## Quality Assurance Project Plan

# Sammamish River
# Temperature and Dissolved Oxygen
# Total Maximum Daily Load Study Design

October 2015
Publication No. 15-03-123

DEPARTMENT OF
ECOLOGY
State of Washington

## Publication Information

Each study conducted by the Washington State Department of Ecology (Ecology) must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completing the study, Ecology will post the final report of the study to the Internet.

This Quality Assurance Project Plan is available on Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1503123.html

Data for this project will be available on Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search Study ID MROS0001.

Ecology's Activity Tracker Code for this study is 15-035.

**Federal Clean Water Act 1996 303(d) Listings Addressed in this Study.** See "Study area" and "Impairments addressed by this TMDL" sections.

---

## Author and Contact Information

Teizeen Mohamedali
P.O. Box 47600
Environmental Assessment Program
Washington State Department of Ecology
Olympia, WA 98504-7710

Communications Consultant: phone 360-407-6834.

Washington State Department of Ecology - www.ecy.wa.gov

- Headquarters, Lacey 360-407-6000
- Northwest Regional Office, Bellevue 425-649-7000
- Southwest Regional Office, Lacey 360-407-6300
- Central Regional Office, Union Gap 509-575-2490
- Eastern Regional Office, Spokane 509-329-3400

***Cover photo:*** The Sammamish River, north of Redmond looking upstream (south) from the NE 116th St. Bridge. Photo taken by Ralph Svrjcek in July 2014.

# Quality Assurance Project Plan

# Sammamish River
# Temperature and Dissolved Oxygen
# Total Maximum Daily Load Study Design

October 2015

**Approved by:**

| | |
|---|---|
| Signature: | Date: October 2015 |
| Ralph Svrjcek, Client, Water Quality Program, NWRO | |
| Signature: | Date: October 2015 |
| Dave Garland, Client's Unit Supervisor, Water Quality Program, NWRO | |
| Signature: | Date: October 2015 |
| Kevin Fitzpatrick, Client's Section Manager, Water Quality Program, NWRO | |
| Signature: | Date: October 2015 |
| Teizeen Mohamedali, Author, EAP | |
| Signature: | Date: October 2015 |
| Meghan Rosewood-Thurman, Co-Author / Field Lead, EAP | |
| Signature: | Date: October 2015 |
| Kirk Sinclair, Co-Author / Hydrogeologist, EAP | |
| Signature: | Date: October 2015 |
| Karol Erickson, Author's Unit Supervisor, EAP | |
| Signature: | Date: October 2015 |
| George Onwumere, Field Lead's Unit Supervisor, EAP | |
| Signature: | Date: October 2015 |
| Will Kendra, Author's Section Manager, EAP | |
| Signature: | Date: October 2015 |
| Jessica Archer, Section Manager for Project Study Area, EAP | |
| Signature: | Date: October 2015 |
| Joel Bird, Director, Manchester Environmental Laboratory | |
| Signature: | Date: October 2015 |
| Bill Kammin, Ecology Quality Assurance Officer | |

Signatures are not available on the Internet version.
EAP: Environmental Assessment Program
NWRO: Northwest Regional Office

# 1.0 Title Page and Table of Contents

## Table of Contents

# List of Figures

## List of Tables

Page

# 2.0 Abstract

The Sammamish River is located in King County, in western Washington State. It flows for about 13.8 miles between Lake Sammamish and Lake Washington. Before human modifications, the river was more like a slow-moving slough, with extensive floodplains and a meandering channel. Since the 1900s, it has been heavily modified to accommodate human activities such as farming, flood control, and development.

Several reaches of the Sammamish River are not meeting the criteria in the state's surface water quality standards for temperature and dissolved oxygen (DO). Cool temperatures and high DO are necessary to protect aquatic life and salmonid habitat. When water bodies do not meet criteria, the Washington State Department of Ecology (Ecology) must conduct a Total Maximum Daily Load (TMDL) study and develop a water cleanup plan. The purpose of the study and plan is to identify pollution sources, determine pollutant levels that will meet state standards, and implement actions to reduce pollution.

This Quality Assurance Project Plan describes the TMDL study that Ecology is conducting, including the methods, data quality procedures, study design, water quality modeling approach, and other details.

Ecology will collect field data from June through September 2015 and will use these data to develop and calibrate a numeric water quality model to simulate continuous temperature, DO, and other water quality parameters in the Sammamish River. Ecology will then use the model to determine the maximum allowable level of heat loads and nutrient inputs that are needed for the river to be in compliance with water quality standards.

# 3.0 Background

Ecology is conducting this Total Maximum Daily Load (TMDL) study to investigate water quality impairments for temperature and dissolved oxygen (DO) in the Sammamish River.

## 3.1 Study area and surroundings

### Geographic Setting

The Sammamish River is located in the Puget Sound lowlands of Washington State, and it is about 13.8 miles long. It is an unusual river in the sense that it flows between two lakes; it has its headwaters at the outlet of Lake Sammamish and eventually drains into Lake Washington.

The total drainage area of the Sammamish River, including Lake Sammamish, is about 241 square miles, of which 101 square miles are in the Lake Sammamish basin. The drainage area downstream of Lake Sammamish is therefore about 140 square miles. The whole watershed is at fairly low elevation and low gradient. The headwaters are at an elevation of about 29 ft and the outlet is about 17 ft above sea level.

Four main tributaries drain to the Sammamish River. These tributaries are as follows, from upstream to downstream order: Bear Creek[1], Little Bear Creek, North Creek, and Swamp Creek, with drainage areas of 47, 15, 29, and 25 square miles, respectively. Numerous, smaller tributary creeks also contribute to the Sammamish River.

The Sammamish River is located primarily within King County, with a portion of the upper watershed within Snohomish County. The Sammamish Watershed is mostly suburban watershed, with several urban centers but also has some relatively large areas that remain undeveloped. The Sammamish River watershed downstream of Lake Sammamish includes areas of unincorporated King and Snohomish Counties, as well as the cities of Bellevue, Bothell, Brier, Everett, Kenmore, Kirkland, Lynnwood, Maltby, Mill Creek, Mountlake Terrace, Mukilteo, Redmond, Sammamish, and Woodinville.

The Sammamish River has a long history of changes due to farming, development, channel modifications, and other human activities since the early 1900s. This history of the study area and human influences are discussed in more detail in Section 3.1.2.

### TMDL Study Area

Figure 1 illustrates the extent of the Sammamish Watershed and also identifies the focus area of this particular TMDL study, which covers a subset of the Sammamish Watershed. The TMDL study area for this project is focused on the mainstem of the Sammamish River, beginning downstream of the outlet of Lake Sammamish at Marymoor Park at River Mile (RM)[2] 12.8 and

---

[1] Bear Creek is sometimes locally also referred to as "Big Bear Creek".

[2] For this QAPP and study, River Miles (RM) are based on the distance upstream calculated from the mouth of Lake Washington based on the National Hydrography Database (NHD) flowline GIS layer for Washington (unless otherwise specified). These may or may not coincide with USGS or WDFW RM.

ending at Blyth Park at RM 2.6.

Backwater from Lake Washington influences the lowest 2.6 miles of the river, and this stretch is therefore not included within the TMDL study area. Since Swamp Creek enters the Sammamish River downstream of Blyth Park, it is also excluded from the TMDL study area. The jurisdictions that fall within the TMDL study area include King County and the cities of Bellevue, Bothell, Kirkland, Redmond, and Woodinville (Figure 5).

The three other major tributaries (Bear, Little Bear, and North Creeks) are also part of the Sammamish River watershed. These are included in the study in terms of their flow and loading to the mainstem Sammamish River (i.e., they will be monitored at their mouths), but we do not intend to collect data or model these tributary sub-watersheds upstream of their mouths. The relative effects of heat and nutrient loads from each of these three major tributaries and sub-watersheds will be quantified and analyzed in this study, but a separate effort will distribute that pollutant loading to upstream jurisdictions. Bear Creek already has a completed temperature and DO TMDL and cleanup plan that has been approved by the U.S. EPA.[3]

While this TMDL study will address the effect of tributary loading (of heat and nutrients) on the mainstem impairments on the mainstem Sammamish River, it will not directly address any water quality violations in the major tributaries. These will be addressed in a separate TMDL study at a later date. The water quality violations and listings to be addressed by this TMDL are described in more detail in Section 3.2, under *Impairments Addressed by this TMDL*.

[3] Bear Creek and Swamp Creek also both have completed and approved TMDLs and cleanup plans that have been approved by the U.S. EPA.

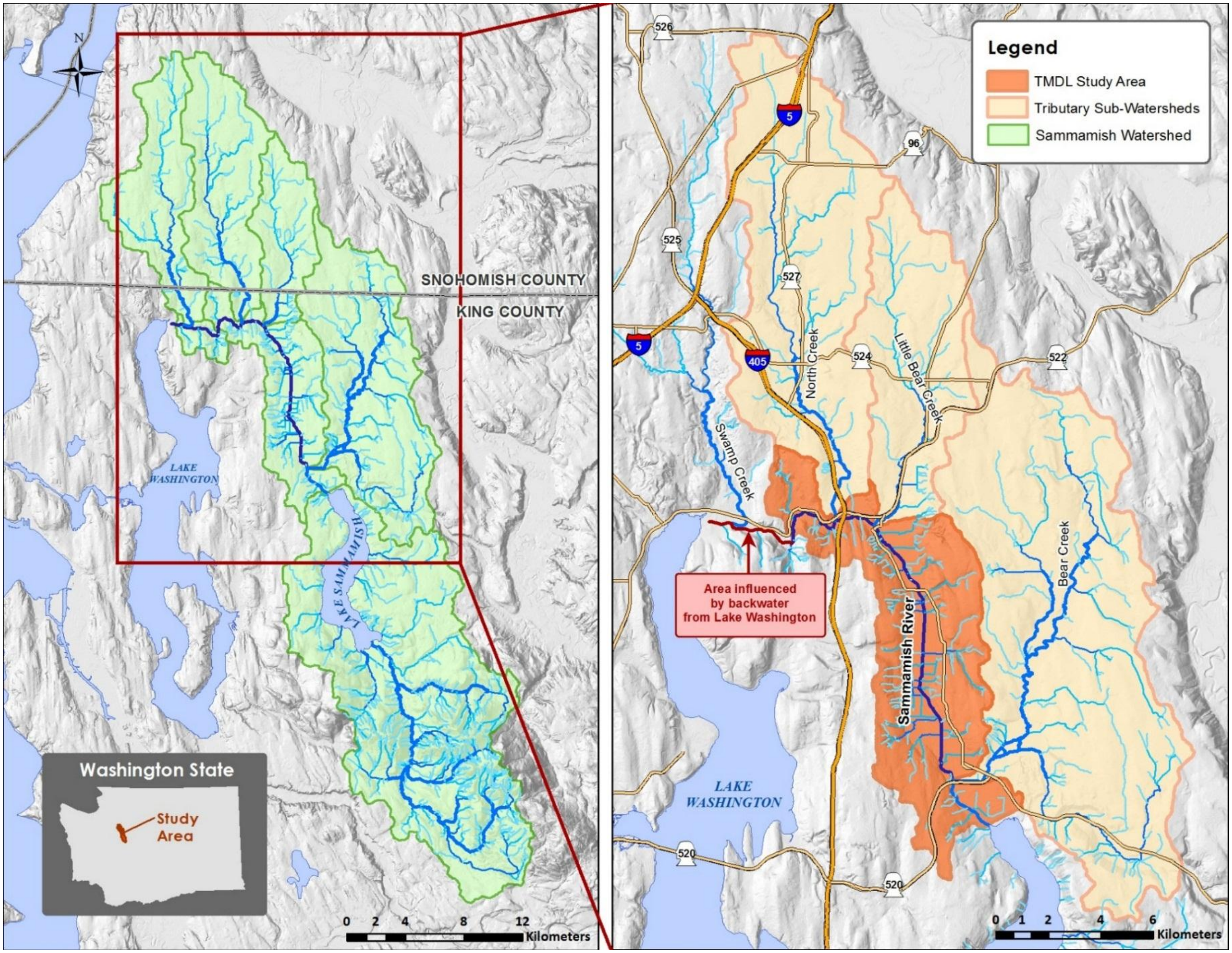



Figure 1. Map of the entire Sammamish Watershed (left) and the TMDL study area and periphery sub-watersheds (right).

## Climate

The climate in the area is characterized by warm, dry summers and cool, wet winters. The climate is relatively moderate due to the proximity to the Pacific Ocean and prevailing winds that blow from the ocean (Liesch et al., 1963).

Table 1 presents a summary of 1986-2010 average monthly air temperatures and precipitation observed at a NOAA Coop station located on the north-western shore of Lake Washington, about four miles south of the downstream end of the Sammamish River. Monthly average air temperatures recorded here range between 36-47$^o$F (2.2-8.3$^o$C) in the cooler winter months and between 56-76$^o$F (13-24$^o$C) in the warmer summer months.

Annual precipitation at this same location is about 35.5 inches per year and is not expected to be very variable within the study area, since the elevation difference between the upper and lower watershed are minimal.

Table 1. Average monthly max/min air temperatures and precipitation observed from 1986 through 2010 at Seattle Sand Pt WSFO[4], COOP ID: 457470 (WRCC, 2015).

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average Maximum Air Temperature ($^o$F) | 47.0 | 50.2 | 53.7 | 58.7 | 64.5 | 69.7 | 75.6 | 76.1 | 71.3 | 60.6 | 51.8 | 46.3 | N/A |
| Average Minimum Air Temperature ($^o$F) | 37.0 | 36.9 | 39.2 | 42.8 | 47.9 | 52.3 | 56.0 | 56.7 | 52.8 | 46.8 | 41.1 | 36.6 | N/A |
| Average Total Precipitation (inches) | 4.99 | 2.88 | 3.74 | 2.81 | 2.23 | 1.61 | 0.77 | 0.97 | 1.39 | 3.18 | 5.59 | 5.33 | 35.5 |

Figures 2 and 3 present daily summaries of air temperature and precipitation, respectively, at the same station from October 1986 through January 2015.

[4] Weather Service Forecast Office

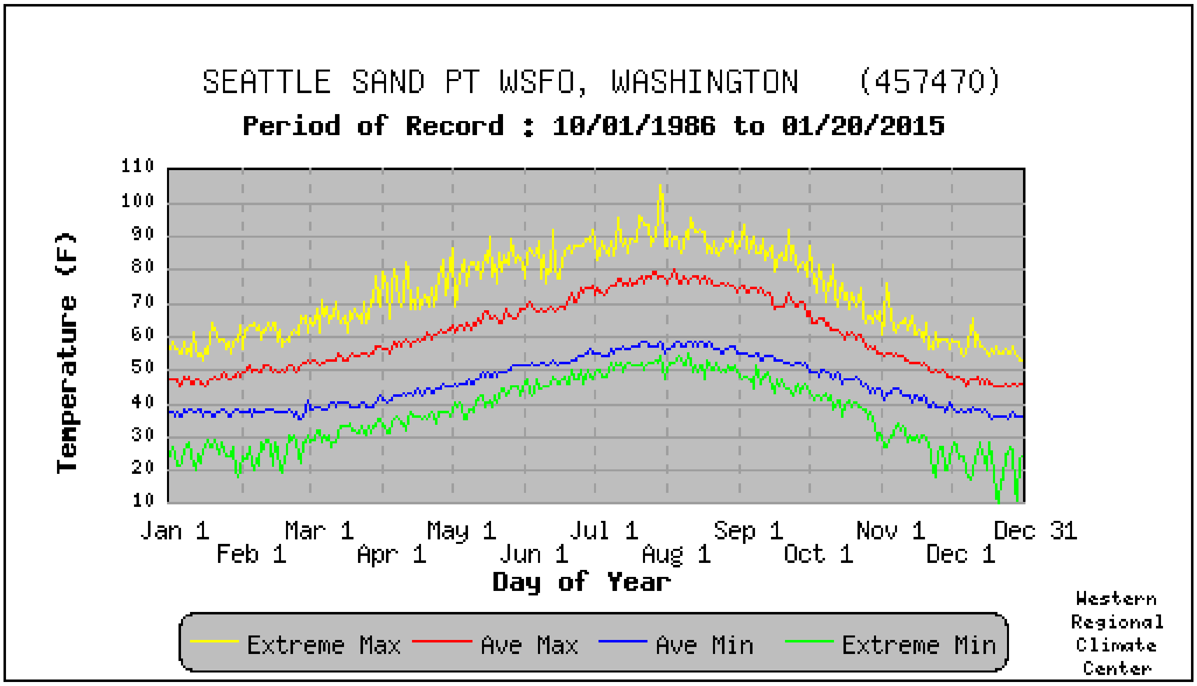



Figure 2. Extreme and average max/min of daily air temperatures recorded from 1986 through 2015 at Seattle Sand Pt WSFO, COOP ID: 457470 (WRCC, 2015).

