Lake Union/Lake Washington Ship Canal System

The following write-up relies heavily on the *Lake Union/Lake Washington Ship Canal Subarea Chapter* by Douglas Houck (with substantial contributions by Deb Lester and Scott Brewer) of the *Draft Reconnaissance Assessment – Habitat Factors that Contribute to the Decline of Salmonids* by the Greater Lake Washington Technical Committee (2001).

Overview

Lake Union and the Lake Washington Ship Canal are located in the city of Seattle and combine to serve as the primary outlet of Lake Washington into Puget Sound. In 1916, drainage from Lake Washington into the Black River was blocked and the Ship Canal and Hiram M. Chittenden Locks were constructed to allow navigable passage between Puget Sound, Lake Union, and Lake Washington and provide better flushing in Lake Washington.

The Lake Union/Lake Washington Ship Canal system is comprised of the Montlake Cut, Portage Bay, Lake Union, the Fremont Cut, and the Salmon Bay Waterway. The Montlake Cut is an approximately 100-foot wide channel with concrete bulkheads extending along the length of the channel. Portage Bay is located west of the Montlake Cut and has a natural surface connection to Lake Union. Lake Union covers an approximately 581-acre area. The average depth within the lake is 32 feet. Lake Union is linked to the Salmon Bay Waterway through the Fremont Cut, a steel, rip-rapped channel.

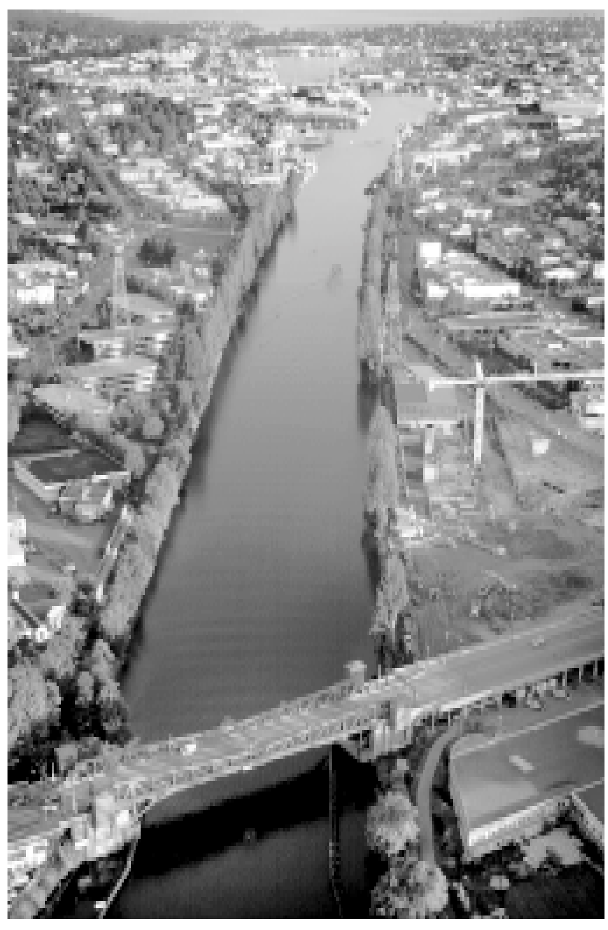
Historical Modifications

Physical Changes

The Lake Union/Lake Washington Ship Canal system has experienced extensive modification beginning in the late 19th century. Historically, no surface water connection existed between Lake Union and Lake Washington. A natural ridge separated the two lakes. Hydrology in Lake Union likely was supported by underground springs, intermittent streams, and stormwater runoff. A small stream flowed from Lake Union into Salmon Bay, which was a long, shallow, tidally influenced, embayment of Puget Sound. In the late 1800s, a chute was constructed between Lake Washington and Lake Union and the existing stream flowing to Salmon Bay was excavated to allow movement of harvested timber from Lake Washington to Puget Sound.

In 1916, the 8.6 mile long Lake Washington Ship Canal was completed, which included the construction of the Montlake Cut, the Fremont Cut, and the Chittenden Locks. The new Ship Canal provided navigable passage for commercial vessels, barges, and recreational boaters between Lake Washington and Puget Sound.

