**U.S. Army Corps**
**of Engineers**
Seattle District

# Lake Washington Ship Canal Water Quality Monitoring and Analysis Plan

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# Introduction

Lake Washington is a large freshwater lake within the Seattle metropolitan area that historically drained to Puget Sound via the Black River and the Duwamish River. In 1916, the US Army Corps of Engineers, Seattle District (CENWS) constructed the Lake Washington Ship Canal (LWSC) to provide for both deep and shallow navigation between Puget Sound and Lake Washington as well as a means for the passage of anadromous fish to upstream spawning grounds. The LWSC connects these water bodies via the Hiram Chittenden Locks and two canals: the Montlake Cut between Lake Washington and Lake Union, and the Fremont Cut between Salmon Bay and Lake Union (Figure 1).

The Hiram Chittenden Locks, located at the entrance to Salmon Bay, separate Puget Sound (saltwater) from Lake Washington (freshwater). The locks consist of a double lock (small and large) and a fixed concrete gravity dam structure with six gated spillways, saltwater drain, guide walls, and a fish ladder. A result of operating the locks is a potential for saltwater intrusion into the LWSC, Lake Union, and Lake Washington, which can affect the freshwater environment. To assure that saltwater intrusion is kept to a minimum, the CENWS operates the locks to minimize saltwater entering the LWSC, and monitors salinity at various locations and depths through the LWSC.

This monitoring and analysis plan provides details on the methods and protocols used to monitor salinity in the LWSC. This plan was developed in accordance with *Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies* (Ecology 2001), and includes the following elements:

- Project organization
- Project description
- Monitoring procedures
- Data quality objectives
- Data assessment procedures and corrective actions
- Data management procedures.