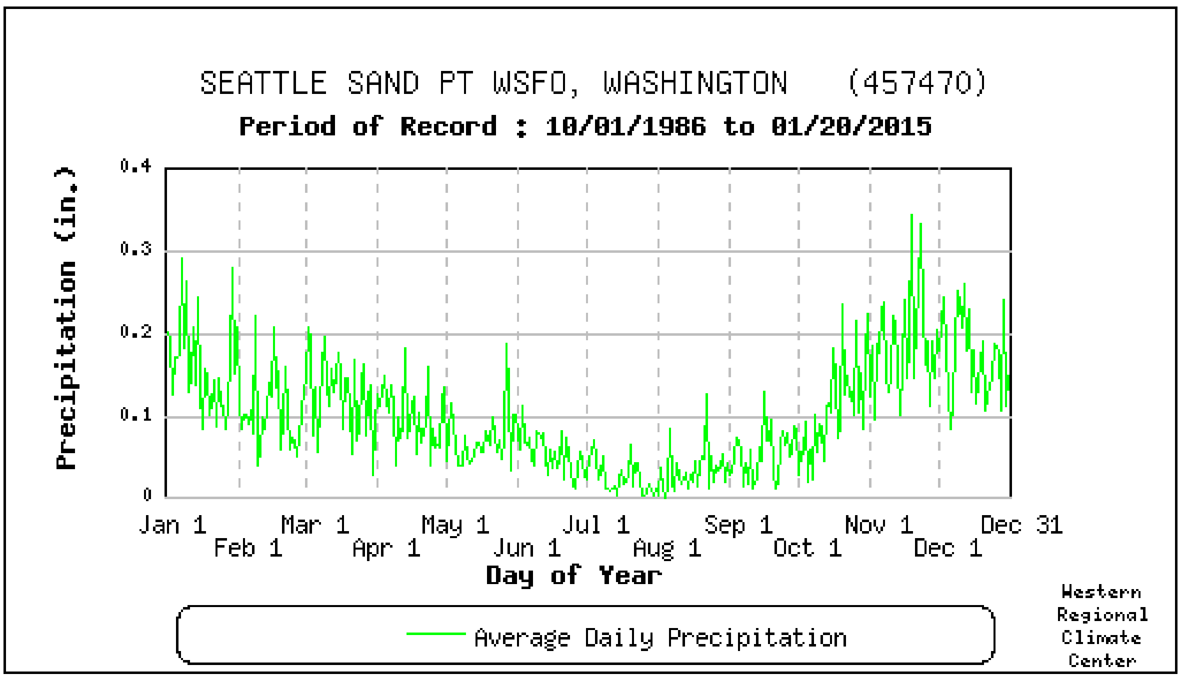



Figure 3. Average daily air precipitation recorded from 1986 through 2015 at Seattle Sand Pt WSFO, COOP ID: 457470 (WRCC, 2015).

## Geology and Hydrogeology

Lake Sammamish and its distributary, the Sammamish River, occupy one of several pronounced north-south trending glacial channels that formed about 15,000 years ago as the Puget Lobe of the Vashon Glacier advanced into and later retreated from the Puget Sound lowland, during the last continental glaciation (Booth, 1994). As the Vashon glacier advanced, it laid down thick deposits of advance outwash (silt, sand, and gravel), till, and other drift deposits throughout much of the Puget lowland. Additional deposits of glacio-lacustrine drift, recessional outwash, and other deposits were laid down as the ice retreated.

With the withdrawal of Vashon ice, the ancestral Sammamish River occupied a low-lying glacial channel that remained when the ice withdrew from the central King County/Redmond area. The broad, low-gradient Sammamish glacial channel favored the deposition of fine-grained alluvium across most of the valley bottom and the formation of numerous oxbow ponds and floodplain wetlands (Collins et al., 2003).

Recent studies of the Sammamish valley suggest that groundwater interacts with the river channel mostly within the alluvium and Vashon recessional deposits that immediately underlie the valley floor (Carey, 2003; King County, 2005a). The major tributary streams to the Sammamish River (e.g., Bear, Little Bear, and North Creeks) that drain the surrounding uplands are sustained during the summer months by groundwater that discharges mostly from aquifers contained within deposits of Vashon advance and recessional outwash. These upland aquifers may also recharge the Sammamish alluvial aquifer along the valley perimeter (Carey, 2003).

Shallow groundwater in the valley interior generally follows the local topography. It generally flows down-valley (southeast to northwest) and from the valley perimeter toward the Sammamish River, which serves as a regional drain/point of discharge for area groundwater (King County, 2005a).

## Hydrology

Flow to the Sammamish River is now primarily controlled by a broad-crested weir just downstream of the outlet of Lake Sammamish at RM 13.3. The weir was constructed by the U.S. Army Corps of Engineers in 1964 primarily to protect against spring flooding in the Sammamish River valley and to maintain water surface levels in Lake Sammamish (NHC, 2010). The project also involved widening the channel and deepening the river throughout most of its length by about five ft (FEMA, 1978). More details on the history of the river and hydrologic modifications are discussed in Section 3.1.2 *History of the Study Area.*

The concrete weir controls lake outflow and was built primarily to eliminate flooding in the Sammamish Valley. The weir and downstream Transition Zone (a 1,400 ft-long ramp below the weir) was built with a design flow of 1,500 cfs while keeping Lake Sammamish levels below 29.0 ft NGVD[5] (USACE, 1962). The design objectives also included maintenance of minimum summer lake levels. A narrow notch in the middle of the river was added in 1998 to allow for the passage of fish and small boats, e.g., canoes or kayaks.

[5] Equivalent to 32.6 NAVD

The longest continuous streamflow station on the Sammamish River is at 116th Street, at about RM 9.5. USGS Station 12125200 had a flow gage at this location from 1965 through 2006. In 2006, King County took over monitoring and established a real-time telemetry station at this same location (called Station 51T). Figure 4 presents the daily average and daily range of streamflow for the period of record for this location.

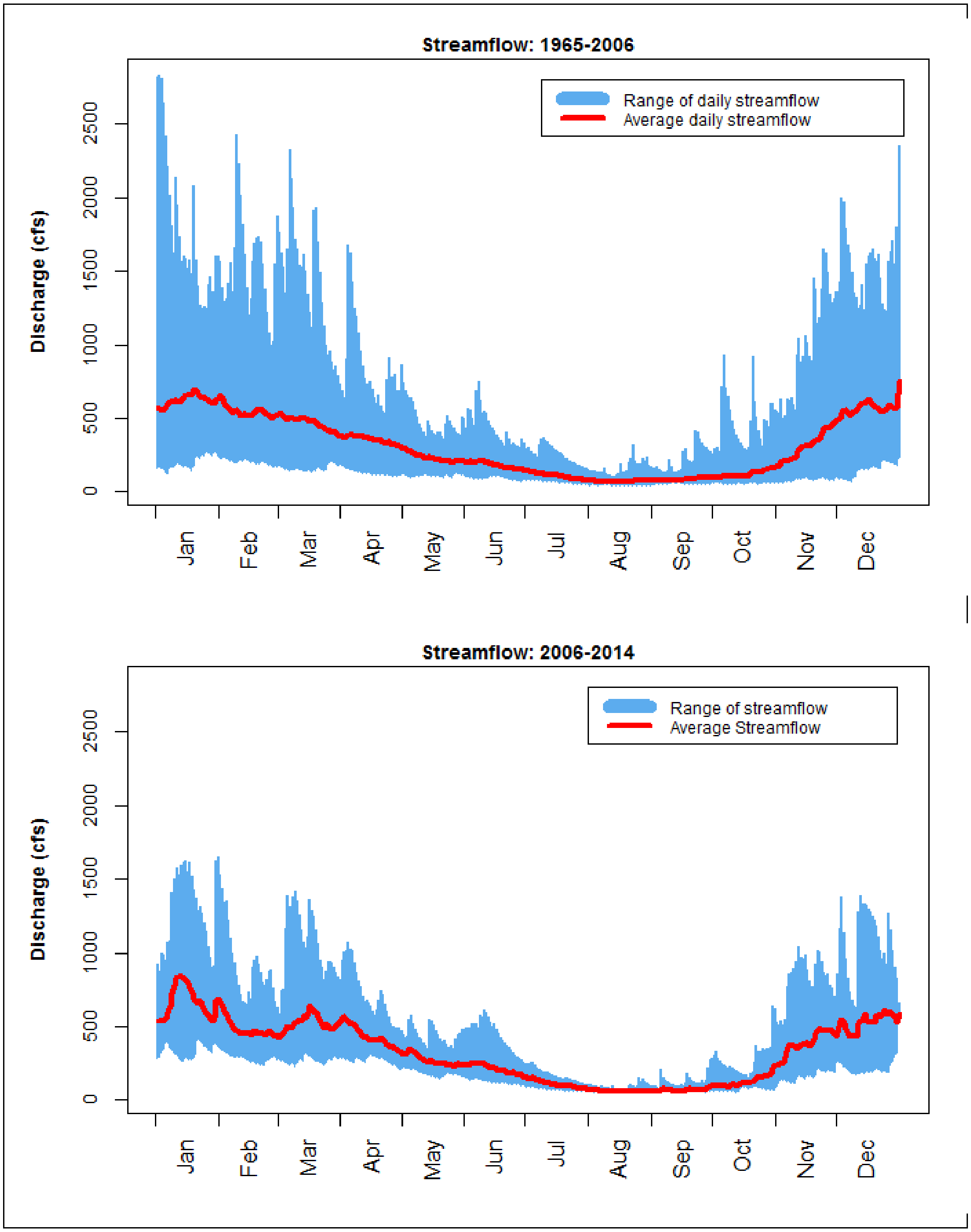



Figure 4. Average daily streamflow and range on the Sammamish River at 116th St (RM 9.5) measured by the USGS at Station 12125200 from 1965 through 2006 (top) and by King County at Station 51T between 2006-2014 (bottom).

From 1965 through 2006, the daily average streamflow varied between 66 cfs and 751 cfs. Actual daily streamflow appears relatively variable from year to year, especially during the wetter months of November through March, as evidenced by the range of values observed in the streamflow record. From 2006 through 2014, the daily average streamflow at this same location varied between 57 cfs and 841 cfs.

Table 2 summarizes monthly flows between June and September for the complete period of record at 116$^{th}$ St. Flows are lowest during the month of August, with an average of 67 cfs and a monthly range of 25-320 cfs between 1965 through 2014. The 7Q10 low flow in 1954-2014 was 64 cfs.

Table 2. Monthly minimum, maximum, and mean flows on the Sammamish River at 166$^{th}$ Street between June and September for the period of record (1965-2014).

| | Jun | Jul | Aug | Sep |
|---|---|---|---|---|
| Minimum Streamflow (cfs) | 60 | 42 | 25 | 34 |
| Maximum Streamflow (cfs) | 754 | 367 | 320 | 416 |
| Mean Streamflow (cfs) | 198 | 109 | 67 | 78 |

The Sammamish River doubles in terms of flow magnitude between the upstream end at the outlet of Lake Sammamish and when it discharges into Lake Washington due to flow contributions from its four major tributaries (Figure 5). Distributed (groundwater) inflows make up about 5% of the total flow contribution, according to hydrologic modeling analysis by King County (2009).

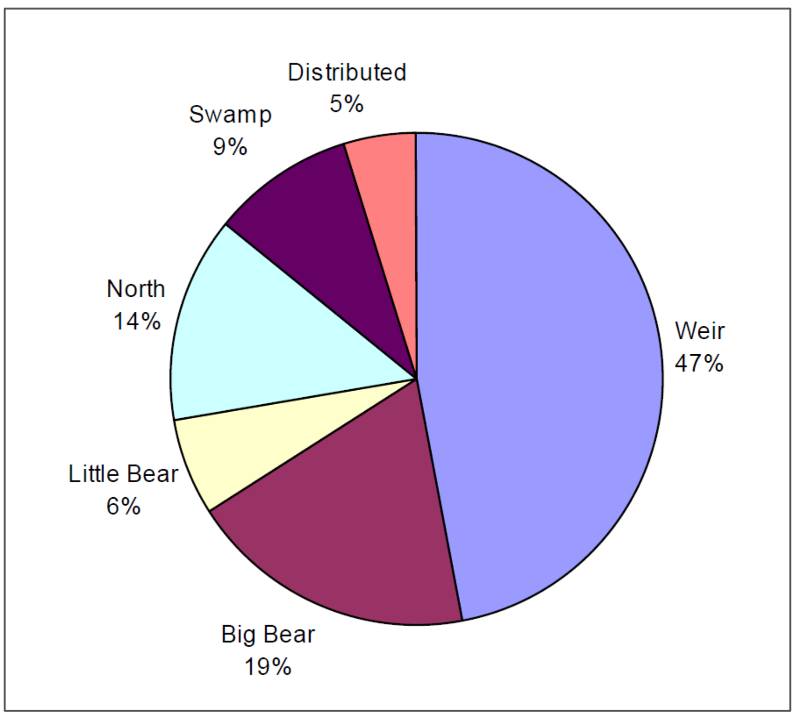



Figure 5. Estimated annual average inflow contributions to the Sammamish River, 1995 - 2003 (Source: Figure 13 of King County, 2009).

Flow at the downstream end is influenced by backwater from Lake Washington up through about RM 2.6 near Blyth Park (King County, 2009).

## Land Use

Land uses in the TMDL study area include residential, urban commercial, agricultural, open space, and recreational. A large part of the Sammamish River watershed and tributary watersheds upstream are urbanized, primarily with low to medium density residential development.

The upstream end of the Sammamish River starting at the Lake Sammamish outlet includes recreational areas at Marymoor Park, as well as urban, commercial, and residential development in the City of Redmond. Downstream of the confluence with Bear Creek (RM 12.3) is the Willows Run Golf Course, a large turf farm, Sixty Acres Park (owned by King County), and a number of small nurseries and crop farms. King County's Farmland Preservation Program protects agricultural uses and prohibits other development along significant portions of the river valley between Redmond and Woodinville (NHC, 2010).

As the river veers west near the confluence with Little Bear Creek (RM 5.4), it passes through the cities of Woodinville and Kenmore, where commercial and industrial development increases. After the I-405 Bridge and the confluence with North Creek (RM 4.4), the river passes through the city of Bothell. In the last reaches of the river between Bothell and the Lake Washington outlet just past Kenmore, there are a few more open recreation areas and two more golf courses (Wayne Public Golf Course and Inglewood Golf Club). Swamp Creek (RM 0.75) drains into the Sammamish River within the City of Kenmore and into the reaches affected by backwater, before the Sammamish River discharges to Lake Washington.

## Vegetation

Based on General Land Office (GLO) maps and field notes, the riverine forests of the Puget Sound lowlands in the mid-19$^{th}$ century were a hardwood-conifer mix where hardwoods dominated in terms of abundance, but conifers accounted for most of the biomass (Collins et al., 2003). In Liesch et al. (1963), the native vegetation in northwest King County is stated to be originally dominated by conifers. Kerwin (2001) describes the original Sammamish River corridor as "densely forested with cedar, hemlock, and Douglas fir, with willows and deciduous vegetation dominating close to the river banks."

Most of the original old-growth forest was heavily logged from the 1870s and into the early 1900s and replaced by development, and revegetated with big leaf maple, vine maple, red alder, and willow (Kerwin, 2001 and Liesch et al., 1963). The riparian vegetation in the late 1990s along the river was documented to be invasive, non-native reed canary grass and Himalayan blackberry along more than half of the river's total length (R2 Resource Consultants, 1999). Buffer restoration projects have restored sections of the Sammamish River buffer, but a lot more of the banks are dominated by invasive, low shade plant species.

## Salmon and Habitat

The Sammamish River is an important salmon migration corridor, linking Lake Washington to Lake Sammamish. The Issaquah Salmon Hatchery (in operation since 1936) is managed by Washington State Department of Fish and Wildlife which annually releases 2,000,000 fingerling fall Chinook into Issaquah Creek. The annual return goal of 1,600 is regularly achieved and these fish migrate through the Sammamish River. Other documented salmonid species in the Sammamish River and tributaries include coho, sockeye, kokanee, steelhead, rainbow, and coastal cutthroat trout (Kerwin, 2001).

The four major tributaries to the Sammamish River (Bear, Little Bear, North, and Swamp Creeks) are all major salmon-bearing streams. Kerwin (2001) identified the following habitat-limiting factors for salmon in the Sammamish River:

- Culverts that block passage between the mainstem and several smaller tributaries.
- Erosion of streambeds and banks, which limits the quality and quantity of spawning substrate.
- Loss of channel complexity/connectivity, resulting in reduced interception of cool groundwater and recruitment of sand and gravel into the channel, and disconnection of the river from off-channel habitats.
- Degraded riparian conditions, less cover, forage, refugia, and large woody debris recruitment.
- Altered flow due to weir operations and altered hydrology due to logging, development, and urbanization.
- High water temperatures from a combination of factors including limited shade, degraded cool-water refugia, channelization, and channel deepening.
- Nutrient loads which contribute to stream productivity (e.g., macrophyte growth) and oxygen consumption.
- Pesticides and herbicides entering the mainstem from irrigation returns and drainage ditches.

## Potential Pollutant Sources

Both point and nonpoint pollution sources may be contributing to water quality problems in the Sammamish River. Ecology reviewed aerial photography and conducted several visual surveys (via boat) of the river in late 2014 and early 2015 to look for potential pollutant sources to the Sammamish River.

### Lake Sammamish

Water from Lake Sammamish has a big influence on Sammamish River water quality – both on temperatures and nutrient levels. The Willowmoor weir is designed to “skim” warmer upper layers of Lake Sammamish as it drains to the Sammamish River. This water from Lake Sammamish therefore contributes to warming in the upper reaches Sammamish River, especially during the summer/late fall. The weir is currently under review for modification and replacement due its age and functionality. The few alternatives being explored include approaches to cool down water temperatures in the upper Sammamish River within the Willowmoor floodplain area.