In a 1943 report published by the Washington State Pollution Commission, 45 industries were



The Ship Canal between Lake Union & Salmon Bay is totally man-made.

listed adjoining Lake Union (Tomlinson 1977). Along with the marinas, houseboats, and commercial docks, there were 10 machine shops and metal foundries, 10 lumber and plywood mills; 12 fuel and oil storage and service facilities; 8 companies dealing in sand, gravel, concrete or asphalt; the Seattle City Light Power Plant and the Seattle Gas (coal gasification) Plant. The gas plant was listed as one of the worst sources of water pollution, routinely discharging oily wastes through inadequate filters and occasionally spilling large quantities of oil so that the surface of the water was covered and fish were killed in its vicinity. Sewage and storm drainage also contributed to the pollutant loading of the lake. In the 1943 report, most of residences and commercial establishments and up to 200 houseboats lining the shoreline had direct sewage outfalls to the lake (Tomlinson 1977).

Current land use along the shores of the Lake Union system still consists primarily of water-dependent commercial and industrial uses including marinas, commercial shipyards, and drydocks. Other commercial development and single and multi-family residences also border the shoreline. Habitat in the Ship Canal and Lake Union is much more modified than that in Lake Washington. The shoreline is heavily armored and the presence of bulkheads, docks, and over-water structures provides virtually no natural shoreline within the system (Weitkamp *et al.,* 2000). Lake Union and the Lake Washington Ship Canal still support a large live-aboard and houseboat community. Portage Bay, however, has retained shallow water habitat (Weitkamp et al 2000). The south side of Portage Bay, portions of the Gas Works Park shoreline, and small areas at the south end of Lake Union are the only areas that have retained any seemingly natural shoreline characteristics (Weitkamp et al 2000).

The construction of the Ship Canal coupled with the rerouting of Cedar River to Lake Washington has resulted in substantial impacts on Cedar River chinook migration patterns and behavior. Effects on chinook have not been quantified; however, it is expected that migration through the highly modified environments of the Lake Union/Lake Washington Ship Canal system and the Locks provide less favorable habitat than did the Duwamish estuary (Weitkamp *et al.,* 2000).

Limnological Changes

Construction of the Ship Canal and intensive shoreline development has resulted in substantial limnological changes within the Lake Union/Ship Canal watershed. Changes in limnological characteristics include temperature, and dissolved oxygen.

Temperature

Surface water temperatures in the Lake Union/Lake Washington Ship Canal system can reach 20-22° Celsius during the summer. Air temperature appears to be the primary factor in contributing to warm lake temperatures (Weatherbee, 2000). Historical data indicates that peak surface water temperatures are not increasing. However, the onset of warm water conditions appears earlier than historically occurred and the duration of the high temperatures are increasing from an average of 31 days per year in the 1970's to approximately 80 days per year (Weitkamp *et al.*, 2000).

Dissolved Oxygen

The Lake Union/Lake Washington Ship Canal system serves as a transitional zone between the freshwater environment of Lake Washington and the saltwater environment in Puget Sound. Surface water quality is influenced by flow from Lake Washington into the Lake Union/Lake Washington Ship Canal system. In general, since the 1960s the water quality in Lake Union has improved, when compared with conditions experienced since the early 1900s. Historical data indicate the lower depths of Lake Union experienced anaerobic conditions year-round due to high saltwater concentrations which prevented mixing (Smith 1927, Collias 1954). This condition most likely was initiated soon after operation of the Chittenden Locks began in 1916 and lasted until 1966 when a saltwater barrier was constructed. During the 1960s, the City of Seattle intercepted most of the direct discharge of raw sewage into the lake, and the gas plant ceased operation and was turned over to the City for use as a park (Greater Lake Washington Technical Committee 2001). Lake Union still experiences periods of anaerobic conditions that typically begin in June and can last until October. This lack of mixing, along with a significant oxygen sediment demand, can reduce dissolved oxygen levels to less than 1 mg/l. These low DO concentrations would prevent fish from using the water column below 10 meters depth.

