.950	0.008%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
7.111	0.005%	0.003%	0.008%	0.000%	0.000%	0.000%	0.003%	0.000%	0.000%	0.000%
7.273	0.005%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
7.434	0.005%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
7.596	0.003%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
7.758	0.003%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
7.919	0.003%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.081	0.003%	0.003%	0.008%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions
6/18/2009 Doug Beyerlein

Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
8.242	0.003%	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.404	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.566	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.727	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
8.889	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.051	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.212	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.374	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.535	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.697	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
9.859	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.020	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.182	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions 6/18/2009 Doug Beyerlein										
Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
10.343	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.505	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.667	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.828	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
10.990	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.152	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.313	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.475	0.003%	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.636	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.798	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
11.960	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.121	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.283	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions
6/18/2009 Doug Beyerlein

Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
12.444	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.606	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.768	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
12.929	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.091	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.253	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.414	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.576	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.737	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
13.899	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
14.061	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
14.222	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
14.384	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

Wolfe Creek Seasonal Flow Duration Analysis Clear Creek Solutions 6/18/2009 Doug Beyerlein										
Flow (cfs)	March		April		May		June		July	
	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %	Lower+Upper %	Lower %
14.546	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
14.707	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
14.869	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.030	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.192	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.354	0.003%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.515	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.677	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
15.838	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%
16.000	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%	0.000%

WWHM3 Subbasin Area and Land Use Delineations

Wolf Creek Subbasins ***All values are in acres***

Original

SIMPLIFIED LAND USE AREAS

Land Use Areas (All flat except where noted)								
	Impervious (roads)	Impervious (rooftops)	Lawn	Forest	Field	Total		
Upper Basin	6.07	0.00	0.00	24.06	13.1	43.23	**13 ac forest moderate	
A-D	1.93	1.93	2.58	3.55		10.00		
F	0.33	0.33	0.44	0.28		1.38		
E, G, H	1.02	1.38	1.60	1.80		5.81		
I	1.36	1.36	1.81	6.79		11.32		
J, K	1.01	1.27	1.52	5.86		9.67		
M	0.18	0.00	0.12	0.31		0.62	Total Basin	Total Lower Subbasin
L	0.23	0.23	0.30	4.26		5.01	87.03	43.80