King County evaluated Lake Sammamish water quality in a recent report and showed that lake total phosphorus (TP) averaged about 32 µg/L in the 1960s. TP levels decreased in the late 1970s primarily because of the diversion of wastewater in 1968 which was originally discharging to the Sammamish River via Issaquah Creek. After this diversion, it took about seven years for TP levels to decrease, reaching an apparent equilibrium to below 20 µg/ between 1975 and 1986 (King County, 2014). In the 1980s, the lake was at an apparent equilibrium of around 17 µg/L, but levels increased to over 20 µg/L by the mid-1990s, likely as a result of increased urbanization surrounding the lake. A decrease in internal phosphorus loading to and from sediments within the lake is suspected to be responsible for the currently stable level of about 17.5 µg/L phosphorus in recent years.

An earlier predictive model by King County (1995) suggested that at full watershed build-out, annual phosphorus levels would increase to 28 µg/L. In 1994, a goal of 22 µg/L was set to protect the quality of the lake and this level has only been exceeded once since then (King County, 2014).

Lake turnover usually occurs in early November after a long period of stratification that starts in May, so lake mixing events are not expected to exacerbate phosphorus loading to the Sammamish River during the summer (King County, 2014).

**Nonpoint Pollution Sources**

As noted earlier, potential nonpoint pollution sources include several golf courses, a turf farm, plant nurseries, crop farms, and livestock rearing operations. Although the floodplain is relatively flat, there could be surface runoff and discharges from these watershed activities. Ecology observed a few piped discharges during our river surveys. These will be monitored to measure temperature and nutrient levels.

Onsite septic systems are not expected to be a major pollution source, since the urbanized areas of the floodplain are served by the municipal wastewater services including Northshore Water and Sewer District, City of Bothell, City of Woodinville, and City of Redmond utilities. Some onsite septic systems likely remain in selected rural or agricultural areas.

Hydromodifications can also be considered a form of nonpoint pollution, depending on how these changes affect the river’s water quality. Human activities such as removing large trees along waterways, withdrawal of ground or surface waters, and changing the natural channel geomorphology and hydrologic processes can increase water temperatures. Large stretches of the Sammamish River have few, if any, trees within the riparian zone, which increases sum exposure and limits shading to the river.

Ecology has also noted a number of large water withdrawal systems along the Sammamish River. Slightly more than 70 water rights and 10 water right claims are associated with the Sammamish River. Water rights and claims documents do not always specify the exact place of use or the exact quantity of water being used. Initial analysis of these water rights documents by

Ecology's Water Resources Program estimated a total of 17.7 cfs instantaneous diversions and a total of 2199 acre-ft in annual diversions from the Sammamish River.  These estimates most likely exceed actual diversion quantities and have not been field-verified.

**Point Source Pollution Sources**

Point sources in the Sammamish River TMDL area include discharges from:

- 73 construction stormwater general permittees (note that many of these are temporary in nature and may not be active throughout the study timeframe).
- 19 industrial stormwater general permittees.
- Phase I municipal stormwater permittees – King County and Washington State Department of Transportation (WSDOT).
- Phase II municipal stormwater permittees, including the cities of Bothell, Kirkland, Redmond and Woodinville[6].

These permittees have the potential to discharge warm stormwater (in the event of a summer rainfall event), nutrients, and possibly could affect groundwater levels that provide summer baseflows for local water bodies.

### 3.1.1 Logistical problems

Logistical problems are discussed in Section 4.7.

### 3.1.2 History of study area and human influences

The Sammamish River has been extensively modified since early 1900s to reduce flooding impacts and accommodate various human activities such as navigation and floodplain agriculture.  Prior to these hydrological modifications, the river was less like a river and more like a slow-moving slough, also known as Squak Slough.  The river was naturally slower, wider, longer, and more meandering than it is today (Chrzastowski, 1983).  Historically, wetlands nearly filled the Sammamish River valley, as the river meandered downstream.

In 1916, the mean level of Lake Washington was decreased as part of the development of the Lake Washington Ship Canal and Lock System – this increased the flow rate of the river between the two lakes and drained most of the sloughs and wetland habitats, especially in the lower reaches (Kerwin, 2001 and King County, 2009).  The complexity of the natural floodplain was eliminated around the same time as the river was channelized and straightened, and drainage ditches were constructed to improve farmlands (Kerwin, 2001).  During settlement of the Sammamish Valley, most of the river's historic wetland areas and oxbows were drained or obliterated as the river was progressively dredged and channelized to enhance local farming efforts, aid navigation, and reduce seasonal flooding (Martz, et al., 1999).

[6] A very small portion (a few blocks) of the city of Bellevue is technically within the TMDL study area, but is not included in this list since the area included is negligible in terms of pollutant contribution.

The river was essentially straightened by 1936 as a result of efforts by local agricultural and drainage districts, allowing the valley to be converted into more valuable farm land and, later, commercial and residential development. Following significant floods in the 1950s, more dredging was done, and the dredging spoils were deposited along the river banks, forming “levees” along the river during the 1960s (Kerwin, 2001).

In 1962, the U.S Army Corps of Engineers channelized and deepened the river by about five feet throughout the valley, removing its connection to the floodplain (Kerwin, 2001; Stickney and McDonald, 1977). These changes effectively shortened the river from its approximate original length of about 17 miles to its current length of 13.5 miles between the weir and the confluence with Lake Washington (King County, 2009).

In 1964, as part of the same project, King County and the U.S. Army Corps of Engineers constructed a weir at the Lake Sammamish outlet to eliminate flooding in the Sammamish River valley and reduce maximum flood elevations and seasonal water surface elevations in Lake Sammamish (King County, 2009). In 1998, the weir was modified to improve salmonid passage during low flow (King County, 2009).

By 1990, a combination of agricultural fields and low-density residential, office, and warehouse space covered most of the valley. Most of the more recent 20$^{th}$ century changes in the watershed have been a result of urban and suburban development that affects the hydrology through land cover changes and water withdrawals (Kerwin, 2001). Restoration opportunities are limited, due to flood control features and urban and agricultural land use (R2 Resource Consultants, 2010).

### 3.1.3 Parameters of interest

The parameters of interest in this study are DO and temperature. Cool temperatures and high levels of DO are necessary to protect aquatic life and salmonid habitat. These parameters are discussed in more detail in section 3.2, under *Water Quality Standards and Numeric Targets.*

### 3.1.4 Results of previous studies

The Sammamish River, surrounding watershed, and its connected water bodies, including Lake Sammamish and Lake Washington, have been the subject of numerous studies and models over the years. The list of studies below is a subset of these, specific to the main channel of the Sammamish River. There are a number of other studies that we might consider during analysis if they are found to be relevant. If used, these will be documented in the final report.

**Migratory Behavior of Adult Chinook Salmon Spawning in the Lake Washington Watershed in 1998 as Determined With Ultrasonic Telemetry (Fresh et al., 1999, Draft)**

This collaborative study involved tracking the migratory behavior of Chinook salmon spawning in the Lake Washington Watershed (LWW) in 1998 using ultrasonic telemetry. The study found that of the 78 Chinook salmon tagged at the Ballard Locks (entrance to Lake Washington), 60 spawned somewhere within the LWW.

Tagged fish that migrated through the Sammamish River were detected in Bear Creek and Issaquah Creek (the main tributary to Lake Sammamish). On average, the fastest fish spent an average of 4.3 days in the Sammamish River, while the slowest spent an average of 15.4 days in the river. Tagged fish were only detected−and appeared to spend the greatest amount of time−in a limited number of pools that provided cool water refugia. The fish moved quickly though the warmest reaches, e.g., near Marymoor Park. The study results emphasized the need for more cool-water pools/refugia, especially in reaches that are warmer and those that do not have the influence of cooling from cooler tributary inflows.

**Groundwater/Surface Water Interactions in the Upper Sammamish River (Carey, 2003)**

This Ecology study involved the installation of piezometers at nine locations along the upper six miles of the Sammamish River in August 2001 to observe groundwater/surface water interactions during the fall low-flow period. Water level data indicated that at most locations and times (with a few exceptions), groundwater discharges to the river. This pattern was consistent with the specific conductance data that also generally increased from upstream to downstream, since groundwater generally has higher conductivity.

**Sammamish River Valley Groundwater Study 2003-2004 Data Report (King County, 2005a)**

In 2003 and 2004, King County installed and monitored 21 wells in three subareas of the Sammamish River Valley between Marymoor Park and Woodinville to assess groundwater interactions with surface water and to also assess the quality and quantity of this groundwater.

The study found that concentrations of most constituents generally met the standards established in the Safe Drinking Water Act and other Washington State criteria. In shallow wells, there was some indication of surface water infiltration, as well as seasonal fluctuation as groundwater levels responded to precipitation. The groundwater level data also showed that flow is typically toward the Sammamish River and down the river corridor.

**Sammamish River Diel pH and Dissolved Oxygen Study (King County 2005b)**

In this study, field data along the Sammamish River and its tributaries were collected during summer 2003 to aid the development of a water quality model to simulate temperature, DO, and pH dynamics in the Sammamish River. Three locations along the Sammamish River had long-term deployments of YSI Extended Deployment System (EDS) sondes from June through October 2003 (with some data gaps). In addition, there were several shorter 7-day deployments of YSI instruments at up to five locations along the Sammamish River.

Data from this effort showed that the river frequently failed to meet state water quality standards for temperature and DO. The highest water temperatures were recorded at the outlet of Lake Sammamish, and the river generally cooled as it moved downstream. The largest diel temperature and oxygen ranges and the lowest minimum DO concentrations were recorded at the Redmond Railroad Bridge (near Redmond Way) and at NE 116$^{th}$ St. in late July.

Specific conductance was consistently higher at the most downstream location relative to the most upstream location, indicating sources of water with higher conductance other than the lake outlet – such as groundwater and tributary influences. Dense beds of aquatic plants (macrophytes) were also observed between Redmond and Woodinville.

**King County CE-QUAL-W2 Water Quality Modeling (King County, 2009)**

A combination of historical data and summer 2003 data were used to developed and calibrate a 2D (vertically stratified) water quality model of the Sammamish River using CE-QUAL-W2 (version 3.2). The model did well at simulating water temperatures, except in the lower portion of the river influenced by backwater from Lake Washington. The model did not perform as well for other water quality constituents, particularly DO, primarily due to its inability to adequately capture aquatic plant growth dynamics in the river.

The report suggested that that the model's ability to simulate temperature and DO could be improved by better quantification of: ungauged surface and groundwater inputs of heat (i.e., temperature), dissolved solids (measured as specific conductance), and nutrients, as well as a better quantification of aquatic plant biomass.

**Floodplain Mapping Study for the Sammamish River (NHC, 2010)**

This flood study of the Sammamish River was prepared for King County, to be submitted to the Federal Emergency Management Agency (FEMA). It involved the creation of revised floodplain and floodway maps to represent current hydraulic and hydrologic conditions of the Sammamish River.

The study first involved the use of an existing HSPF (Hydrologic Simulation Program – FORTRAN) watershed model of the basins tributary to Lake Sammamish and the Sammamish River, to simulate flow inputs from tributary basins. A HEC-RAS (Hydrologic Engineering Center River Analysis System) river model was then developed to route flows down the Sammamish River. The study involved the use of 117 cross-sections of the river channel that were developed using 2009 data from a combination of field surveys (for bathymetry), and detailed topographic data from aerial photographs (for overbank areas).

The model was calibrated to a few different flood events and scenarios and can potentially be re-calibrated to a low-flow scenario.

**Assessment of Summer Temperatures and Feasibility and Design of Improved Adult Chinook Thermal Refuge Habitat in the Sammamish River (R2 Resource Consultants, 2010)**

This study assessed the availability of thermal refuge habitat, quantified cool water habitat volumes at select locations, and identified approaches to increasing such habitat in the Sammamish River for adult migrant Chinook salmon during the warm summer and fall months. The study included taking longitudinal measurements of surface and bottom water temperatures along the whole length of the Sammamish River during July and August 2010, with a focus on identifying cooling locations within pools and at the confluence of tributaries. The study also evaluated the effectiveness of (1) physical measures to extend the cool water plume and tributary confluences and (2) low-flow augmentation at select tributaries.

Bear Creek, North Creek, Little Bear Creek, and Gold Creek were all found to have greater cooling influences than other measured tributaries. The analysis also showed that the greatest increases in thermal refuge availability could be achieved by augmenting low flows at Bear Creek and North Creek and by installing a log structure at Gold Creek to retard mixing and increase the cooling effect if this creek at the confluence.

**On the Feasibility of Constructing Suitable Juvenile Salmonid Off-Channel Habitat on the Sammamish River, City of Bothell (R2 Resource Consultants, 2013)**

In this study, R2 Consultants evaluated the feasibility of reconnecting an old channel and floodplain of the Sammamish River located within the City of Bothell limits. This reconnection would increase juvenile salmon habitat quantity and quality, restore floodplain plant communities, connectivity and function, and increase opportunities for public involvement and education.

The study involved collecting groundwater and survey data, analyzing groundwater flow and temperature patterns, and hydraulic modeling of alternative proposed channel configurations. Feasibility was assessed by how the project might improve salmon habitat and factors/constraints that could influence project construction.

**Sammamish River Brazilian Elodea Removal, King County (Herrera Environmental Consultants, 2013)**

This report documents invasive species removal contracted by King County on the Sammamish River between August 5 and 14, 2013. To document water-level and water quality effects of the project, summer water temperatures, water levels, and DO were measured in Lake Sammamish and Sammamish River during both 2012 and 2013. The area treated was a 1.5 mile stretch of the Sammamish River between NE 145$^{th}$ Street and NE 124$^{th}$ Street. A total of 10.8 tons of Brazilian elodea were removed along river segments that were easily accessed over the 1.5 mile reach.

Brazilian elodea affects river water levels because the dense shoot and leaf biomass obstructs flow, essentially raising the effective river bottom and increasing channel roughness. Diel fluctuations in DO and pH have been observed during the summer in the Sammamish River and were attributed to photosynthesis and respiration of submerged plants and attached algae throughout the river (King County, 2005b). In addition, plant decay during the late fall/winter senescence period decreases DO and pH. The temperature criterion (16$^{o}$C) was exceeded at all lake and river stations on all days of both summer study periods. The maximum 7-DADMax temperature in the Sammamish River (24$^{o}$C) occurred at Marymoor Park in August 2012 and 2013.

### 3.1.5 Regulatory criteria or standards

See section 3.2, under subheading *Water Quality Standards and Numeric Targets*.

## 3.2 Total Maximum Daily Load (TMDL) studies

### What is a TMDL?

A TMDL is a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

**Federal Clean Water Act requirements**

The Clean Water Act established a process to identify and clean up polluted waters. The Clean Water Act requires each state to have its own water quality standards designed to protect, restore, and preserve water quality. Water quality standards consist of (1) designated uses for protection, such as cold water biota and drinking water supply and (2) criteria (usually numeric) to achieve those uses.

*The Water Quality Assessment (WQA) and the 303(d) List*

Every two years, states are required to prepare a list of water bodies that do not meet water quality standards. This list is called the Clean Water Act 303(d) list. In Washington State, this list is part of the Water Quality Assessment (WQA) process.

To develop the WQA, Ecology compiles its own water quality data along with data from local, state, and federal governments, tribes, industries, and citizen monitoring groups. All data in this WQA are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the assessment. The list of waters that do not meet standards [the 303(d) list] is the Category 5 part of the larger assessment.

The WQA divides water bodies into five categories, described below. Those not meeting standards are given a Category 5 designation, which collectively becomes the 303(d) list].

Category 1 – Waters that meet standards for parameter(s) for which they have been tested.

Category 2 – Waters of concern.

Category 3 – Waters with no data or insufficient data available.

Category 4 – Polluted waters that do not require a TMDL because they:
- 4a. – Have an approved TMDL being implemented.
- 4b. – Have a pollution-control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, culverts.

Category 5 – Polluted waters that require a TMDL – the 303(d) list.

Further information is available at Ecology's [Water Quality Assessment website](#).

The Clean Water Act requires that a TMDL be developed for each of the water bodies on the 303(d) list.

### TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed, and it specifies how much pollution needs to be reduced or eliminated to achieve clean water. Ecology, with the assistance of local governments, tribes, agencies, and the community then develops a strategy to control and reduce pollution sources and a monitoring plan to assess effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *Water Quality Improvement Report* (WQIR).

Ecology submits the WQIR to the U.S. Environmental Protection Agency (EPA) for approval. Once EPA approves the WQIR, Ecology develops a *Water Quality Implementation Plan* (WQIP) within one year if it is not already included in the WQIR. The WQIP identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

### Who should participate in this TMDL?

Water pollution in the Sammamish River appears to come from diffuse, nonpoint sources and/or from permitted stormwater point sources. The area subject to this TMDL is indicated by the dark orange "TMDL Study Area"' in Figure 1. All upstream watershed areas within the study area have the potential to affect downstream oxygen levels and water temperatures. Therefore, all areas contributing excessive levels of nutrients, solar radiation, or other factors contributing to high water temperatures and low DO levels must use the appropriate best management practices to reduce impacts to water quality within the TMDL study area. During the study phase of this TMDL, Ecology will contact major stakeholders including the Muckleshoot Tribe, Snoqualmie Tribe, affected cities and counties, WSDOT, and a limited number of environmental groups.

Nonpoint source pollutant load targets will be set in this TMDL. Potential nonpoint sources of pollution include local golf courses, recreational areas, and agricultural and residential activities.

Similarly, all point source dischargers (listed in Section 3.1 *Potential Pollutant Sources*) that fall within the TMDL footprint must also comply with the TMDL. Among them are six local municipalities identified in Figure 6. Ecology will invite their participation in this TMDL study via an advisory committee and in implementing actions to improve water quality in the watershed.