Sediment

Historical industrial practices within the Lake Union/Lake Washington Ship Canal system have resulted in bottom sediment contamination. Although quantitative data is limited, varying concentrations of organic compounds from historic sawmill practices have been identified in various areas within the Lake Union/Lake Washington Ship Canal system (Parametrix, 1992; Cubbage, 1992; Metro, 1993; Herrera and Brown & Caldwell, 1994; Hansen et al., 1994). Another identified contaminated area exists along the shoreline at the north end of Lake Union at Gas Works Park (Weitkamp *et al.,* 2000).

Exotic Plants and Animals

In addition to changes in the littoral zone and limnology, exotic plants and animals (i.e., non-native) have affected the Lake Union/Lake Washington Ship Canal ecosystem. Twenty-three non-native fish species have been identified in adjacent Lake Washington (Warner and Fresh 1998). Some of these species are known to prey on juvenile salmon (e.g., smallmouth bass) while others are potential competitors with juvenile salmonids for food (Fayram 1996; Kahler et al. 2000).

Eurasian milfoil (*Myriophyllum spicatum*), an exotic aquatic plant, was introduced into Lake Washington in the 1970's. Milfoil exists within portions of Lake Union and the Ship Canal; however, milfoil appears to affect less shoreline in the Ship Canal and Lake Union than in Lake Washington. This is most likely a result of deeper areas in the Ship Canal and Lake Union.

Chinook Utilization of the Lake Union/ Lake Washington Ship Canal System

The Lake Union/Lake Washington Ship Canal system is used by chinook during two stages in their lifecycle.

- ❏ Adult upstream migration, and
- ❏ Juvenile outmigration and rearing

Adults. Adult chinook salmon use the Lake Union/Lake Washington Ship Canal system as a migration corridor to upstream spawning grounds. The precise migration routes through Lake Union and the Ship Canal are unknown; however, their residency is expected to be brief (a few days). Water temperatures may influence initial entrance into the Lake Union/Lake Washington Ship Canal system from the Locks as evidenced by the delay observed in adult passage through the Locks during high water temperatures in 1998 (Fresh et al., 1999).

Juveniles. Little data is available on how juvenile chinook move through the Lake Union/ Lake Washington Ship Canal system. Habitat requirements for rearing and outmigrating chinook are not expected to vary significantly between Lake Washington and the Lake Union/ Lake Washington Ship Canal system (Weitkamp *et al.,* 2000). As a result, the littoral, shallow area along the shoreline is expected to be the preferred habitat for juvenile chinook. Given the limited quantities of these habitats, the Ship Canal may serve primarily as a migratory corridor rather then a rearing and foraging area for juvenile chinook.

Habitat Requirements

Juvenile Habitat Requirements

Juvenile chinook use the Lake Union/Lake Washington Ship Canal system for outmigration and rearing. In order for chinook to successfully carry out these activities the habitat must supply sufficient food and refuge from predation. Physical barriers (habitat access) should not block access to the migration corridor and water quality should be of sufficiently high quality that juvenile fish are not directly or indirectly harmed in passing through the Lake Union/Ship Canal system. We looked at each of these habitat needs to assess what is known about their condition in the Lake Union/Ship Canal system and their effect on juvenile chinook. Due to the intensive industrial and commercial land use within the area, overall habitat conditions are more modified in the Lake Union/Lake Washington Ship Canal system than in Lake Washington.

Predator Avoidance

Predation was identified as a known factor of decline in the WRIA 8 Draft Reconnaissance Assessment (Greater Lake Washington Technical Committee 2001). Predation on outmigrating juvenile chinook is likely high in constricted passage areas throughout the Lake Union/Lake Washington Ship Canal system (Ruggerone, 1992). High predation areas include the narrow regions of the Ship Canal and the Locks. Predation rates on juvenile chinook are highest in June, which corresponds to the peak outmigration period in Lake Union (Tabor, 2000; DeVries, 2000; Fayram, 1996).

Results from a 1999 predator study in the Ship Canal area shows that predation by bass and pikeminnows on chinook was also very high (Tabor 2000). Smolts per predator ranged from 0.4 for pikeminnows, to 0.3 for smallmouth bass, to 0.1 for largemouth bass (May through July). Chinook smolts represented approximately 50% of the 30 salmonids consumed by the predators and identified to the species level. Bass as small as 138 mm were found to eat smolts of ~90 mm in size. Pikeminnows tended to aggregate at key locations such as the outlet of the UW Hatchery and the point at the north end of Lake Union. Relatively few predators were encountered in Salmon Bay (Tabor 2000).