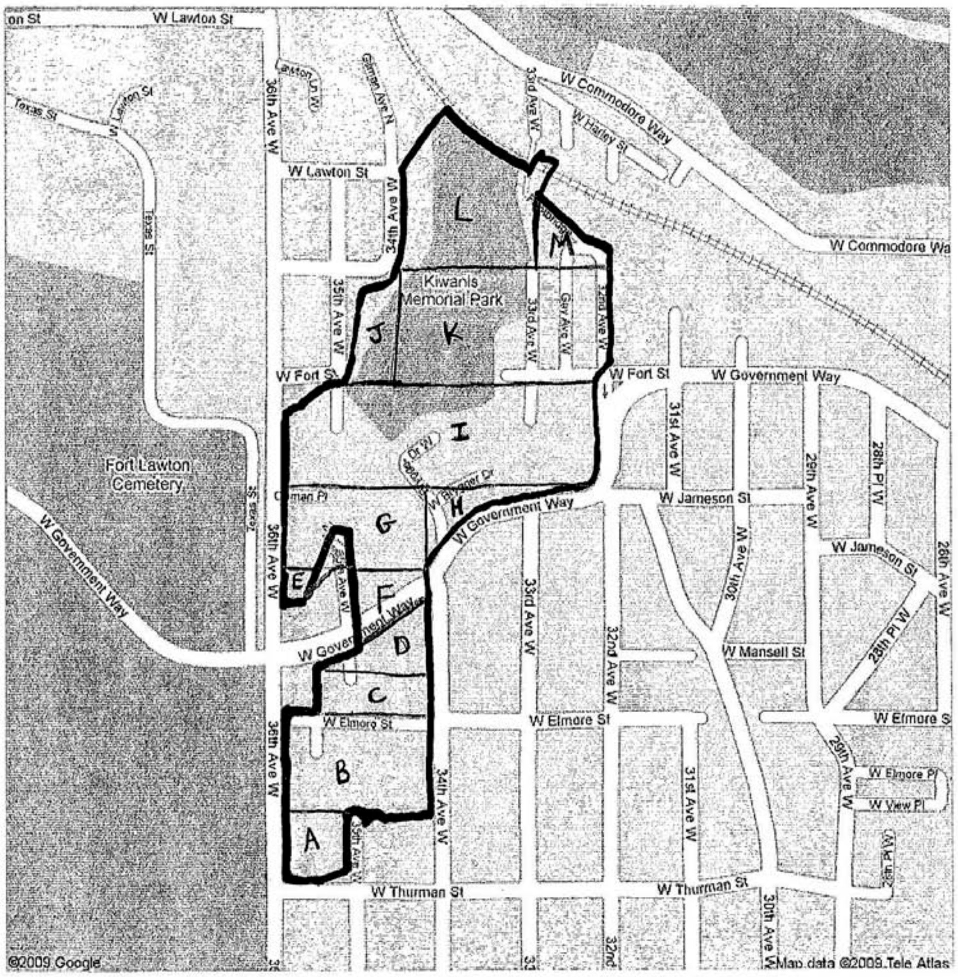
UPPER AND LOWER SUBBASINS

REVISED	Roads, Flat	Roofs	A,Lawn,Flat	C,Lawn,Flat	A,Forest,Flat	C,Forest,Flat	A,Forest,Mod	A, Pasture, Flat	Total
Upper+A-D	8.00	1.93	2.58	0.00	14.61	0.00	13.00	13.10	53.23
F	0.33	0.33	0.44	0.00	0.28	0.00	0.00	0.00	1.38
E, G, H	1.02	1.38	0.00	1.60	0.00	1.80	0.00	0.00	5.81
I	1.36	1.36	0.00	1.81	0.00	6.79	0.00	0.00	11.32
J, K	1.01	1.27	0.00	1.52	0.00	5.86	0.00	0.00	9.67
M	0.18	0.00	0.00	0.12	0.00	0.31	0.00	0.00	0.62
L	0.23	0.23	0.00	0.30	0.00	4.26	0.00	0.00	5.01
									87.03

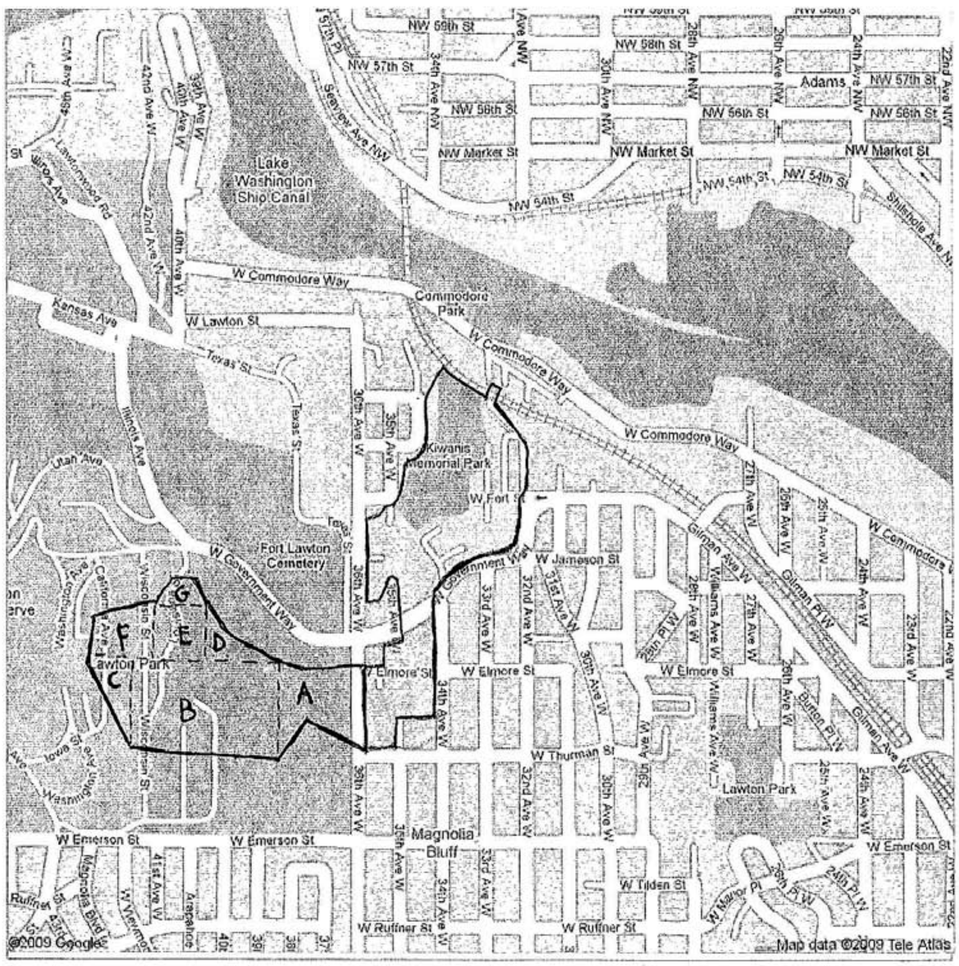
LOWER SUBBASINS

REVISED	Roads, Flat	Roofs	A,Lawn,Flat	C,Lawn,Flat	A,Forest,Flat	C,Forest,Flat	A,Forest,Mod	A, Pasture, Flat	Total
Upper	0.00	0.00	0.00	0.00	11.06	0.00	13.00	13.10	37.16
A-D	1.93	1.93	2.58	0.00	3.55	0.00	0.00	0.00	10.00
F	0.33	0.33	0.44	0.00	0.28	0.00	0.00	0.00	1.38
E, G, H	1.02	1.38	0.00	1.60	0.00	1.80	0.00	0.00	5.81
I	1.36	1.36	0.00	1.81	0.00	6.79	0.00	0.00	11.32
J, K	1.01	1.27	0.00	1.52	0.00	5.86	0.00	0.00	9.67
M	0.18	0.00	0.00	0.12	0.00	0.31	0.00	0.00	0.62
L	0.23	0.23	0.00	0.30	0.00	4.26	0.00	0.00	5.01
									43.80

Lower Subbasin Area Delineations



Upper Subbasin Area Delineations



1 of 1

5/19/2009 11:40 AM