No tribal lands are contained within the TMDL footprint; therefore, no allocations will be made directly to tribal entities. However, the Muckleshoot Tribe and Snoqualmie Tribe will be participating in the development and implementation of this TMDL.

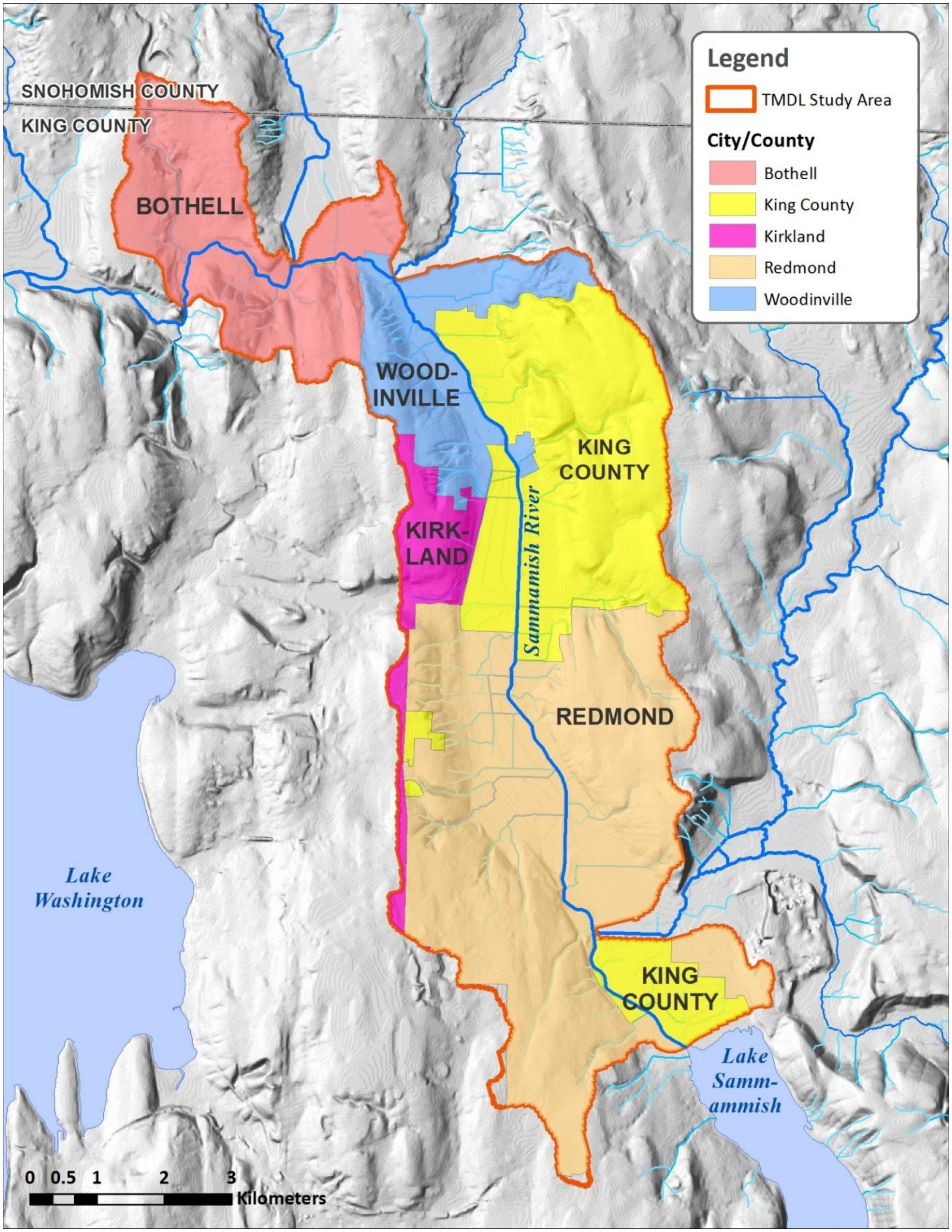



Figure 6. City and county jurisdictions within the TMDL study area.

## Elements the Clean Water Act requires in a TMDL

*Loading Capacity, Allocations, Seasonal Variation, Margin of Safety, and Reserve Capacity*

A water body's *loading capacity* is the amount of a given pollutant that a water body can receive and still meet water quality standards. The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a water body into compliance with the standards.

The portion of the receiving water's loading capacity assigned to a particular source is a *wasteload* or *load* allocation. If the pollutant comes from a discrete (point) source subject to a National Pollutant Discharge Elimination System (NPDES) permit, such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a *wasteload allocation*. If the pollutant comes from diffuse (nonpoint) sources not subject to an NPDES permit, such as general urban, residential, or farm runoff, the cumulative share is called a *load allocation*.

The TMDL must also consider *seasonal variations*, and include a *margin of safety* that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A *reserve capacity* for future pollutant sources is sometimes included as well.

Therefore, a TMDL is the sum of the wasteload and load allocations, any margin of safety, and any reserve capacity. The TMDL must be equal to or less than the loading capacity.

*Surrogate Measures*

To provide more meaningful and measurable pollutant loading targets, this TMDL may also incorporate *surrogate measures* other than daily loads. EPA regulations [40 CFR 130.2(i)] allow other appropriate measures in a TMDL. See the Glossary section of this document for more information.

Potential surrogate measures for use in this TMDL are discussed below. The ultimate need for, and the selection of, a surrogate measure for use in setting allocations depends on how well the proposed surrogate measure matches the selected implementation strategy.

This TMDL will use effective shade as a surrogate measure of heat flux to fulfill the requirements of the federal Clean Water Act Section 303(d) for a temperature TMDL. Using effective shade as a surrogate is allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR § 130.2(i)).

Effective shade is defined as the fraction of incoming solar shortwave radiation that is blocked by vegetation and topography from reaching the surface of the stream. A decrease in effective shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. This approach has been used consistently and successfully in Ecology's previous temperature TMDLs. For ease of implementation, load allocations may be reported, where applicable, in terms of surrogates for solar radiation such as: shade, size of tree necessary in the riparian zone to produce adequate shade, channel width, channel width-to-depth ratio, or miles of active eroding stream banks. The final TMDL will include language that describes stream heating processes and all the factors involved. This might include a discussion of hydromodifications which can also contribute to stream heating and pollutant transport.

## Why is Ecology conducting a TMDL study in this watershed?

Ecology is conducting a TMDL study in this watershed because data collected in the mainstem Sammamish River do not meet the water quality criteria for temperature and DO. Various segments of the Sammamish River have been on the 303(d) list since 1996, and more listings have been added through 2012. Also, this water body is important to WRIA 8 as it's the migration path to a diminished but distinct Bear Creek Chinook salmon population.

**Impairments addressed by this TMDL**

The main beneficial uses to be protected by this TMDL are aquatic life uses which include core summer salmonid habitat and salmonid spawning, rearing, and migration. These uses will be protected by ensuring that temperature and DO concentrations eventually meet water quality standards in the water body. This TMDL will address all temperature and DO listings on the mainstem Sammamish River and select small tributaries (Table 3).

Table 3. Category 5 (impaired) water bodies for temperature and dissolved oxygen from the 2012 Water Quality Assessment.

| Water body Name | Parameter | Listing ID | NHD Reachcode | WBID | Township | Range | Section |
|---|---|---|---|---|---|---|---|
| Sammamish River | Temperature | 4805 | 17110012000092 | WA-08-1100 | 25 | 5 | 11 |
| Sammamish River | Dissolved oxygen | 10646 | 17110012000087 | none | 26 | 5 | 8 |
| Sammamish River | Dissolved oxygen | 12670 | 17110012000092 | WA-08-1090 | 25 | 5 | 11 |
| Peters Creek | Dissolved oxygen | 42080 | 17110012001010 | none | 26 | 5 | 34 |
| Peters Creek | Temperature | 42081 | 17110012001010 | none | 26 | 5 | 34 |
| Sammamish River | Dissolved oxygen | 42085 | 17110012000092 | none | 25 | 5 | 2 |
| Willows Creek | Dissolved oxygen | 42119 | 17110012000187 | none | 25 | 5 | 3 |
| Unnamed Creek ($116^{th}$ Ditch) | Dissolved oxygen | 42155 | 17110012000966 | none | 26 | 5 | 27 |
| Sammamish River | Dissolved oxygen | 48012 | 17110012000088 | none | 26 | 5 | 9 |
| Sammamish River | Dissolved oxygen | 48013 | 17110012000090 | none | 26 | 5 | 27 |

NHD: National Hydrography Data set
WBID: Water body Identification

The study will look at this watershed more thoroughly and may find other impaired water bodies for temperature and DO.

This TMDL will not address the following other 2012 Category 5 (303(d)) listed segments in the watershed:

- Any listings downstream of RM 2.6 – this area is influenced by backwater from Lake Washington, and conditions are more analogous to lake conditions than river conditions. Any listings based on river criteria are therefore likely inapplicable.
- Temperature and DO listings on the following major tributaries: Little Bear Creek, North Creek and Swamp Creek. These are fairly large sub-watersheds, and addressing these listings will require additional detailed investigation of each creek, which is beyond the current TMDL scope[7].
- Temperature and DO listings in Lake Sammamish and its tributaries are not within the TMDL footprint of this study, even though these areas are upstream of and eventually drain to the Sammamish River.
- Listings for bacteria or other parameters (e.g., toxics) within the TMDL footprint will not be addressed by this TMDL study.

### How will the results of this study be used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve clean water. This is done by assessing the situation, recommending practices to reduce pollution, and establishing limits as needed for permitted facilities contributing pollution. Where the study identifies major sources or source areas of pollution, Ecology and local partners will use these results to figure out where to focus water quality improvement activities. Sometimes the study suggests areas for follow-up sampling to further pinpoint sources for cleanup.

## Water Quality Standards and Numeric Targets

Specific water quality criteria for temperature and DO in the Sammamish River to protect core summer salmonid habitat are:

- Temperature criteria: highest 7-DADMax temperature must not exceed 16°C.
- Dissolved oxygen criteria: lowest 1-day minimum should not be below 9.5 mg/L.

Each parameter is described in more detail below.

### Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.
Temperature levels fluctuate over the day and night in response to changes in weather, climate, and river flows. Since the health of aquatic species is tied predominantly to the pattern of

[7] Bear Creek is not listed here since temperature, DO, and bacteria TMDLs were completed in 2008 for Bear, Evans, and Cottage Lake Creeks, so there are no longer any 303(d) listings for this sub-watershed for those parameters.

maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

In the Washington State Water Quality Standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) (WAC 173-201A-200).

In this TMDL, the designated aquatic life use to be protected in the Sammamish River is *core summer salmonid habitat.* For *core summer salmonid habitat*, the highest 7-DADMax temperature must not exceed 16°C more than once every ten years on average.

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criteria. When a water body is naturally warmer than the above-described criteria, the state provides a small allowance for additional warming due to human activities. In this case, the combined effects of all human activities must also not cause more than a 0.3°C increase above the naturally higher (inferior) temperature condition.

A model is used to determine whether the water body is naturally high in temperature. In the model, natural conditions can be represented by changing various model parameters. The approach usually involves adjusting model inputs that increase vegetation heights and canopy density to represent "system potential vegetation" based on the climate and soils of the area, to represent what would naturally grow within the riparian zone (in the absence of human activities). The model is then run to see how much this improves shading and cools stream temperatures. Other parameters in the model can also be modified to represent a more natural river channel and river processes, to reflect the hydro. The model roughly approximates natural conditions and is appropriate for determining the implementation of the temperature criteria. This model results in what is called the "system thermal potential" or "system potential" of the water body.

In addition to the maximum criteria noted above, compliance must also be assessed against criteria that limit the incremental amount of warming, by human actions, of otherwise cool waters. When water is cooler than the criteria noted above, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted as follows:

1. Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/(T+7) as measured at the edge of a mixing zone boundary (where "T" represents the background temperature as measured at a point or points unaffected by the discharge.
2. Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not at any time exceed 2.8°C.

While the criteria generally applies throughout a water body, it is not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that measurements should be taken from well-mixed portions of rivers and streams. For similar reasons, measurements should not be taken from anomalously cold areas such as at discrete points where cold groundwater flows into the water body, unless the intention is to specifically monitor and identify cool water/thermal refugia.

**Dissolved oxygen**

Aquatic organisms are very sensitive to reductions in the level of DO in the water. The health of fish and other aquatic species depends on maintaining an adequate supply of oxygen dissolved in the water. Oxygen levels affect growth rates, swimming ability, susceptibility to disease, and the relative ability to endure other environmental stressors and pollutants. Washington State designed the criteria to maintain conditions that support healthy populations of fish and other aquatic life.

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiratory requirements of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criterion is based on the lowest 1-day minimum oxygen concentrations that occur in a water body.

A number of factors can result in low DO levels. Warm water can hold less oxygen then cold water and reduce DO saturation, and therefore high temperatures can also contribute to low DO levels. Nutrient enrichment may lead to low DO levels and increase the occurrence of excessive primary productivity leading to harmful algal blooms and macrophyte growth. Large biomass of primary producers may be associated with severe diurnal swings in DO concentrations. The combination of biological, biochemical and chemical processes at the sediment-water interface, called sediment oxygen demand, can also consume DO in the overlying water.

In the Washington State water quality standards, freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities, some of which are specified for individual rivers, lakes, and streams.

In this TMDL, the designated aquatic life use to be protected in the Sammamish River is *core summer salmonid habitat.* For *core summer salmonid habitat*, the lowest 1-Day minimum temperature must not fall below 9.5 mg/L more than once every ten years on average.

The criterion above is used to maintain conditions where a water body is naturally capable of providing full support for its designated aquatic life uses. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a water body is naturally lower in oxygen than the criteria, the state provides an additional allowance for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/l decrease below that naturally lower oxygen condition. In the model, natural levels of oxygen are often approximated by removing all human sources of nutrients to the river system. Other human watershed and hydrologic alterations that affect DO levels can also be factored into the modeling of natural conditions for DO.

While the numeric criteria generally apply throughout a water body, the criteria are not intended to apply to discretely anomalous areas such as in shallow stagnant eddy pools where natural features unrelated to human influences are the cause of not meeting the criteria. For this reason, the standards direct that one take measurements from well-mixed portions of rivers and streams. For similar reasons, samples should not be taken from anomalously oxygen-rich areas. For example, in a slow-moving stream, focusing sampling on surface areas within a uniquely turbulent area would provide data that are erroneous for comparing to the criteria.

## Global Climate Change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005). Factors affecting these changes include climate influences at both annual and decadal scales and air temperature increases. When air temperatures increase, more precipitation falls as rain rather than snow, which melts of the winter snowpack earlier. While the Sammamish River is not fed by snowmelt, the warmer air temperatures and changes in precipitation due to climate change could still have an impact on the Sammamish River's flow regime and river temperatures.

Ten climate change models were used to predict the average rate of climatic warming in the Pacific Northwest (Mote et al., 2005). The average warming rate is expected to be in the range of 0.1-0.6°C (0.2-1.0°F) per decade, with a best estimate of 0.3°C (0.5°F) (Mote et al., 2005). Eight of the ten models predicted proportionately higher summer temperatures, with three indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperatures improved by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help offset the changes expected from global climate change. These improvements may keep conditions from getting worse. It will take considerable time, however, to reverse those human actions that contribute to excess stream warming. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our stream resources.

These efforts may not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

Ecology is conducting this TMDL study to meet Washington State's water quality standards based on current and historic patterns of climate. Changes in stream temperature associated with global climate change may require further modifications to the human-source allocations at some time in the future. However, the best way to preserve our aquatic resources and to minimize future disturbance to human industry would be to begin now to protect as much of the thermal health of our streams as possible.

# 4.0 Project Description

## 4.1 Project goals

Our project has three main goals:

1. Develop a predictive water quality model to help understand the dynamic influence of various factors on temperature and DO conditions in the Sammamish River during critical low-flow conditions.
2. Identify and quantify pollution sources and areas with degradation of riparian and watershed functions where restoration is needed to correct temperature and DO impairments and make progress towards bringing the Sammamish River into compliance with water quality standards.
3. Develop an implementation strategy and propose actions needed to improve temperature and DO levels in the Sammamish River.

## 4.2 Project objectives

The project goals will be accomplished through the following objectives:

- Install two telemetry stations (one at the headwater boundary and one along the mainstem) to measure continuous flow, temperature, DO, pH, and specific conductance throughout the summer field study period (between the first week of June 2015 and the first week of October 2015).
- Install thermistors along the mainstem, at the mouth of major tributaries, and all other measurable inflows to monitor continuously throughout the summer study period.
- Conduct two to three synoptic surveys at several locations along the mainstem, tributaries, and other inflows to collect grab samples for a variety of water quality parameters, and deploy hydrolabs for continuous monitoring.
- Establish the river’s flow balance by measuring streamflows via a seepage run, which involves taking flow measurements along the mainstem and tributaries.
- Install piezometers to evaluate the spatial and temporal influence of groundwater on temperature and DO along the river, including measuring water levels, taking spot hydrolab measurements, and taking water quality grab samples.
- Conduct bi-weekly nitrogen and phosphorus sampling to better characterize nutrient dynamics throughout the summer at core mainstem stations and major tributaries.
- Estimate macrophyte and periphyton biomass, density, and nutrient content by taking physical sub-samples, estimating percent coverage within transects.
- Take hemiview photographs and solar pathfinder measurements along the length of the river to estimate percent effective shade, and measure vegetation heights at a few locations to ground-truth LiDAR data.