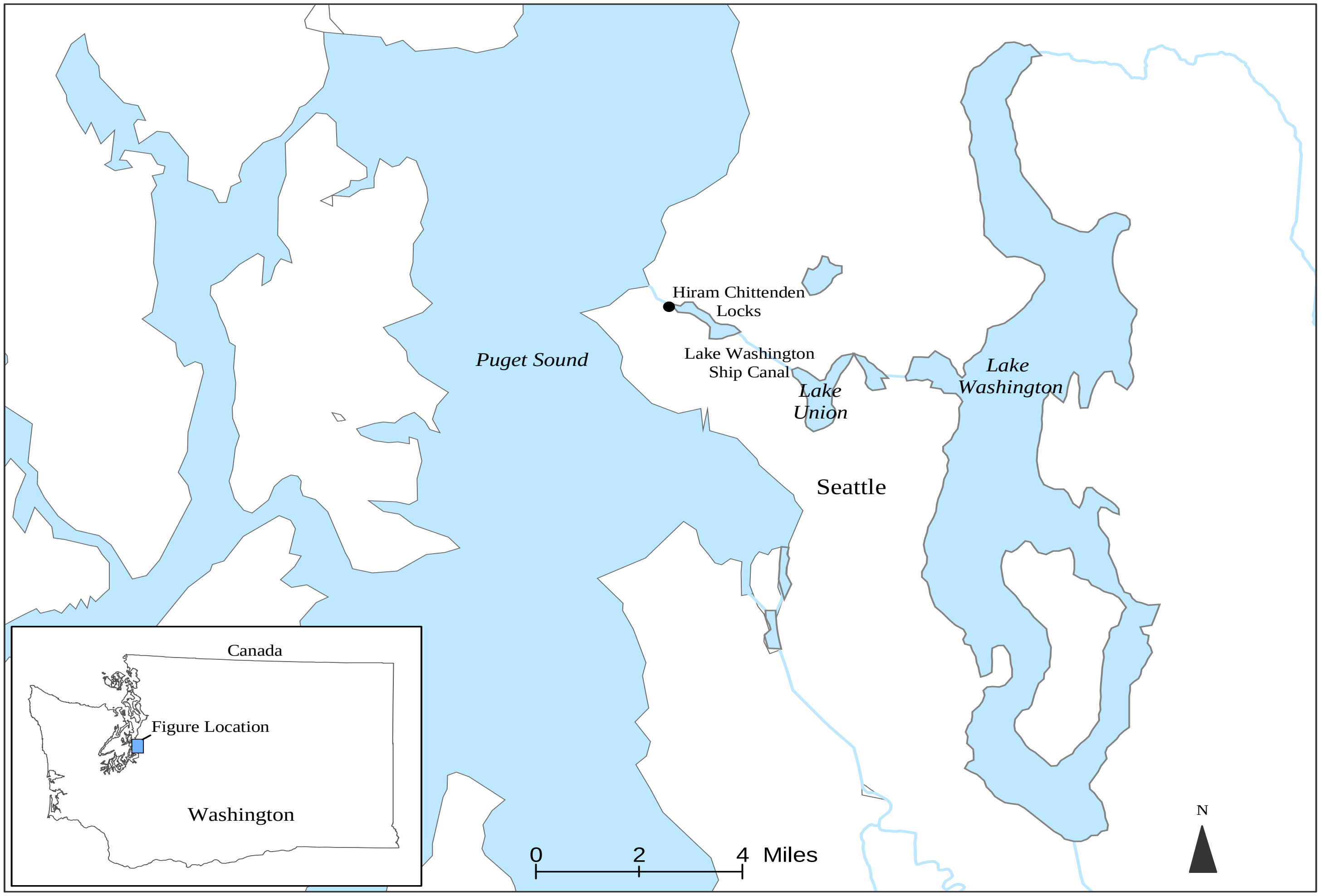


**Figure 1. Vicinity map of the Lake Washington Ship Canal water quality monitoring program in King County, Washington.**

# Project Organization and Schedule

The following section outlines the project organization and schedule for the Lake Washington Ship Canal water quality monitoring program.

## Project Organization

The COE is responsible for the Lake Washington Ship Canal water quality monitoring program. They conduct all water quality monitoring. Specific responsibilities of key personnel are identified below:

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| | |
|---|---|
| Kent Easthouse | Project manager |
| Louis Reed | Field scientist |
| Amy Klein | Field scientist |
| Ray Strode | Data transmission |

## Project Schedule

The Lake Washington Ship Canal water quality monitoring program is conducted according to the schedule shown in Table 1. The program collects hourly readings from several depths at five different locations from April through October. The sensors are calibrated in the field monthly to ensure proper readings. They are then removed from November through March when flows are highest and there is no risk of saltwater encroachment on Lake Washington. From November through February sensors are cleaned and repaired. Sensors are calibrated in March to ensure proper function before deployment in April.

**Table 1. General schedule for Lake Washington Ship Canal monitoring project.**

| | |
|---|---|
| January-February | Clean/repair sensors to ensure proper function |
| March | Calibrate sensors, prepare for field deployment |
| April 1 | Ship Canal sensors in place |
| May 1 | Recalibrate sensors |
| June 1 | Recalibrate sensors |
| July 1 | Recalibrate sensors |
| August 1 | Recalibrate sensors, Order conductivity standards for next March calibrations |
| September 1 | Recalibrate sensors |
| October 1 | Recalibrate sensors |
| November 1 | Remove, clean, and send sensors in for repair |

# Project Description

The following section provides background information, monitoring program objectives, and parameters of concern for the Lake Washington Ship Canal water quality monitoring program.

## Background Information

Operation of the Hiram Chittenden Locks raises vessels about 22 feet from tide level of Puget Sound's Shilshole Bay to the freshwater system of the Lake Washington Ship Canal at Salmon Bay. A consequence of each lockage is that denser saltwater flows from the bottom of the locks into the lighter freshwater in Salmon Bay. Lock operators attempt to reduce the amount of saltwater intrusion using the following operational methods:

- Small locks versus large locks – The large locks require about 25 times more lake water (86,000 $m^3$) than the small locks to fill and thus allows more saltwater to enter the ship canal during each lockage. When water and flow levels are low, use of the large locks is limited.

- Saltwater drain – Located on the floor of the large lock, the saltwater drain plays a significant role in removing much of the saltwater from Salmon Bay, preventing an increase in saltwater concentrations of Lake Washington.

- Saltwater barrier – A barrier wall is raised during large lockages to block saltwater from entering Salmon Bay, thus reducing the amount of saltwater entering the system. The barrier is only lowered for deep draft vessels.

During the summer period of heavy boating use at the locks and low natural flushing, the saltwater drain cannot keep up with the amount of saltwater entering the freshwater system, and saltwater intrudes into the Fremont Cut, Lake Union, and the Montlake Cut. Because saltwater is denser than freshwater, if saltwater were allowed to enter Lake Washington it would create density stratification and possibly affect the sediment water ecosystem within the lake. To prevent impacting the ecosystem of Lake Washington, the Washington Department of Ecology (DOE) has established a water quality standard for salinity at the University Bridge of 1 part-per-thousand (ppt). Judicious operation at the locks is necessary to meet water quality criteria while still maintaining the proper elevations in the freshwater system.