Other species of fish that may also prey on outmigrating juveniles include yellow perch, prickly sculpin, rainbow trout, cutthroat trout, and river lamprey.

Juvenile chinook use shallow, littoral habitats to avoid predators. These habitats within the Lake Union/Lake Washington Ship Canal system have been dramatically reduced through bank hardening and dredging along the shoreline. In addition, overwater structures along the shoreline have disrupted growth of aquatic vegetation, which can be used as a refuge from predators. A loss of shallow, nearshore habitats has most likely resulted in juveniles becoming more susceptible to predation.

Food Availability

There is little direct information on what species chinook are feeding on in Lake Union and the Ship Canal. It is likely that the prey base is similar to that in Lake Washington (chironomids and *Daphnia*). Bank hardening, bulkheads, and overwater structures in shoreline areas could affect production of key invertebrate species such as chironomids (midge larvae). This could occur as a result of substrate changes, loss of insect production from a loss of riparian vegetation or shading of littoral habitats by overwater structures.

Competition from introduced species could also reduce food availability to juvenile chinook. Coevolution among species and their habitat leads to the development of niches and behaviors that can reduce adverse interactions and allow species to share the resources. However, juvenile chinook are exposed to both natural and exotic competitors in Lake Union (including hatchery chinook) in a habitat type (lake) in which they did not coevolve (Weitkamp, *et. al,* 2000). Aggressive competitors may force juvenile chinook into less desirable habitats, including areas where food is scarce or where fish are more susceptible to predators.

Water Quality

Higher predation rates, creation of a thermal water barrier, and direct mortality of adult chinook salmon are suspected to be a consequence of warmer temperatures in the Lake Union/Lake Washington Ship Canal system during the summer. Juvenile chinook migrating through the Lake Union/Lake Washington Ship Canal system to Puget Sound are expected to inhabit mostly surface waters and avoid the low oxygen waters at lower depths (Weitkamp *et al.,* 2000). During the peak juvenile outmigration in June, bottom oxygen levels become stressful (median: 4.3 mg/l) and can decline to lethal levels in July (Davis, 1975). However, temperatures do not appear to be a limiting factor for juvenile salmon because high water temperatures occur generally after peak migration of juvenile salmonids. In July, when the latter portion of the juvenile chinook migrate through the canal and Lake, surface oxygen remains sufficient (Weitkamp *et al.,* 2000).

Surface water discharge from nearby industrial and commercial facilities, in addition to four combined sewer overflow (CSO) locations, contribute to water quality degradation in the Lake Union/Lake Washington Ship Canal system. Water quality in this system is lower in comparison to Lake Washington and has been included on Ecology's list of impaired and threatened waterbodies, pursuant to Clean Water Act 303(d). In general, since the 1960s the water quality in Lake Union has improved, when compared with conditions experienced since the early 1900s. Water quality impacts on chinook have not been quantified and require further study.