- Conduct one travel time dye study to calculate travel time and velocities.
- Use flow and stage data and HEC-RAS to characterize the hydraulic characteristics of the mainstem.
- Use RMA to evaluate stream productivity and reaeration rates at key stations where continuous hydrolabs are deployed.
- Develop and calibrate a predictive temperature and DO water quality model of the Sammamish River under critical conditions.
- Use the water quality model to evaluate various pollution reduction scenarios and establish load and wasteload allocations.
- Use historic information and data to develop our best estimate of natural conditions for the Sammamish River.
- Use the results of the technical analysis to help inform and develop a water quality cleanup plan/improvement report.

## 4.3 Information needed and sources

The existing models, tools, and GIS information that will be used for this project are described below. New models (the Shade model and QUAL2Kw water quality model) that will be developed specifically for this project are discussed in Section 7.1.

### HEC-RAS Model

The Hydrologic Engineering Center River Analysis System (HEC-RAS) is a computer model developed and maintained by the U.S. Army Corps of Engineers. It simulates one-dimensional steady and unsteady flow river hydraulic calculations[8] (U.S. ACOE, 2010). A HEC-RAS model of the entire length of the Sammamish River was developed and calibrated by Northwest Hydraulic Consultants (NHC, 2010) for King County to perform flood analysis.

King County has already provided Ecology with this existing HEC-RAS model, which contains detailed channel cross-section and geometry information. The study involved the use of 117 cross-sections of the river channel that were developed using 2009 data from a combination of field surveys (for bathymetry) and detailed topographic data from aerial photographs (for overbank areas).

The channel geometry information from this HEC-RAS model will be used to define the channel hydraulics for the QUAL2Kw model that will be developed for this project. This will be done in the following steps:

- The existing HEC-RAS model will first be recalibrated to 2015 low-flow conditions using 2015 stage and flow hydrographs. Several King County gages exist along the river, and

[8] HEC-RAS can also be used for sediment transport-mobile bed modeling and water temperature analysis, but we will not be using those capabilities of the model for this project.

streamflow measurements will also be collected during the synoptic surveys for this project. This recalibration will likely involve changes to the existing Manning's "n" values in the HEC-RAS model, since macrophyte growth is known to affect the river's hydrodynamics in the summer by increasing bottom friction (King County, 2009). Calibrated Manning's "n" values will be compared to any available values in literature and previous studies for channels that have aquatic plant growth along the river bottom.

- Once calibrated to low-flow conditions, several low-flow scenarios within the range of historic flows during the summer season that include the expected range of low flows will be run in HEC-RAS to develop rating curve relationships between streamflow and channel velocity, depth, and width.
- These rating curve relationships will then be used directly in QUAL2Kw to define the channel's hydraulics for each model segment.

## GIS Information

### LiDAR Elevation Data

LiDAR (Light Detection and Ranging) technology provides high resolution elevation data, and are available for the TMDL study area. For our study area, the following LiDAR datasets are available via the Puget Sound LiDAR Consortium (http://pugetsoundlidar.ess.washington.edu/index.htm):

- 2014 data for City of Redmond - cover almost the entire City of Redmond boundary, which includes the headwater of the Sammamish River to just downstream of the 124$^{th}$ St Bridge at about RM 8.5.
- 2002-2003 data for King County - cover all of King County, which includes all of our study area.

Both the above LiDAR data sets include a "ground model" that defines the elevation of the ground surface, as well as a "top of surface model" that defines the elevation of features above the ground, e.g., vegetation and buildings.

For this study, LiDAR data will be used primarily to (1) define the topography of the riparian zone along the Sammamish River on each side of the stream and (2) calculate riparian vegetation heights and the heights of other features on the ground surface within this zone. This topography and height information is used directly by the Shade model to simulate stream shading from topography and vegetation.

### Aerial Imagery

A number of different aerial imagery data sets are available for the study area:

- 2013 NAIP Imagery - from USGS's National Agriculture Imagery Program. Readily available for the whole state at a resolution of 1.0 m.
- 2013 City of Redmond Imagery - cover the city of Redmond at a resolution of 6 inches.

- 2010 King County Imagery - cover western King County at a resolution of 6 inches.

If cities within the TMDL study area have aerial imagery for their jurisdictions with a higher resolution than the NAIP imagery, we will use those where available. Aerial imagery will primarily be used to digitize land cover within the riparian buffer zone and identify vegetation species and density along the modeled reaches of the Sammamish River.

**TTools**

The TTools ArcView extension was original developed by Oregon Department of Environmental Quality (ODEQ). It has been recently redeveloped by Ecology in Python script to upgrade its compatibility with new versions of ArcGIS and enhance the tool's speed and usability. The tool enables the user to sample spatial data within the riparian zone. It uses input spatial data sets such as LiDAR elevation, vegetation heights, and other riparian characteristics to develop vegetation and topography data perpendicular to the river channel at user-specified intervals, e.g., at cross-sections every 100 m along the channel.

For this project, TTools will be used to sample stream width, aspect, topographic shade angles, elevation, and riparian vegetation for incorporation into the Shade model.

### Historic Information

Historic information (e.g., historical aerial photographs or drawings/maps of the river channel, and published reports and journal articles), if available, will be used to improve the model's representation of natural conditions. This information will be used to understand land use changes, impervious surfaces, changes in the channel and floodplain, and other conditions.

## 4.4 Target population

The target population for this project includes temperature, nutrients, DO, and other environmental parameters and functions related to instream temperatures and productivity in the Sammamish River during summer low-flow conditions.

## 4.5 Study boundaries

The study area boundaries are described in Section 3.1 and illustrated in Figure 1. The study is located within WRIA 8 and within HUC 17110012 (8-digit HUC code).

While the model boundary will start at RM 12.8, which is about 130 ft below the weir and about 0.5 miles downstream of the lake outlet, it will include any diffuse inputs to the Sammamish River between the Lake Sammamish outlet and the upstream model boundary.

## 4.6 Tasks required

The tasks required to meet project goals are discussed in Section 4.2. More details on the technical approach and field and lab tasks are described in Section 7.

## 4.7 Practical constraints

Logistical conditions that could interfere with sampling include:

- Excessive precipitation during typically dry periods, e.g., preceding or during a synoptic flow event.
- Scheduling conflicts, sample bottle delivery errors, vehicle or equipment problems, or limited availability of personnel or equipment. This can be mitigated to some extent by having backup equipment on hand and giving clear instructions to field teams on what to do if equipment fails.
- Site access issues. This is unlikely, since the Sammamish River generally has excellent public access along the length of the river. There is a public pedestrian/bike trail along almost the entire length of the river. There are also several parks and bridges at key monitoring locations. If there are any unforeseen site access issues, we will find a nearby alternate sampling location.
- Inability to measure certain inflows e.g. from culverts that can be seen but cannot be accessed or easily measured.
- Inability to measure non-wadeable flows on the mainstem. Personnel safety will always be the first consideration. It may be possible to get high-flow measurements at some locations by measuring flow from a bridge or other non-wading method. If this cannot be done, then gaging station data will be used instead, as available.

If any of the above circumstances interfere with data collection and quality, it will be noted and discussed in the final report.

## 4.8 Systematic planning process

This QAPP represents the systematic planning process.

# 5.0 Organization and Schedule

## 5.1 Key individuals and their responsibilities

Table 4. Organization of project staff and responsibilities.

| Staff<br>(all are EAP except client) | Title | Responsibilities |
|---|---|---|
| Ralph Svrjcek<br>Water Quality Program<br>Northwest Regional Office<br>Phone: 425-649-7165 | EAP Client | Clarifies scope of the project. Acts as point of contact between EAP staff and interested parties. Coordinates information exchange. Forms technical advisory team and organizes meetings. Reviews the QAPP and technical report. Prepares and implements TMDL report for submittal to EPA. |
| To be determined | Project Manager/Principal Investigator | Analyzes and interprets data. Performs technical analysis and water quality modeling. Authors technical sections of the draft and final TMDL report. |
| Teizeen Mohamedali<br>Modeling and Information Support Unit<br>Statewide Coordination Section<br>Phone: 360-715-5209 | QAPP Author | Writes the QAPP, provides advice and oversight during field sampling. |
| Meghan Rosewood-Thurman<br>Directed Studies Unit<br>Western Operations Section<br>Phone: 360-407-7692 | Field Lead | Leads and oversees sampling, including transportation of samples to the laboratory. Responsible for field data collection, coordination, and recording field information. Conducts QA review of data, and enters data into EIM. Helps write QAPP. |
| Kyle Krueger<br>Directed Studies Unit<br>Western Operations Section | Field Assistant | Helps collect samples and records field information. |
| Kirk Sinclair<br>Groundwater/Forests & Fish Unit<br>Statewide Coordination Section<br>Phone: 360-407-6557 | Hydrogeologist | Coordinates the groundwater sampling portion of the field effort, installs piezometers, and conducts review and analysis of groundwater-related data. |
| Ryan Whittaker<br>Eastern Regional Operations Unit/Freshwater Monitoring Unit<br>Eastern Operations Section<br>Phone: 509-665-5382 | Seepage Run Lead | Conducts seepage runs/streamflow measurements and related tasks. |
| Karol Erickson<br>Modeling and Information Support Unit<br>Statewide Coordination Section<br>Phone: 360-407-6694 | Unit Supervisor for QAPP Author | Provides internal review of the QAPP, approves the budget, and approves the final QAPP. |
| Will Kendra<br>Statewide Coordination Section<br>Phone: 360-407-6698 | Section Manager for QAPP Author | Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP. |

| Staff<br>(all are EAP except client) | Title | Responsibilities |
|---|---|---|
| George Onwumere<br>Directed Studies Unit<br>Westside Operations Section<br>Phone: 360-407-6730 | Unit Supervisor for Field Lead & Assistant | Provides internal review of the QAPP, approves the budget, and approves the final QAPP. |
| Jessica Archer<br>Westside Operations Section<br>Phone: 360-407-6596 | Section Manager for the Study Area | Reviews the project scope and budget, tracks progress, reviews the draft QAPP, and approves the final QAPP. |
| Joel Bird<br>Manchester Environmental Laboratory<br>Phone: 360-871-8801 | Director | Reviews and approves the final QAPP. |
| William R. Kammin<br>Phone: 360-407-6964 | Ecology Quality Assurance Officer | Reviews and approves the draft QAPP and the final QAPP. |

EAP: Environmental Assessment Program
EIM: Environmental Information Management database
QAPP: Quality Assurance Project Plan

## 5.2 Special training and certifications

All field staff involved in this project either already have the relevant experience in following SOPs or will be trained by more senior field staff who do. Any staff helping in the field who lack sufficient experience will always be paired with someone who does have the necessary training and experience and who will then lead the field data collection and oversee/mentor less experienced staff.

A licensed professional engineer will review the technical analysis and modeling before the project report and results are finalized.

## 5.3 Organization chart

See Table 4.

## 5.4 Project schedule

Table 5. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

| Field and laboratory work | Due date | Lead staff |
|---|---|---|
| Field work completed | October 2015 | Meghan Rosewood-Thurman |
| Laboratory analyses completed | October 2015 | |
| Environmental Information System (EIM) database | | |
| EIM Study ID | MROS0001 | |
| Product | Due date | Lead staff |
| EIM data loaded | April 2016 | Meghan Rosewood-Thurman |
| EIM data entry review | May 2016 | Paul Anderson |
| EIM complete | June 2016 | Meghan Rosewood-Thurman |
| Final TMDL/WQI report | | |
| Author lead / Support staff | To be determined | |
| Schedule | The schedule for this project is still to be determined. We estimate that it will take the principal investigator about two years to complete the technical analysis, modeling, and TMDL report writing for this project once field data are reviewed in June 2016, assuming they are working on this project full-time. | |

## 5.5 Limitations on schedule

Potential field-related constraints are addressed in Section 4.7. Any unforeseen limitations that would affect the project schedule will be discussed with the appropriate supervisor as needed.

## 5.6 Budget and funding

The budget in Table 6 assumes three synoptic surveys, including sampling of 24 unnamed inflows that were identified during reconnaissance and an additional maximum of 10 stormwater outfalls, if they have measurable flow. The third synoptic is a backup and may not be conducted if the first two surveys go smoothly. The actual number of sites may also change.

Table 6. Tentative costs for laboratory analysis.

| Parameter | # of Field Samples | Field Duplicates | Field Blanks | Total # of samples | $/ Sample | Subtotal |
|---|---|---|---|---|---|---|
| Alkalinity | 72 | 8 | 6 | 86 | $18.43 | $1,585 |
| Ammonia (NH3) | 258 | 26 | 8 | 292 | $14.09 | $4,114 |
| BOD 5 | 36 | 4 | 3 | 43 | $59.61 | $2,563 |
| Chloride | 72 | 8 | 6 | 86 | $14.09 | $1,212 |
| Chlorophyll a - water (lab filter) | 42 | 5 | 4 | 51 | $59.61 | $3,040 |
| Dissolved Organic Carbon | 72 | 8 | 6 | 86 | $38.98 | $3,352 |
| Nitrite/Nitrate | 258 | 26 | 8 | 292 | $14.09 | $4,114 |
| Orthophosphate (OP) | 258 | 26 | 8 | 292 | $16.26 | $4,748 |
| Total SS (incl. non-volatile) | 54 | 5 | 4 | 64 | $26.02 | $1,665 |
| Total Organic Carbon (TOC) | 36 | 4 | 3 | 43 | $35.77 | $1,538 |
| Total Persulfate Nitrogen (TPN) | 258 | 26 | 8 | 461 | $18.43 | $5,382 |
| Total Phosphorus (TP) | 258 | 26 | 8 | 461 | $19.50 | $5,694 |
| Total Suspended Solids (TSS) | 36 | 4 | 3 | 43 | $11.92 | $513 |
| Turbidity | 36 | 4 | 3 | 43 | $11.92 | $513 |
| Periphyton - Chl a + AFDW[1] | 12 | 2 | | 14 | $84.54 | $1,184 |
| Periphyton P[1] | 12 | 2 | | 14 | $90.00 | $1,260 |
| Periphyton C/N[1] | 12 | 2 | | 14 | $67.19 | $941 |
| Macrophyte - Chl a + AFDW[1] | 12 | 2 | | 14 | $84.54 | $1,184 |
| Macrophyte P[1] | 12 | 2 | | 14 | $90.00 | $1,260 |
| Macrophyte C/N[1] | 12 | 2 | | 14 | $67.19 | $941 |
| | | | | | **Grand Total =** | **$46,801** |

# 6.0 Quality Objectives

Quality objectives are statements of the precision, bias, and lower reporting limits necessary to meet project objectives. Precision and bias together express data accuracy. Other considerations of quality objectives include representativeness and completeness. Quality objectives apply equally to laboratory and field data collected by Ecology, to data used in this study collected by entities external to Ecology, and to other analysis methods used in this study.

Ecology's freshwater monitoring unit will be installing two telemetry stations to continuously monitor flow for this project (and beyond), following a separate QAPP (Hallock, 2009).

## 6.1 Decision Quality Objectives (DQOs)

DQOs are not necessary for this project. The TMDL process includes the assessment of uncertainty and assignment of a Margin of Safety.

## 6.2 Measurement Quality Objectives (MQOs)

Field sampling procedures and laboratory analysis inherently have associated error. Measurement quality objectives state the allowable error for a project. Precision and bias provide measures of data quality and are used to assess agreement with measurement quality objectives.

### 6.2.1 Targets for precision, bias, and sensitivity

#### 6.2.1.1 Precision

Precision is a measure of the variability in the results of replicate measurements due to random error. Precision is usually assessed by analyzing duplicate field measurements or lab samples. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Table 7 presents field measurement MQOs for precision and bias, as well as the manufacturer's stated accuracy, resolution, and range for the field equipment that will be used in this study.

#### 6.2.1.2 Bias

Bias is the difference between the population mean and the true value of the parameter being measured. Bias is usually addressed by calibrating field and laboratory instruments, and by analyzing lab control samples, matrix spikes, and standard reference materials. Laboratory QC procedures, such as blanks, check standards, and spiked samples, presented in Table 8, will provide a measure of any bias affecting sampling and analytical procedures for this project.