## Project Goals and Objectives

The goal of this program is to monitor saltwater intrusion into the LWSC to ensure that lock operations do not result in exceeding the DOE 1 ppt salinity water quality criteria at the University Bridge (Figure 1). The data collected may also be used in the future for modeling of the interaction and effects that the locks have on Lake Washington and Lake Union.

## Monitoring Design

The Corps of Engineers actively monitors salinity concentrations in the ship canal and ensures that the DOE water quality standard is not violated. In 1992 the Corps installed seventeen sensors located at five different sites from the locks to the University Bridge (Figure 2). These sensors are operated each year from April to November and report salinity, conductivity, and temperature every hour. These sensors are closely monitored and lock operations are adjusted to control salt entering the system.

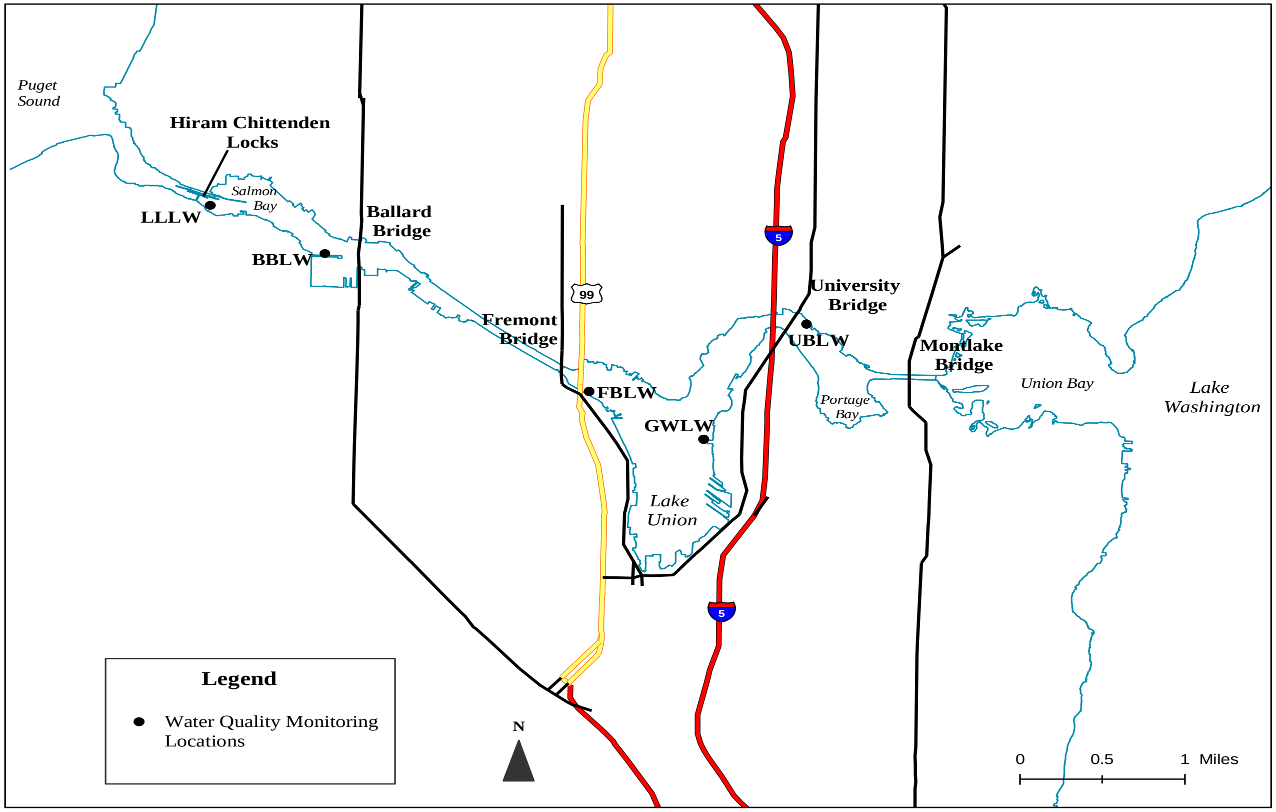


**Figure 2. Lake Washington Ship Canal water quality monitoring locations.**

# Monitoring Procedures

Monitoring procedures generally follow Puget Sound Estuary Program (PSEP) Protocols (USEPA 1990 and 1996). This section identifies water quality monitoring, data collection, and calibration procedures.