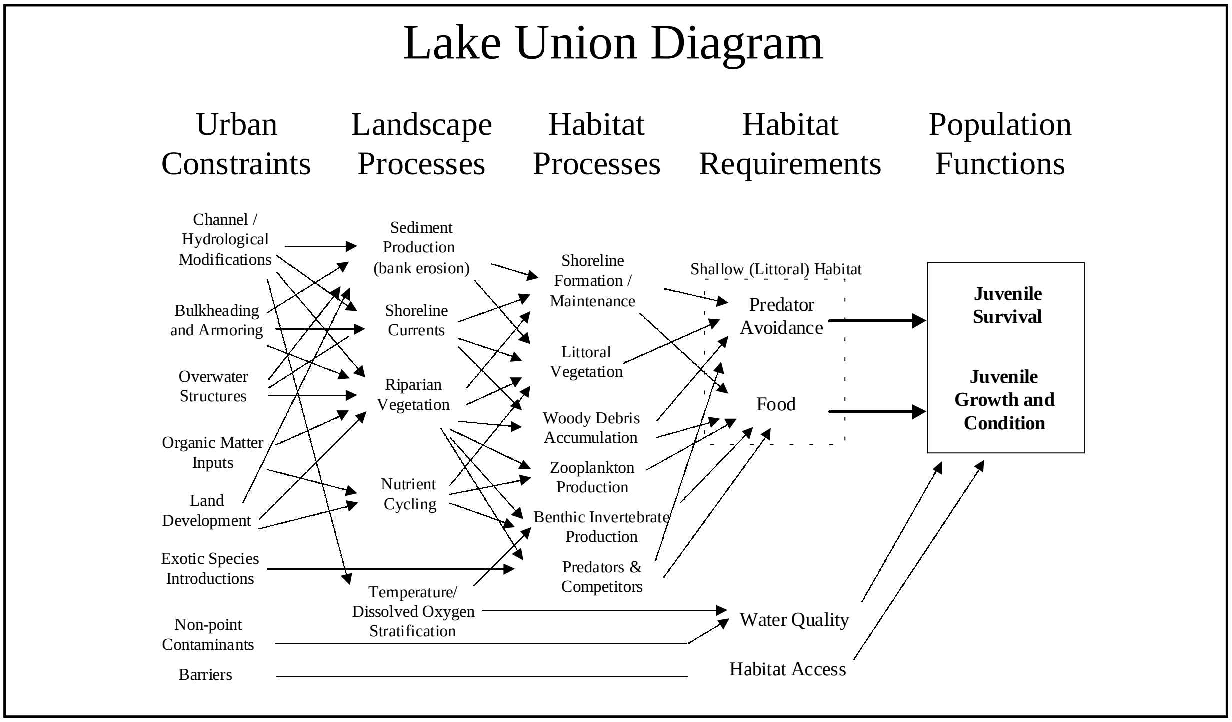


Figure 5. Hierarchical relationship between urban constraints, landscape processes, and chinook habitat requirements in the Lake Union / Lake Washington Ship Canal system.

Impacts on juvenile fish from sediment contaminants within the Lake Union/Lake Washington Ship Canal system also have not been quantified. However, the chemical properties of these sediment contaminants result in them binding to other bottom elements, which potentially limits their availability for uptake in the water column and epithelial cells in fish (Weitkamp *et al.,* 2000). The issue of impacts of contaminated sediments on migrating chinook juveniles needs further study.

Habitat Access

There are no physical barriers that prevent migration through the Lake Union/Lake Washington Ship Canal system, except for the Chittendon Locks at the western end. There have been fish passage problems at the Locks throughout their history. Observation and physical alterations to improve successful passage at the Locks continue (see Locks section). Piers, bulkheads, and over-water structures are thought to potentially affect juvenile outmigration; however, little data is available in this regard.

Landscape and Habitat Forming Processes and Trophic Interactions

Recent studies indicate that chinook fry prefer shallow areas with small substrates (sand and gravel) (Roger Tabor, USFWS, personal communication). Shallow littoral habitats provide both foraging opportunities and protection from predators. They may also provide important behavioral cues to migrating juvenile chinook salmon. The formation and maintenance of shallow littoral areas is dependent upon complex interactions among a number of physical and biological processes. These processes can be generally described to be hierarchical with respect to habitat formation, with landscape (watershed) processes driving localized habitat forming processes responsible for creating and maintaining the shallow littoral habitat required for juvenile chinook salmon survival and growth (Figure 5).

Land use within Lake Union and the Ship Canal is primarily composed of water-dependent commercial and industrial uses, including marinas, commercial shipyards, and dry-docks. Other commercial and residential development also borders the shoreline of Lake Union. Overwater coverage, bulkheads, and shoreline armoring associated with these uses is extensive. As a result, there is relatively little shallow water habitat (natural or altered) along the Lake Union shorelines (Weitkamp et al 2000). The presence of hardened shorelines and piers has severely reduced available nearshore habitats by juvenile chinook. Bank armoring has resulted in a loss of shallow water habitat and aquatic vegetative covering that served as prey species recruitment and protection from predators. In addition, bank hardening has resulted in the limitation of substrate recruitment into the lake system from upland environments that creates beaches and shallow water habitats.