Table 7. Measurement quality objectives for field measurements and equipment.

| Parameter | Equipment /Method | Bias (median) | Precision– Field Duplicates (median) | Equipment Accuracy | Equipment Resolution | Equipment Range | Expected Range |
|---|---|---|---|---|---|---|---|
| **Water Quality Measurements** | | | | | | | |
| Water Temperature | Hydrolab® | See Table 9 | ± 0.2°C | ± 0.1°C | 0.01°C | -5 to 50°C | 0 to 30°C |
| Specific Conductance | Hydrolab® | See Table 9 | 5% RSD | ± (0.5% + 1 uS/cm) | 1 uS/cm | 0 to 100,000 uS/cm | 20 to 500 uS/cm |
| pH | Hydrolab® | See Table 9 | ± 0.2 s.u. | ± 0.2 units | 0.01 s.u. | 0 to 14 s.u. | 6 to 10 s.u. |
| Dissolved Oxygen – Luminescent (LDO) | Hydrolab® | See Table 9 | 5% RSD | ± 0.1 mg/L at <8 mg/L; ± 0.2 mg/L at 8 to <20 mg/L[a] | 0.01 mg/L | 0 to 60[c] mg/L | 0.1 to 15 mg/L |
| Dissolved Oxygen – Clark Cell | Hydrolab® | See Table 9 | 5% RSD | ± 0.2 mg/L at <20 mg/L[a] | 0.01 mg/L | 0 to 50[b] mg/L | 0.1 to 15 mg/L |
| Chlorophyll *a - in vivo* | Hydrolab® | | 10% RSD | ± 3% | 0.01 ug/L | 0.03 to 50 ug/L[c] | 0.1 to 50 ug/L |
| Oxidation-Reduction Potential | Hydrolab® | | 10% RSD | ± 20 mV | 1 mV | -999 to 999 mV | -999 to 999 mV |
| **Flow Measurements** | | | | | | | |
| Streamflow | EAP SOP #024 | n/a | 10% RSD | n/a | n/a | n/a | 0.01 to 2,000 cfs |
| Velocity | Marsh McBirney | ±0.05 ft/s[e] | n/a | ±2% + zero stability[d] | 0.01 ft/s | -0.5 to +20 ft/s | 0.01 to 10 ft/s |
| Velocity | StreamPro ADCP | n/a | n/a | ±1.0% or ±0.007 ft/sc | 0.003 ft/s | -16 to +16 ft/s | 0.01 to 10 ft/s |
| Velocity | OTT MF Pro | n/a | n/a | ±2.0% or ±0.05 ft/sc[a] | 0.003 ft/s | 0 to +10 ft/s | 0.01 to 10 ft/s |
| Depth | OTT MF Pro | n/a | n/a | ±2.0% or ±0.05 ft | 0.003 ft | 0 to +10 ft | 0.01 to 10 ft |
| **Continuous Temperature Monitoring** | | | | | | | |
| Water Temperature | Hobo Water Temp Pro v2 | n/a | n/a | ±0.2°C at 0° to 50°C[ae] | 0.02°C at 25°C | -40° to +50°C | 0 to 30°C |
| Air Temperature | Hobo Water Temp Pro v2 | n/a | n/a | ±0.2°C at 0° to 50°C[ae] | 0.02°C at 25°C | -40° to 70°C | -5 to 40°C |
| Relative Humidity | Hobo Pro | n/a | n/a | ±3% | 0.03% | 0.03% to 100% | 30% to 100% |

RSD: Relative Standard Deviation
[a] accuracy is diminished outside of listed range
[b] greater than natural range
[c] equipment range is dynamic, listed range is for medium sensitivity setting
[d] zero stability check criteria, not a measurement of bias
[e] also the MQO for accuracy assessed by pre- and post-deployment water bath checks

Table 8. Measurement quality objectives for laboratory analysis parameters.

| Analysis | Method | Method Lower Reporting Limit[a] | Lab Blank Limit | Check Standard (% recovery limits) | Matrix Spikes (% recovery limits) | Precision – Lab Duplicates (RPD) | Precision – Field Duplicates (median)[b] |
|---|---|---|---|---|---|---|---|
| Alkalinity | SM 2320B | 5 mg/L | <½ RL | 80-120% | n/a | 20% | 10% RSD |
| Ammonia | SM4500NH3H | 0.01 mg/L | <½ RL | 80-120% | 75-125% | 20% | 10% RSD |
| Biological Oxygen Demand (5-day) | SM5210B | 2 mg/L | <0.2 mg/L | 70-125% | n/a | 20% | 25% RSD |
| Chloride | EPA300.0/ SM4110C | 0.1 mg/L | <MDL | 90-110% | 75-125% | 20% | 5% RSD |
| Chlorophyll *a* – water | SM10200H3 | 0.05 ug/L | n/a | n/a | n/a | 20% | 20% RSD |
| Chlorophyll *a* – plant tissue | SM10200H3 | 0.05 ug/L | n/a | n/a | n/a | 20% | 50% RSD |
| Dissolved Oxygen (Winkler) | SM4500OC | 0.05 mg/L | n/a | n/a | n/a | n/a | ± 0.1 mg/L |
| Dissolved Organic Carbon | SM5310B | 1 mg/L | <MDL | 80-120% | 75-125% | 20% | 10% RSD |
| Total Organic Carbon | SM5310B | 1 mg/L | <MDL | 80-120% | 75-125% | 20% | 10% RSD |
| Nitrate/Nitrite | SM4500NO3I | 0.01 mg/L | <½ RL | 80-120% | 75-125% | 20% | 10% RSD |
| Total Persulfate Nitrogen | SM4500NO3B | 0.025 mg/L | <MDL | 80-120% | 75-125% | 20% | 10% RSD |
| Orthophosphate | SM4500PG | 0.003 mg/L | <MDL | 80-120% | 75-125% | 20% | 10% RSD |
| Total Phosphorus | SM4500PF | 0.005 mg/L | <MDL | 80-120% | 75-125% | 20% | 10% RSD |
| Turbidity | SM2130 | 0.5 NTU | < 1/10th RL | 90-105% | n/a | 20% | 15% RSD |
| Total Suspended Solids | SM2540D | 1 mg/L | ±0.3 mg | 80-120% | n/a | 20% | 15% RSD |
| Total Non-Volatile Suspended Solids | <1 – 2000 mg/L | SM 540B & E | ±0.3 mg | 80-120% | n/a | 20% | 15% RSD |
| Ash Free Dry Weight – plant tissue | SM10300C(5) | 0.05 ug/L | n/a | n/a | n/a | 20% | 50% RSD |
| Total Nitrogen, Total Carbon – plant tissue | EPA440.0 | 0.01% of DW | n/a | 85-115% | 75-125% | 20% | 50% RSD |
| Total Phosphorus – plant tissue | EPA200.7 | 0.01% of DW | n/a | 85-115% | 75-125% | 20% | 50% RSD |

RL: reporting limit
MDL: method detection limit
[a] reporting limit may vary depending on dilutions
[b] field duplicate results with a mean of less than or equal to 5 times the reporting limit will be evaluated separately.

Field staff will minimize bias in field measurements and samples by strictly following measurement, sampling, and handling protocols. Environmental Assessment Program (EAP) staff will assess bias in field samples by submitting field blanks. Field staff will prepare blanks in the field by:

- For most water quality samples, filling the bottles directly with deionized water. For filtered parameters, deionized water will be filtered through a new syringe and filter into the sample bottle.
- Handling and transporting the filtering equipment and blank samples to MEL in the same manner that the rest of the samples are processed.

Table 8 outlines analytical methods, expected precision of sample duplicates, and method reporting limits. The targets for precision of field duplicates are based on historical performance by MEL for environmental samples taken around the state by EAP (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives.

For field measurements, EAP staff will:

- Minimize bias in the Hydrolab® sonde field measurements (both instantaneous and continuous measurements) by pre-calibrating before each run/deployment.
- Performing field checks against Hydrolab® sonde field measurements.
- Assess any potential bias from instrument drift in Hydrolab® sonde measurements by:
    - For pH and specific conductance, post-checking the probes against NIST-certified pH and conductance standards.
    - For DO, post-checking the sonde against 100% saturation and comparing Winkler DO samples to field measured DO values.
    - For temperature, checking the sonde's temperature readings before and after each run using a NIST-certified thermometer.
- Assess bias from instrument fouling by collecting a final measurement upon retrieval of a deployed sonde, then immediately cleaning the sensors at the site, and finally taking another measurement immediately after cleaning.

In general, field staff will follow procedures outlined by Wagner (2006) to assess bias. Any data corrections applied to the continuous data will be applied following procedures outlined in Wagner (2006).

Table 9 presents the data quality bias objectives for the Hydrolab data, for both instrument drift and fouling checks.

Table 9. Measurement quality objectives for Hydrolab post-deployment and fouling checks.

| Parameter | Units | Accept | Qualify | Reject or Qualify |
|---|---|---|---|---|
| Water Temperature | °C | < or = + 0.2 | > + 0.2 and < or = + 0.8 | > + 0.8 |
| Specific Conductance[a] | uS/cm | < or = + 5% | > + 5% and < or = + 15% | > + 15% |
| pH | std. units | < or = + 0.2 | > + 0.2 and < or = + 0.8 | > + 0.8 |
| Dissolved Oxygen[b] | % saturation | < or = + 5% | > + 5% and < or = + 15% | > + 15% |

[a] Criteria expressed as a percentage of readings; for example, buffer = 100.2 uS/cm and Hydrolab = 98.7 uS/cm; (100.2-98.7)/100.2 = 1.49% variation, which would fall into the acceptable data criteria of less than 5%.
[b] When Winkler data are available, they will be used to evaluate acceptability of data in lieu of % saturation criteria.

Corrected data will be assigned an accuracy rating based on combined fouling and calibration corrections applied to the record (Table 10). Data assigned a "poor" rating will not be used in data analysis. For qualified data where a data correction could not be confidently applied, the project manager may choose to exclude the data from data analysis based on a thorough QC review.

Table 10. Ratings of accuracy for data corrections based on combined fouling and calibration drift corrections applied to record.

| Measured Field Parameter | Ratings of Accuracy of Data Corrections | | | |
|---|---|---|---|---|
| | Excellent | Good | Fair | Poor |
| Water Temperature | ≤ ± 0.2°C | > ± 0.2 – 0.5°C | > ± 0.5 – 0.8°C | > ± 0.8°C |
| Specific Conductance | ≤ ± 3% | > ± 3 – 10% | > ± 10 – 15% | > ± 15% |
| pH | ≤ ± 0.2 units | > ± 0.2 – 0.5 units | > ± 0.5 – 0.8 units | > ± 0.8 units |
| Dissolved Oxygen | ≤ ± 0.3 mg/L or ≤ ± 5%, whichever is greater | > ± 0.3 – 0.5 mg/L or > ± 5 – 10%, whichever is greater | > ± 0.5 – 0.8 mg/L or > ± 10 – 15%, whichever is greater | > ± 0.8 mg/L or > ± 15%, whichever is greater |

### 6.2.1.3 Sensitivity

Sensitivity is a measure of the capability of a method to detect a substance. It is commonly described as detection limit. In a regulatory sense, the method detection limit (MDL) is usually used to describe sensitivity. The method reporting limit is usually a little higher than the MDL, and can also be used. For this project, the method reporting limit for each laboratory method is reported in Table 8 and MDLs are presented in Table 21 (Section 9.2).

### 6.2.2 Targets for comparability, representativeness, and completeness

#### 6.2.2.1 Comparability

To ensure comparability to previously collected Ecology data, field staff will strictly follow EAP protocols, adhere to data quality criteria, and all field measurements will follow approved EAP SOPs (Table 18, Section 8.1).

Comparability to King County data (if used for this project) will be evaluated by locating some monitoring locations close to or at the same location as King County stations.

#### 6.2.2.2 Representativeness

The study is designed to collect sufficient data, meet study objectives, and assess spatial and temporal variability of the measured parameters throughout the study area during the low-flow season. Sampling locations are strategically distributed throughout the watershed to represent different land uses, bracket relevant jurisdictions, and capture all significant inflows to the mainstem. The sampling frequency is also designed to meet study objectives. A combination of continuous measurements, grab samples, spot measurements, and historic data will together represent a wide range of temporal conditions within the low-flow period.

To check if continuous hydrolab data collected at a single spot in a well-mixed region of the stream are representative of the river cross-section, we will compare these data to hydrolab measurements taken across a transect at a few stations (approximately 20% of stations) during the study.

#### 6.2.2.3 Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for this study is to correctly collect and analyze 100% of the samples for each of the sites. However, problems occasionally arise during sample collection that cannot be controlled; thus, a completeness of 95% is acceptable.

Potential problems are site access problems, equipment malfunction, or sample container shortages. If equipment fails or samples are damaged, Ecology will attempt to recollect the data the following day, if possible. In general, the study is designed to accommodate some data loss and still meet project goals and objectives. For example, we are planning for three synoptic surveys, but two surveys should provide sufficient data for model calibration. The third synoptic survey therefore will provide us with additional data in case there are any data completeness issues associated with either of the other two surveys.

## 6.3 Model Quality Evaluation

To meet the objectives of this project, model quality results should be comparable to other models used in similar TMDL studies. A summary of results for comparison is available in *A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies* (Sanderson and Pickett, 2014). Sensitivity analysis will also be conducted to assess the variability of the model results to specific parameters.

### 6.3.1 Model performance

Model performance will be assessed both quantitatively and qualitatively to evaluate the quality of model calibration and model results. Because of uncertainty and lack of available literature on model performance criteria, inherent error in input and observed data, and the approximate nature of model formulations, absolute criteria for model acceptance or rejection are not appropriate.

This study will assess how well the model is calibrated by evaluating goodness-of-fit using the following methods. The methods described below will use appropriate spatial and temporal pooling of data to help provide a more comprehensive understanding of model uncertainty.

#### 6.3.1.1 Precision

Precision is a measure of the variability in the model results relative to measured values. This study will evaluate precision and model variability using the root-mean-square-error (RMSE), a commonly used measure of model variability. The RMSE is defined as the square root of the mean of the squared difference between observed and simulated values. Other metrics that might also be used to access precision include the Relative Standard Deviation or the Nash-Sutcliffe Coefficient.

#### 6.3.1.2 Bias

Bias is the systematic deviation or difference between the modeled and observed (i.e., measured) values. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration. Mathematically, we will evaluate bias in this study through use of standard metrics such as the mean error or relative percent difference (% RPD). The % RPD provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

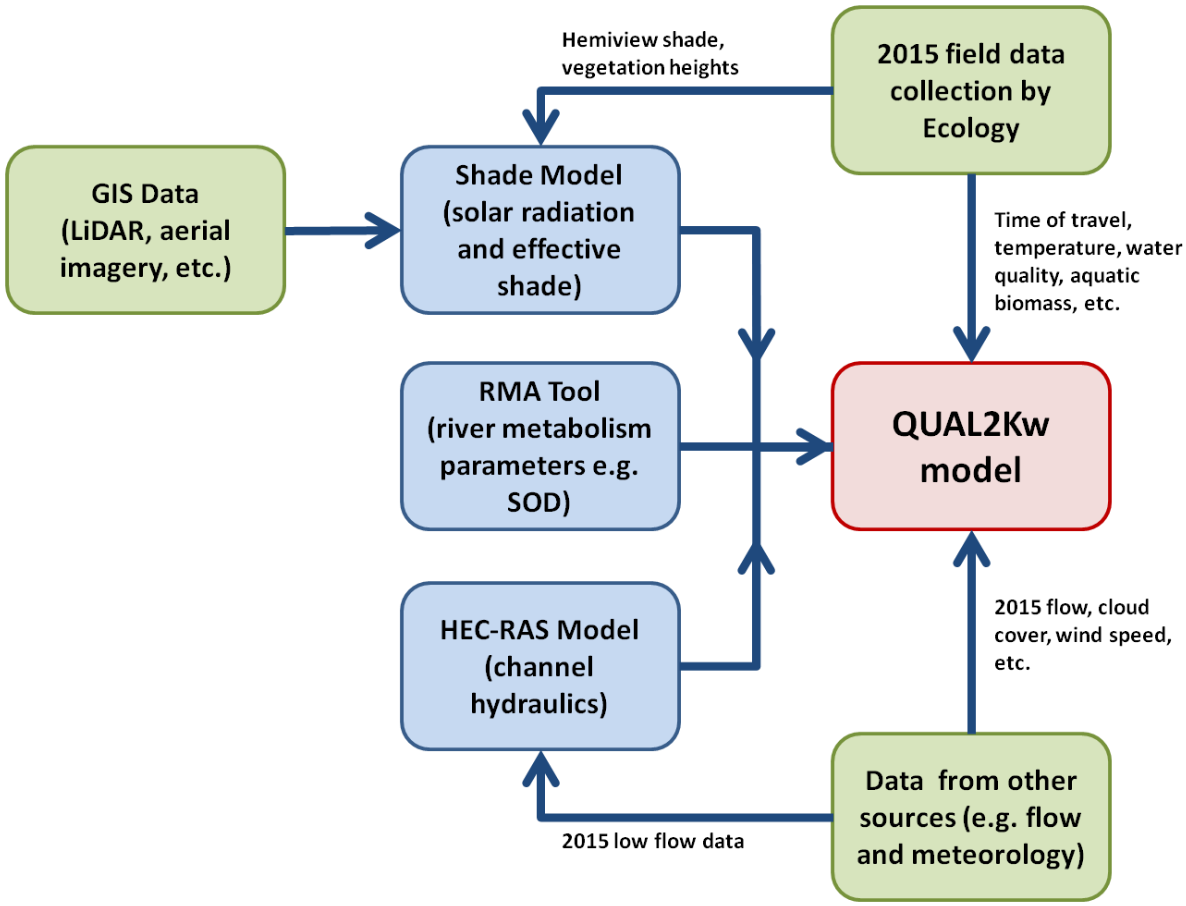
#### 6.3.1.3 Qualitative assessment

Graphical assessment and spatial assessments with GIS will be used to provide a qualitative assessment of the goodness-of-fit to supplement the quantitative methods. QUAL2Kw results can be graphically assessed to compare observed and measured values along the length of the modeled stream segment, or over the course of a particular time period. Evaluating these plots and graphs will be part of the model assessment process.

# 7.0 Sampling Process Design (Experimental Design)

## 7.1 Study Design

The schematic below illustrates the general study design, including the data, tools and models that will be used and how they are related to each other. The sampling design for this project is primarily driven by the data needs for the models that will be used to perform the TMDL analysis.




The main tools and models that will be used for this project are described in more detail below, followed by a description of the field data collection that will support model development and calibration.

### Shade Model

Ecology's Shade model (Shade.xls—a Microsoft Excel spreadsheet) is available for download at http://www.ecy.wa.gov/programs/eap/models.html (Ecology, 2003) will be used to evaluate solar radiation and effective shade along the Sammamish River.