## Water Quality Monitoring

Between April and November, water quality data is collected hourly from 17 water quality probes at five stations in the LWSC (Figure 2). Monitoring station details are summarized in Table 2. Water quality parameters monitored at each station include:

- Temperature
- Conductivity
- Salinity
- Depth.

Measurements of parameters are performed using Hydrolab MiniSonde 4a multiprobes. The probes are attached at various depths to a quarter-inch steel cable anchored to the lake bottom. The monitoring depths are specific to each site, with the deepest probe positioned about 1 foot off the bottom. Each sensor is designated a specific location and given a unique SDI12 address to assure reliable data transmission (Table 2).

## Data Collection

Data collection methods generally follow procedures set forth in the *U.S. Corps of Engineers Plan of Action for Dissolved Gas Monitoring 2003* (USCOE 2002 and are briefly summarized below. Instrumentation at the LWSC consists of a Hydrolab MiniSonde 4a water quality probe, a Geomation 2380 data collection platform (DCP), and a power source. The water quality probe and DCP are powered by a 12-volt battery that is charged by a 120-volt AC line. Measurements are made every hour. The data are transmitted via radio to (1) the Seattle District's HEC-DSS water quality database, and (2) the Corps of Engineers Northwestern Division (CENWD) Columbia River Operational Hydromet Management System (CROHMS) database.

## Calibration

Data quality assurance and calibration procedures include calibration of instruments in the laboratory and in the field. Prior to deployment and field service visits, all field probes and the secondary standard probe are calibrated in the laboratory according to manufacturer's instructions using the primary standard. All primary standards are National Institute of Science and Technology (NIST) traceable and maintained according to manufacturer's recommendations. Laboratory calibrations of the water quality probes' conductivity sensors are performed using primary standard calibration solutions representative of the expected conductivity/salinity concentrations for that site (Table 2). If any measurement differs by more than 5 percent from the primary standard the probe will be recalibrated. Laboratory calibrations of the temperature sensor are performed using a NIST traceable thermometer. If measurements differ by more than 0.2°C the probe will be returned to the manufacturer for maintenance.

Every month, the currently operating field probes are checked with a laboratory-calibrated probe, which also operates as the secondary standard for the field probe. Prior to calibration, the currently operating field probe is raised from depth and placed in a 5-gallon bucket of ship canal water along with the secondary standard probe. If the field probe disagrees with the secondary probe by more than 5 percent for conductivity or 0.2°C for temperature, the probe will be recalibrated using the primary standard.

**Table 2. Lake Washington Ship Canal monitoring station information.**

| Location / Coordinates | Site | Depth in feet, Pool 22' | SDI12 Address | Calibration Solution |
|---|---|---|---|---|
| | | | | |
| Large Locks | LLLW-A | 18 | 2 | 10,000 uS/cm |
| 047° 38' 30.8" N, 122° 19' 46.8" W | LLLW-B | 27 | 3 | 10,000 uS/cm |
| | LLLW-C | 36 | 4 | 10,000 uS/cm |
| | LLLW-D | 42 | 5 | 10,000 uS/cm |
| | | | | |
| Ballard Bridge | BBLW-A | 11 | 6 | 1000 uS/cm |
| 047° 39' 54.1" N, 122° 23' 37.8" W | BBLW-B | 21 | 7 | 1000 uS/cm |
| | BBLW-C | 32 | 8 | 1000 uS/cm |
| | | | | |
| Fremont Bridge | FBLW-A | 18 | 6 | 1000 uS/cm |
| 047° 38' 44.2" N, 122° 20" 41.3" W | FBLW-B | 31 | 7 | 1000 uS/cm |
| | FBLW-C | 40 | 8 | 1000 uS/cm |
| | | | | |
| Gas Works Park | GWLW-A | 4 | 6 | 1000 uS/cm |
| 047° 38' 30.8" N, 122° 19' 46.8" W | GWLW-B | 11 | 7 | 1000 uS/cm |
| | GWLW-C | 25 | 8 | 1000 uS/cm |
| | GWLW-D | 36 | 9 | 1000 uS/cm |
| | | | | |
| University Bridge | UBLW-A | 6 | 6 | 1000 uS/cm |
| 047° 39' 11.7" N, 122° 19' 06.6" W | UBLW-B | 21 | 7 | 1000 uS/cm |
| | UBLW-C | 35 | 8 | 1000 uS/cm |
| | | | | |

# Data Quality Objectives

The overall quality assurance objective is to ensure that data of known and acceptable quality are obtained. All measurements are performed to yield consistent results that are representative of the media and conditions measured. Specific objectives and procedures for precision, accuracy, representativeness, and completeness are identified below.