The effect of nearshore habitat modification on juvenile chinook rearing within the Lake Union/ Lake Washington Ship Canal system requires further study. It is possible that in a highly altered ecosystem like Lake Union and the Lake Washington Ship Canal, reducing predation by exotic species may be as beneficial or more beneficial to the survival of juvenile chinook salmon than restoration of some of the natural habitat forming processes (e.g. recruitment and routing of woody debris). The role of woody debris in the predator-prey dynamics in the shallow littoral environment is still under debate. While aquatic vegetation patches and wood accumulations may provide important refuge habitats to juvenile chinook, there is some concern that wood accumulation may attract and provide enhanced habitat for some predators. The City of Seattle is funding further research on juvenile chinook salmon in Lake Union and the Ship Canal in 2001.

Preliminary Focus Areas

Based on the analysis above, the following table summarizes our understanding of the most likely significant factors for juvenile chinook survival and fitness in the Lake Union/Lake Washington Ship Canal system.

Population Function	Habitat Requirements	Habitat characteristic/condition	Habitat forming process	Contraints
Juvenile rearing and outmigration	Predator Avoidance	Shallow Water (< 1 m depth) Shallow gradient (< 1% slope) Fine substrates (sand, mud, small gravel) Spatial distribution of refuge/cover/food	Bank erosion and sloughing Stream sediment output	Bulkheading and bank armoring Stream modifications Loss of riparian vegetation Overwater Structures Substrate hardening
	Food Availability		Riparian vegetation Littoral vegetation Stream drift/organic output	
	Water Qaulity	Temperature, some concern; other effects		
	Habitat Access	need more study No barriers		

Among these factors, the protection and restoration of the shallow littoral habitat emerges as a key area of focus.

Habitat Improvement Projects in the Lake Union/Lake Washington Ship Canal System

Habitat improvement projects should focus on improving those habitat qualities that the science indicates will likely provide the greatest benefit for fish. The following table notes projects which have already been done and projects which might be considered and notes the benefits for fish which each project may create.

Project Name Project Cost or estimate Status of Project	Project Description	Habitat Requirement Predctor Avoidance	Food Availability
Arboretum Lakeside Trail $1,000,000 Planned	This project includes extensive restoration of areas of the "Duck Bay" shorelines at the north end of the Arboretum. The project also includes trail restoration, bridge replacement and other improvements.	Restoration of the shallow littoral habitat	
Arboretum Lakeside Trail $210,000 (est) Potential	Creation of a salmon-friendly demonstration garden with daylighted storm drains and plantings along a new stream channel.		Riparian vegetation Stream drift/ organic output
Arboretum Creek No estimate available Potential	One of the "Salmon Friendly Garden" charette sites studied by Seattle Public Utilities and consultants involved restoration of Arboretum Creek, including daylighting that portion of the creek now in a culvert below the SR-520 and Lake Washington Boulevard intersection.		Riparian vegetation Stream drift/ organic output
Commodore Park <$100,000 Potential	The eroded bank area at the westerly end of this park could benefit from a bioengineered slope with native trees and shrub plantings above the existing sandy beach area. Could potentially be combined with other fish passage enhancement at the adjacent Chittendon Locks.	Restoration of the shallow littoral habitat	
South Lake Union No estimate available Planned	Reconfiguration of the pier and docks may provide increased access to the shallow water below by increasing the light penetrating beneath the overwater structures. Preservation of the existing cove at the south west corner will be beneficial.	Restoration of the shallow littoral habitat	Riparian vegetation

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Gas Works No estimate available Potential	The shoreline of this Park offers opportunities to restore shallow water habitats which may be used by juvenile outmigrants.	Restoration of the shallow littoral habitat	Riparian vegetation

Addressing Uncertainties

Key research and assessment issues include:

1. Overall habitat use by juveniles
2. The role of overwater structures (docks and piers) as they influence prey availability and predation on juveniles.
3. The role of woody debris and other structural complexity in predation on juveniles.
4. Whether food availability is a factor of decline in the lake, and whether competitors are having a significant impact.
5. Impact of water quality and sediment on juveniles.
6. Methods for altering the balance between juvenile chinook and their predators to favor chinook.

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