The Shade model was adapted from a program that Oregon Department of Environmental Quality (ODEQ) developed as part of its HeatSource model version 6. The Shade model calculates shade using one of two methods. The first is ODEQ's original method from the HeatSource model version 6 (documentation of ODEQ's HeatSource model is located at http://www.deq.state.or.us/wq/tmdls/tools.htm). The second method is Chen's method, based on the HSPF SHADE FORTRAN program, (Chen, 1998a and Chen, 1998b).

The Shade model quantifies the potential daily solar load and generates percent effective shade at user-specified longitudinal distances along the river channel. Effective shade is the fraction of shortwave solar radiation that does not reach the stream surface because of interception with vegetative cover and topography. Effective shade is influenced by latitude/longitude, time of year, stream geometry, topography, and vegetative buffer characteristics such as height, width, overhang, and density.

The LiDAR data and aerial imagery (described in Section 4.3.2) will be used to develop some of the inputs to the Shade model. The riparian vegetation coverage inputs into the Shade model will contain four specific attributes: vegetation height, vegetation overhang, and average canopy density. Field measurements of effective shade using hemiview photographs along the Sammamish River will also be used to compare modeled effective shade to observed values.

The Shade model will be used to generate longitudinal effective shade profiles. Reach-averaged integrated hourly effective shade (i.e., the fraction of potential solar radiation blocked by topography and vegetation) will be used as input into the QUAL2Kw model.

## RMA Model

The River Metabolism Analyzer (RMA) is a simplified modeling tool developed by Ecology (Pelletier, 2013) that can be used to solve for gross primary production, ecosystem respiration, reaeration, and limitation due to light, temperature, and nutrients. It is available for download here: http://www.ecy.wa.gov/programs/eap/models.html.

The data required to run RMA include:

- Diel DO, pH, and temperature data
- Alkalinity data
- Concentration of the limiting nutrient
- Depth of water where data were collected

Continuous data collected by deployed Hydrolab® probes during synoptic surveys from the 2015 field effort will be used in RMA to analyze reach-scale productivity and respiration. The primary application of the RMA tool for this project will be to (1) understand reach-scale water quality dynamics and (2) estimate the sediment oxygen demand (SOD). Hobson et al. (2014) suggests that the SOD can be estimated by subtracting the gross primary productivity from ecosystem respiration – both of which are outputs of the RMA tool. This SOD can then be used directly in the QUAL2Kw model.

## QUAL2Kw Water Quality Model

Ecology's QUAL2Kw modeling framework (Pelletier et al., 2006; Pelletier and Chapra, 2008) will be used in this study for detailed evaluation of temperature and DO under critical flow and weather conditions.

The original version of Ecology's QUAL2Kw model was a steady-flow model. A new version is now available (http://www.ecy.wa.gov/programs/eap/models.html), which can simulate non-steady, non-uniform flow using kinematic wave (KW) flow routing. The KW approach is described in more detail by Chapra (1997) and allows for a continuous simulation of the river with continuously changing channel velocity and depth in response to changing flows, and time-varying boundary conditions (e.g., tributary loading and meteorology) for periods of up to one year.

Incorporation of KW transport and continuous boundary forcing will allow QUAL2Kw to be used in this project to simulate continuous changes in water quality throughout the summer low-flow period rather than for a single day at a time.

The QUAL2Kw model was selected because it can simulate continuous changes in temperature, nutrients, algal/macrophyte biomass, and DO over the entire growing season, including representation of diel variations. Other features of this model include:

- One dimensional. The channel is well-mixed vertically and laterally. Also includes up to two optional transient storage zones connected to each main channel reach (surface and hyporheic transient storage zones).
- Dynamic heat budget. The heat budget and temperature are simulated as a function of meteorology on a continuously varying time scale. Parameters included that affect stream temperature are effective shade, solar radiation, air temperature, cloud cover, relative humidity, headwater and tributary temperature, and hyporheic flow temperature.
- Dynamic water-quality kinetics. All water quality state variables are simulated on a continuously varying time scale for biogeochemical processes.
- Heat and mass inputs. Point and non-point loads and abstractions are simulated.
- Two algal species in the water column: phytoplankton and bottom algae (periphyton). For this project, since we know that macrophytes are known to be a dominant plant along the length of the river, we will use the phytoplankton parameters to simulate macrophytes instead[9]. Based on the data we collect, if we find that phytoplankton are dominant in certain reaches, we will simulate the two most dominant of these three algal species in different model segments.
- Variable stoichiometry. Luxury uptake of nutrients by the bottom algae (periphyton) is simulated with variable stoichiometry of N and P.
- Sediment diagenesis and heterotrophic metabolism in the hyporheic zone are simulated.

[9] Since the model only has the ability to simulate two groups of algae, not three.

- Automatic calibration. Includes a genetic algorithm to automatically calibrate the kinetic rate parameters.
- Monte Carlo simulation.

Table 11 presents a summary of input and calibration data needed for the model. The model of the Sammamish River will start at NE Marymoor Way, about 130 ft below the weir at RM 12.8 and extend to Blyth Park at RM 2.6. Based on segment lengths of 0.5 to 1 km per segment, that model would contain approximately 17 to 34 segments. The final number of segments used in the model may be adjusted during model development.

Temperature and water quality variables will be simulated continuously, with a time step on the order of minutes, for the course of the 2015 growing season. The beginning, end, and length of the 2015 growing season will depend on conditions but are generally expected to fall between June and September 2015. The model simulation period will therefore be approximately June 20 through the end of September 2015.

Tributary inflows, groundwater inflows/outflows, and point source inflows will be handled as boundary inputs to the mainstem model. Nutrient loads from diffuse inputs, such as groundwater, and direct inputs, such as tributaries, will be measured directly in the field during synoptic surveys and estimated between surveys. Some loads may be estimated based on interpolation, where appropriate.

Once calibrated, the QUAL2Kw model will be used for evaluating TMDL loading capacity and developing allocations under critical conditions.

Table 11. Model input and calibration data needed for QUAL2Kw.

| | Source of Data | Description |
|---|---|---|
| **Model Input Data** | | |
| Channel geometry | From HEC-RAS model | Average velocity, depth, and width or rating curve information relating channel width, depth, and velocities. |
| Effective shade and solar radiation | From Shade model | Shade model will be run continuously for the study period to generate continuous outputs of effective shade. |
| Meteorology | 2015 field effort and nearby weather stations (see Table 14) | Air thermistors will be installed throughout the study period at all mainstem monitoring locations, and relative humidity will be monitored at a subset of stations. Additional meteorological data from external sources include cloud cover, wind direction, wind speed, and solar radiation. |
| Headwater and tributary flows | 2015 field effort, Ecology telemetry stations, and other existing gages (see Table 15) | A telemetry station will be installed at the headwater boundary. Three synoptic surveys will include streamflow measurements of all measureable tributary inputs and supplemented with King County flow gage data to develop continuous tributary inputs. |
| Headwater and tributary temperatures | 2015 field effort | Thermistors will be monitoring continuously throughout study period at model upstream boundary, major/minor tributaries, and all other measurable inflows. |
| Headwater and tributary water quality variables | 2015 field effort | Three synoptic surveys will include grab samples for water quality analysis, deployed hydrolabs at the three major tributaries, and spot hydrolab measurements at all measurable inflows. Bi-weekly N & P samples will be taken at the upstream boundary and all major tributaries. Data will be estimated between measurements. |
| Groundwater flow, temperature and water quality | 2015 field effort, existing King County well data | Piezometer installation for water levels will include thermistors and three levels and water quality sampling during synoptic surveys. Some King County wells will be sampled, if we are given access. |
| **Model Calibration Data** | | |
| Travel time and velocities | 2015 field effort and HEC-RAS model | A travel time dye study will be conducted, and model values will also be compared to HEC-RAS model output. |
| Instream flows | 2015 field effort, Ecology telemetry stations and other existing gages (see Table 15) | Two or three seepage runs will measure mainstem streamflows at key stations, one telemetry station will measure flow continuously throughout the study period, and several King County gages also measure stage/flow along the mainstem. |
| Instream temperatures | 2015 field effort and existing | Thermistors will be monitoring continuously throughout study period along the mainstem. |
| Instream water quality variables | 2015 field effort | One mainstem telemetry station will provide continuous DO data for calibration. Two or three synoptic surveys will provide detailed water quality data, including deployment of hydrolabs along the mainstem. Bi-weekly measurement of N & P parameters at key mainstem stations. |
| Groundwater interactions/ hyporheic exchange | 2015 field effort | Piezometer water levels and a longitudinal specific conductance survey will help characterize groundwater interactions along the river. |
| Bottom algae biomass | 2015 field effort | Periphyton biomass and nutrient content will be measured and analyzed twice during the study. |
| Macrophyte biomass | 2015 field effort | Macrophyte biomass and nutrient content will be measured and analyzed twice during the study. |

### 7.1.1 Sampling locations

The overall study design includes several monitoring/sampling locations distributed throughout the study area. Mainstem stations were selected based on (1) jurisdictional boundaries (e.g., by selecting a sampling location between the end of one city boundary and the start of another), (2) land uses (e.g., monitoring at a location between a change from agricultural and residential land use), and (3) ensuring adequate spatial resolution along the mainstem (at least one station approximately every mile or so).

There are four main sampling networks for this project:

- **Mainstem stations:** a total of nine mainstem stations, including six core stations that will have a higher resolution of surface water sampling for some parameters.
- **Major tributary stations:** monitoring at or close to the mouth of the three major tributaries in the study area.
- **Minor tributaries other unnamed inflows:** monitoring of all smaller tributaries and other visible and accessible inflows. Based on an initial reconnaissance and past studies, there are about six known minor tributaries and 24 other minor unnamed inflows (seeps and outfalls). Some of these may not have measurable flow during the field season.
- **Stormwater stations:** all known or significant permitted NPDES stormwater discharges to the Sammamish River within the model boundaries, if resources allow.

Locations of proposed monitoring stations are presented in Figure 7, and Station ID's, descriptions, and monitoring details are presented in Table 12 and Table 13.

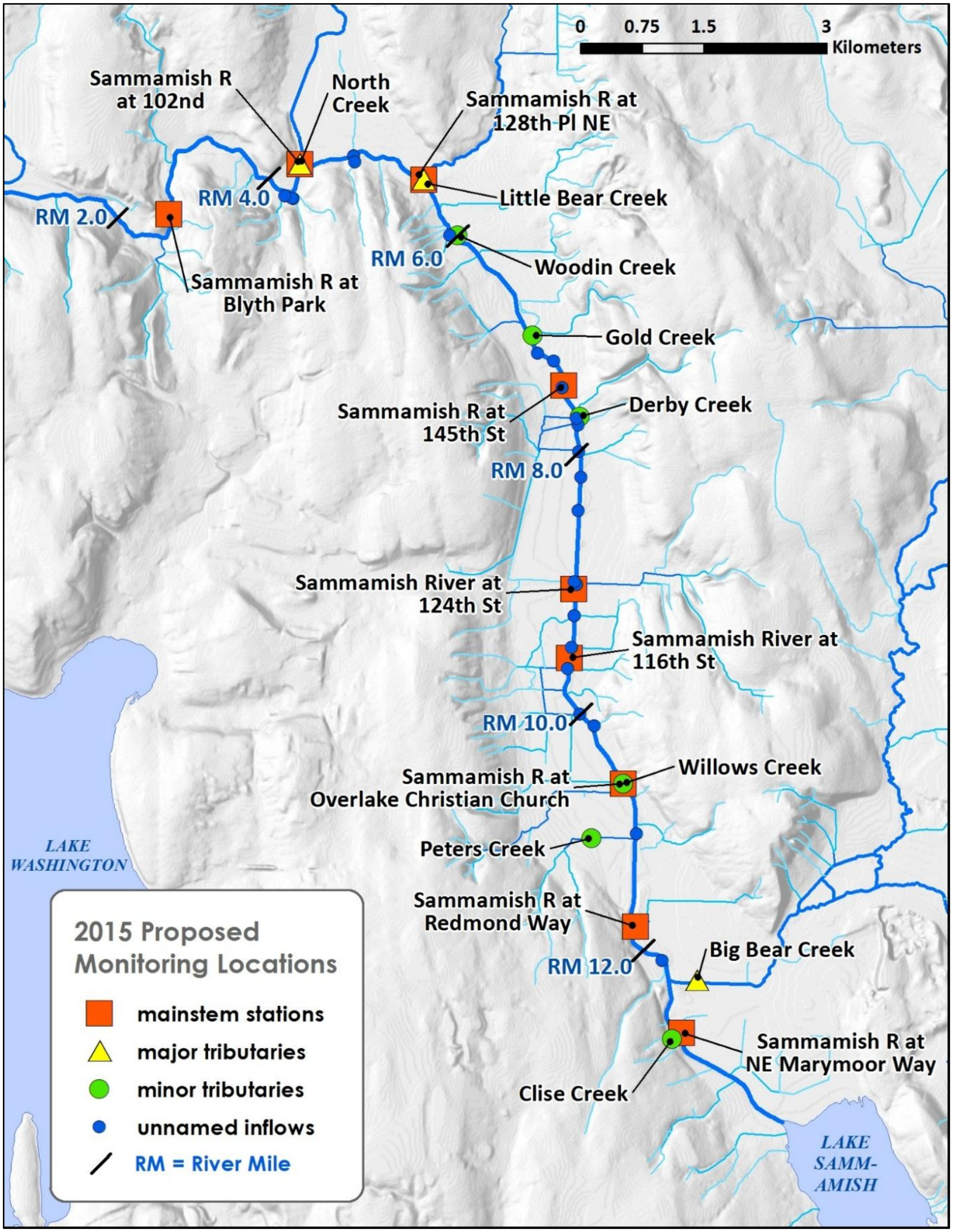



Figure 7. Proposed locations for the 2015 field monitoring (unnamed tributaries/inflows are included but not individually labeled).

Table 12. Mainstem and major tributary monitoring locations, including what data are planned to be collected at which stations.

| Station ID | Telemetry Station | Water Thermistors | Air Thermistors | Relative Humidity | Synoptic Flow & Water Quality | Synoptic Hydrolab deployment | Spot Hydrolab | Instream Piezometers | Bi-weekly N and P | Bi-weekly Winklers | Macrophyte surveys | Periphyton Surveys | Riparian/Shade Surveys | Description | NAD83 Latitude | NAD83 Longitude |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mainstem Stations** | | | | | | | | | | | | | | | | |
| 08-SAMM-12.8 | X | X | X | X | X | | X | X | X | X | X | X | X | Sammamish River at NE Marymoor Way | 47.662333 | -122.124194 |
| 08-SAMM-11.8 | | X | X | | X | | | X | | | | | X | Sammamish River at Redmond Way | 47.673833 | -122.132056 |
| 08-SAMM-10.6 | | X | X | X | X | X | X | X | | | X | X | X | Sammamish River at Overlake Christian Church | 47.689389 | -122.134528 |
| 08-SAMM-9.6 | | X | X | X | X | | X | X | | | | | X | Sammamish River near 116th St | 47.703020 | -122.143660 |
| 08-SAMM-9.0 | X | X | X | | X | | X | X | X | X | X | X | X | Sammamish River at 124th St | 47.710528 | -122.143167 |
| 08-SAMM-7.5 | | X | X | X | X | X | X | X | | | X | X | X | Sammamish River at 145th St | 47.732750 | -122.145500 |
| 08-SAMM-5.5 | | X | X | X | X | X | X | X | | | X | X | X | Sammamish River at 128th Pl NE | 47.754944 | -122.168833 |
| 08-SAMM-4.4 | | X | X | | X | | | X | | | | | X | Sammamish River at 102nd | 47.756333 | -122.188972 |
| 08-SAMM-2.6 | | X | X | X | X | X | X | X | | | X | X | X | Sammamish River at Blyth Park | 47.750583 | -122.210083 |
| **Major Tributaries** | | | | | | | | | | | | | | | | |
| 08-SAMM-Trib12.3 | | X | | | X | X | X | | X | | | | | Big Bear Creek near mouth | 47.668028 | -122.121889 |
| 08-SAMM-Trib5.5 | | X | | | X | X | X | | X | | | | | Little Bear Creek near mouth | 47.756333 | -122.188972 |
| 08-SAMM-Trib4.4 | | X | | | X | X | X | | X | | | | | North Creek at mouth | 47.754944 | -122.168833 |

Table 13. Minor tributary monitoring locations, including what data are planned to be collected at which stations.