- **Precision.** Precision will be assessed using a secondary standard sensor when the monthly field calibration of the sensors occurs. The results of the secondary standard will then be compared to field sensor values. The relative percent difference (RPD) of the secondary standard must be less than or equal to 5 percent.
- **Accuracy.** Accuracy will be assessed by using a primary standard for specific conductance during laboratory calibration of the sensors. The percent recovery of the primary standard is between 90 and 110.
- **Representativeness.** The monitoring design provides readings that represent a range of salinity concentrations and water depths. Representativeness will be ensured by employing consistent and standard monitoring and recalibration procedures.
- **Completeness.** A minimum of 95 percent of the readings transmitted will be judged valid. It is anticipated that all 24 hourly readings will be collected and transmitted each day.

# Data Assessment Procedures and Corrective Actions

Data are reviewed by the quality assurance personnel at the Seattle District. Quality control problems and corrective actions are summarized in a quality assurance worksheet. Values associated with minor quality control problems are considered estimates and assigned a "J" qualifier. Values associated with major quality control problems are rejected and assigned an "R" qualifier. Data assessment procedures are described below for the following quality control elements:

- Completeness
- Methodology
- Field Duplicates
- Control standards.

## Completeness

Completeness will be assessed by comparing the number of valid recorded values to the number of possible values, which are 24 per day. Ninety-five percent of all data must be deemed accurate.

## Methodology

Methodology will be assessed by examination of the transmitted data and field notebook for deviation from this quality assurance project plan. Unacceptable deviations will result in rejected values (R) and will be corrected for future analyses.

## Secondary Standards

Precision of secondary standards will be analyzed. Precision of secondary standards will be calculated according to the following equation:

$$RPD = \frac{(C_1 - C_2) \times 100\%}{(C_1 + C_2)/2}$$

where:

RPD = relative percent difference
$C_1$ = larger of two values
$C_2$ = smaller of two values.

Secondary standard results exceeding the objectives will be noted and used to flag data as estimated or rejected, or correct data upon consideration of all quality control data.

## Primary Standards

Accuracy of primary standards will be checked by the quality assurance officer. Accuracy for these elements will be calculated according to the following equation:

$$\%R = \frac{(M - T) \times 100\%}{T}$$

where:

| | | |
|---|---|---|
| %R | = | percent recovery |
| M | = | measured value |
| T | = | true value. |

Results exceeding the objective will be noted in the quality assurance worksheets, and the probe will be recalibrated. If the objectives are severely exceeded (e.g., more than twice the objective), then the associated probe will be sent to the manufacturer for repair.

# Data Management

Water quality data is collected and transmitted hourly to the DCP at the RCC in Seattle District. The data is then transferred into DSS – the data management system for Seattle. Any editing that occurs in Seattle will be marked in DSS by an indicator string of numbers. The string of numbers applies to both data rejection and estimates.

Once the real-time data are received and missing data are flagged, the following quality assurance review procedures will occur. First, tables of raw data will be visually inspected for erroneous data resulting from DCP malfunctions or improper transmission of data value codes. Second, data tables will be reviewed for sudden increases in temperature, conductivity, or salinity that could not be correlated to any hydrologic event and therefore may be a result of mechanical problems. Third, a data checklist program will be used to assist in identifying erroneous data. Values outside the data checklist program range of acceptable values (0 to 30°C for temperature and 0 to 30 ppt salinity) will be flagged and reviewed to determine if the data are acceptable or an artifact of a DCP or instrument malfunction. Fourth, graphs of the data will also be created and analyzed in order to identify unusual spikes in the data. These spikes will then be further investigated in order to identify the causes of error. Suspect data will be corrected if possible. For instance, data where drift occurred can be easily adjusted through software programs. Data that cannot be corrected will be flagged as rejected and deleted from the database.

# References

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