| Station ID | Water Thermistors | Synoptic Flow & Water Quality | Spot Hydrolab | Description | NAD83 Latitude | NAD83 Longitude |
|---|---|---|---|---|---|---|
| **Minor Tributaries** | | | | | | |
| 08-SAMM-Trib12.8 | X | X | X | Clise Creek near mouth | 47.661639 | -122.125750 |
| 08-SAMM-Trib11.1 | X | X | X | Peters Creek near mouth | 47.683389 | -122.139417 |
| 08-SAMM-Trib10.6 | X | X | X | Willows Creek near mouth | 47.689389 | -122.134528 |
| 08-SAMM-Trib7.7 | X | X | X | Derby Creek near mouth | 47.729420 | -122.142770 |
| 08-SAMM-Trib6.7 | X | X | X | Gold Creek near mouth | 47.738194 | -122.150722 |
| 08-SAMM-Trib6.0 | X | X | X | Woodin Creek near mouth | 47.748917 | -122.163139 |
| **Unnamed Tributaries/Inflows** | | | | | | |
| 08-SAMM-Trib12.1 | X | X | X | Unnamed trib/inflow at RM 12.15 | 47.670160 | -122.127560 |
| 08-SAMM-Trib11.1 | X | X | X | Unnamed trib/inflow at RM 11.1 | 47.683944 | -122.132194 |
| 08-SAMM-Trib10.1 | X | X | X | Unnamed trib/inflow at RM 10.13 | 47.695639 | -122.139389 |
| 08-SAMM-Trib10.0 | X | X | X | Unnamed trib/inflow at RM 10.04 | 47.696917 | -122.141778 |
| 08-SAMM-Trib9.6 | X | X | X | Unnamed trib/inflow at RM 9.62 | 47.701833 | -122.143861 |
| 08-SAMM-Trib9.4 | X | X | X | Unnamed trib/inflow at RM 9.45 | 47.704194 | -122.143278 |
| 08-SAMM-Trib9.21 | X | X | X | Unnamed trib/inflow at RM 9.21 | 47.707639 | -122.142972 |
| 08-SAMM-Trib9.20 | X | X | X | Unnamed trib/inflow at RM 9.2 | 47.707639 | -122.142972 |
| 08-SAMM-Trib9.0 | X | X | X | Unnamed trib/inflow at RM 8.97 | 47.711040 | -122.142700 |
| 08-SAMM-Trib8.9 | X | X | X | Unnamed trib/inflow at RM 8.95 | 47.711370 | -122.143052 |
| 08-SAMM-Trib8.4 | X | X | X | Unnamed trib/inflow at RM 8.42 | 47.719139 | -122.142722 |
| 08-SAMM-Trib8.2 | X | X | X | Unnamed trib/inflow at RM 8.18 | 47.722778 | -122.142370 |
| 08-SAMM-Trib8.0 | X | X | X | Unnamed trib/inflow at RM 7.96 | 47.725583 | -122.142806 |
| 08-SAMM-Trib7.8 | X | X | X | Unnamed trib/inflow at RM 7.79 | 47.728500 | -122.142972 |
| 08-SAMM-Trib7.7 | X | X | X | Unnamed trib/inflow at RM 7.71 | 47.729222 | -122.143278 |
| 08-SAMM-Trib7.5 | X | X | X | Unnamed trib/inflow at RM 7.47 | 47.732500 | -122.145722 |
| 08-SAMM-Trib7.3 | X | X | X | Unnamed trib/inflow at RM 7.25 | 47.735444 | -122.147167 |
| 08-SAMM-Trib7.1 | X | X | X | Unnamed trib/inflow at RM 7.12 | 47.736250 | -122.149778 |
| 08-SAMM-Trib5.9 | X | X | X | Unnamed trib/inflow at RM 5.95 | 47.748917 | -122.164417 |
| 08-SAMM-Trib4.82 | X | X | X | Unnamed trib/inflow at RM 4.82 | 47.757389 | -122.180333 |
| 08-SAMM-Trib4.80 | X | X | X | Unnamed trib/inflow at RM 4.8 | 47.756722 | -122.180139 |
| 08-SAMM-Trib4.24 | X | X | X | Unnamed trib/inflow at RM 4.24 | 47.752528 | -122.190000 |
| 08-SAMM-Trib4.23 | X | X | X | Unnamed trib/inflow at RM 4.23 | 47.752611 | -122.190194 |
| 08-SAMM-Trib4.20 | X | X | X | Unnamed trib/inflow at RM 4.2 | 47.752833 | -122.191306 |

### 7.1.2 Field measurements and frequency

**Continuous Telemetry Stations**

Ecology's Freshwater Monitoring Unit will install two telemetry stations on the Sammamish River that will collect continuous measurements for flow (stage), temperature, DO, pH, and specific conductance. These stations will be installed and maintained following a separate QAPP and set of protocols for Ecology's statewide ambient monitoring program (Hallock, 2009).

One of these stations will be located at NE Marymoor Way (RM 12.8), which is also the upstream model boundary. The second station will be located at 124th St. (RM 9), and will provide key calibration data throughout the model simulation period.

**Continuous temperature monitoring**

In order to develop an accurate temperature model, we will collect continuous temperature data during the entire 2015 growing season (approximately mid-June through the end of September). Data collection will include the deployment of continuous temperature data loggers (thermistors) deployment at all mainstem network sites as well as all major and minor tributaries. Thermistors will be deployed in the first week of June 2015 and will be retrieved in the first week of October 2015.

- All mainstem stations will have one thermistor deployed for water temperature and another for air temperature. The six core mainstem sites will also have a sensor to measure for relative humidity. All other tributary stations with visible flow will have thermistors for water temperature only.
- Thermistors will be programmed to record temperature at 30-minute intervals.
- Water thermistors will be deployed in the thalweg of a stream, suspended off the stream bottom, and in a well-mixed area, typically in riffles or swift glides.
- Data will be downloaded monthly.

**Synoptic Surveys**

Ecology will collect the primary data set for model calibration during two synoptic surveys. The synoptic surveys are planned during the following dates: July 27 - 30 and August 24 - 27. A third synoptic survey in September is planned only as a back-up and will only be conducted if the first two surveys do not go smoothly and compromise the quality or quantity of data collected.

Synoptic surveys will be conducted, when possible, during periods of relatively steady-state conditions (stable or steadily decreasing flow) in the river. Surveys will span a 48 to 96-hour period and involve multiple teams of samplers, in order to collect a large amount of data over the course of three to four days.

If significant precipitation occurs immediately before a scheduled survey, the survey will be delayed or canceled and rescheduled during a backup week.

The synoptic surveys will include:

- Hydrolab® multi-parameter sonde deployments to collect continuous diel data (at 10-minute intervals) for temperature, pH, DO, and specific conductance at six mainstem stations and all three major tributaries. Each deployment will last for 36 hours or longer. Additional deployments at other stations may be added, if equipment is available.
- Water quality samples will be collected as follows:
  - Mainstem and major tributary sites will be visited once in the morning and once in the late afternoon. During morning visits, water quality samples will be taken for: ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate (soluble reactive phosphorus), and total phosphorus. During late afternoon visits, water quality samples will be taken for the following additional parameters: alkalinity, chloride, chlorophyll *a*, dissolved and total organic carbon, total suspended solids, total non-volatile suspended solids, turbidity, and Biochemical Oxygen Demand (5-day BOD, or BOD5).
  - Minor tributaries will be visited once sometime during the day and water quality samples will be taken for the following parameters: ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate (soluble reactive phosphorus), and total phosphorus.
- Manual streamflow measurements will be taken at all mainstem and tributary stations.

### Stormwater Monitoring

Given that critical conditions in the Sammamish River occur during steady-state low-flow conditions, we will not conduct targeted stormwater monitoring during runoff events. However, "stormwater" baseflow from municipal stormwater infrastructure may still discharge to the Sammamish River during non-runoff conditions. If the location of stormwater outfalls and discharges can be identified and are accessible, we will install thermistors to monitor for temperature at these locations throughout the study. During synoptic surveys, grab samples will be taken from any known stormwater outfalls/infrastructure that have measurable flow and will be analyzed for the following parameters: ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate (soluble reactive phosphorus), and total phosphorus.

### Bi-Weekly Nutrient Sampling

After thermistor deployment, supplementary nutrient sampling for key parameters will be conducted bi-weekly at five stations – two mainstem stations, and all three major tributaries. This bi-weekly sampling will include:

- Ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate, and total phosphorus sampling at each bi-weekly sampling event at all five stations.

- Chlorophyll *a* and Total Non-Volatile Suspended Solids (TNVSS) at each bi-weekly sampling event at the upstream telemetry station (which represents the upstream model boundary).
- TNVSS at every other bi-weekly sampling event at all three major tributary stations and the second mainstem station.

This higher frequency of nutrient sampling before, after, and in-between synoptic surveys will allow better characterization of nutrient inputs and inorganic suspended solids from the major tributaries and upstream boundary to develop the model's initial conditions. It will also give us more data points to develop continuous nutrient boundary conditions throughout the model simulation and provide a higher resolution of nutrient data at one key mainstem location for model calibration.

**Groundwater Sampling**

Groundwater and surface-water interactions will be assessed via a combination of field techniques. The groundwater monitoring network will consist of a combination of instream piezometers, springs, or seeps within the study area and shallow off-stream wells, where accessible.

Where site conditions allow, instream piezometers will be installed around mid-June in accordance with standard EAP methodology (Sinclair and Pitz, 2010). The piezometers will be used at discrete points along the river to monitor surface-water and groundwater head relationships, streambed water temperatures, and groundwater quality. At some locations, we may install two piezometers, one on each side of the river, to characterize lateral groundwater flow.

The piezometers are 5-foot by 1.5-inch galvanized pipes that are crimped and perforated at the bottom. The upper end of each piezometer will be fitted with a standard pipe coupler to provide a robust strike surface for installing and capping between sampling events. The piezometers will be driven into the streambed, within a few feet of the shoreline, to a maximum depth of approximately 5 ft. Keeping the top of the piezometer underwater and as close to the streambed as possible will reduce the influence of heat conductance from the exposed portion of the pipe. Following installation, the piezometers will be developed using standard surge and pump techniques to assure a good hydraulic connection with the streambed sediments.

Each piezometer will be instrumented with up to three thermistors for continuous monitoring of streambed water temperatures (Figure 8). In a typical installation, one thermistor will be located near the bottom of the piezometer, one at a depth of approximately 0.5 ft below the streambed and one roughly equidistant between the upper and lower thermistors.

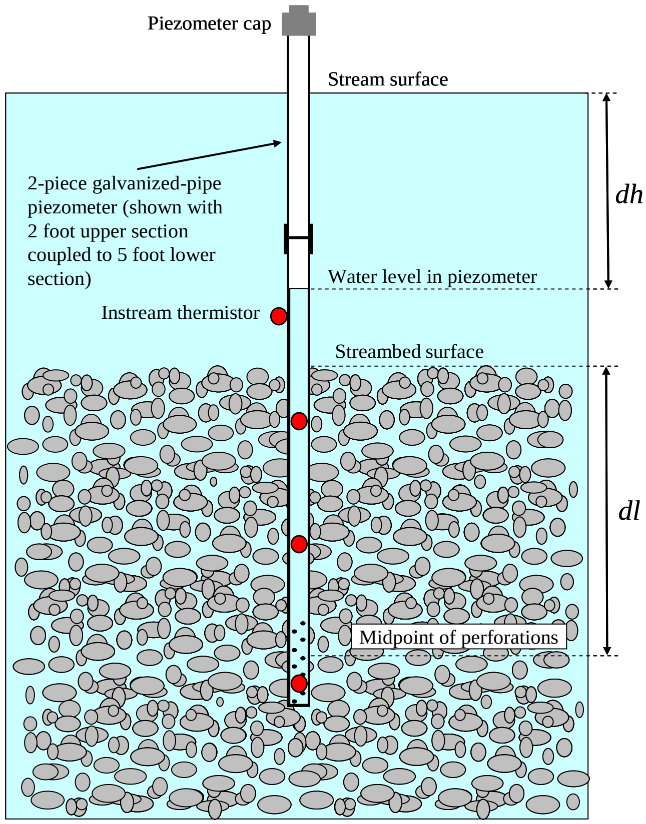



Figure 8. Instream piezometer conceptual diagram (diagram not to scale).

Groundwater piezometer sampling will include:

- Monthly visits to download thermistors and to make spot measurements of stream and groundwater temperatures for later comparison to and validation of the thermistor data.
- Monthly visits to take surface-water stage and instream piezometer water levels using a calibrated electric well probe, steel tape, or a manometer board (as appropriate). The water level (head) difference between the piezometer and the river provides an indication of the vertical hydraulic gradient and the direction of flow between the river and groundwater. When the piezometer head exceeds the river stage, groundwater discharge into the river can be inferred. Similarly, when the river stage exceeds the head in the piezometer, loss of water from the river to groundwater storage can be inferred.
- Two groundwater quality sampling events (scheduled to coincide with the first two synoptic surface-water sampling events) to assess the quality of groundwater discharging to the river. During the synoptic surveys, groundwater samples will be collected from piezometers in gaining stream reaches or seeps if necessary[10]. The samples will be submitted to the laboratory for analysis of alkalinity, chloride, orthophosphate, total phosphorus, nitrate/nitrite, ammonia, total persulfate nitrogen, and dissolved organic carbon.

[10] At locations where two piezometers are installed, nutrient samples will only be taken from one piezometer.

Temperature, water level, specific conductance, pH, and DO will also be measured in the piezometers during the surveys, using a Hydrolab.

To confirm the instream piezometer data set, Ecology will also attempt to arrange access to shallow off-stream monitoring wells to monitor a few local groundwater levels, temperatures, and groundwater quality. When selecting wells, we will give preference to shallow, properly documented wells in close proximity to the Sammamish River. Wells selected for monitoring will also be visited monthly during the study period, to measure groundwater levels. Where owner's permission is granted and site conditions allow, logging thermistors may also be deployed in the wells. Ecology also hopes to collect water quality samples from a subset of the off-stream wells, during each of the two instream piezometer sampling events.

## Longitudinal Profile

Measurements of specific conductance and/or temperature can be used as an indication of the locations and magnitude of groundwater and other flow contributions to the river. One longitudinal specific conductance profile is tentatively planned for this study[11]. Ecology field staff will float down the river, equipped with either a CTD probe (which records specific conductance, temperature and depth) or a Hydrolab® sonde (which records temperature, specific conductance, DO and pH). A global positioning system (GPS) will simultaneously record location coordinates. Most groundwater enters the river from the side rather than the center, so we will explore options of floating down either or both sides of the river rather than in the thalweg.

## Travel Time Dye Study

Travel times will be estimated within several reaches of the Sammamish River to further understand how water and pollutants move through the system and to calibrate the model. Time-of-travel studies will use fluorescent dye (20% Rhodamine Water Tracing Dye, or Rhodamine WT) to trace the movement of a dye cloud from an upstream point to a downstream point, to calculate the average velocity of that body of water. Rhodamine WT dye is used by Ecology, the USGS, and others to provide safe and effective time-of-travel measurements. The methods and protocols used in this survey will follow those prescribed by Kilpatrick and Wilson (1982).

Field measurements of dye concentration in the stream will be made using a Hydrolab DataSonde® equipped with a rhodamine fluorometer, recording measurements every 5-10 minutes at key locations downstream from the initial point of dye release. Over a period of time in the stream, the dye will dissipate, becoming visually undetectable.

We are planning a single dye study sometime in late July, coincident with the first synoptic survey, to capture the time of travel during typical low flow conditions for the study period. If flow conditions change significantly during the study period, or we have adequate resources, a second dye study will be conducted in late August. Based on a simulated dye release in the CE-

[11] This survey will only be carried out if it is deemed necessary, depending on the results of initial piezometer water level data and available field staff/resources.

QUAL-W2 model developed by King County (2009), the estimated travel time of the Sammamish River from the weir to Lake Washington is about 70 hours (2.9 days).

Ecology will notify the appropriate officials and local emergency contacts before injecting the dye. Announcing the dye studies will prevent unnecessary emergency actions in the event a spills complaint is submitted (i.e., someone calls the sheriff or Ecology spills hotline because the river just turned red/pink).

### Periphyton Surveys

Two periphyton surveys are planned: one in June to characterize early summer/initial biomass and a second one in August during peak growth and productivity. Both surveys will be conducted at all or a subset of the six core mainstem stations where periphyton growth on benthic rocks/pebbles is present. At all six sites, profiles of photosynthetically active radiation (PAR) vs. depth will also be measured to estimate vertical light extinction using an underwater irradiameter.

The periphyton surveys will involve:

- Collecting periphyton samples (by scraping from rocks) across a transect perpendicular to river flow. Samples will not be taken if there is no observed periphyton growth.
- Assessing aerial distribution of the periphyton by determining the surface area of each rock by wrapping each rock with foil and then measuring the area of the foil that was needed to cover each rock.
- Placing samples in a 1000 ml amber bottle and sending to the lab for measurement of dry weight, ash-free dry weight (AFDW) nutrient content (total nitrogen, total phosphorus, and total carbon), and chlorophyll *a*.

### Macrophyte Surveys

Two macrophyte surveys are planned at the same time as periphyton surveys – one in June to characterize early summer/initial biomass, and a second one in August during peak growth and productivity. Both surveys will be conducted at the six core mainstem stations.

The macrophyte surveys will involve:

*Percent cover estimates using an echo-sounder*

A Lowrance HDS echo sounder will be used to map submerged aquatic vegetation (in this case, macrophytes). If available, we will pair up with Ecology's aquatic plant specialist, who is experienced in using this equipment[12]. The echo sounder uses hydro-acoustics and can be used to characterize the percent cover and height of macrophytes along the river bottom from a boat

[12] Jenifer Parsons from Ecology's Lakes Monitoring Program has used this technique before and has offered her time and expertise.

while simultaneously recording GPS coordinates. We will take three transects about 50 ft apart at six mainstem monitoring locations.

In addition, visual estimates of overall percent macrophyte cover will be made following approaches described in Parsons (2001) at representative transects along the river and longitudinally as we boat down the river during the echo sounder survey.

*Biomass samples*

Macrophyte samples for biomass estimation will also be collected as follows:

- Macrophyte samples will be collected at four equally-spaced locations across a transect perpendicular to river flow, where conditions allow. Macrophytes will be collected by placing a 0.1 $m^2$ (approximately 30 cm x 30 cm) quadrat on the stream bottom and harvesting all the above-sediment macrophytes within the quadrat.
- Macrophyte samples will be brought back to the stream bank for processing.
- The samples will then be rinsed with river water to remove any loose sediment or obvious critters.
- All the macrophytes from all quadrats will be placed into a single large black bag.
- A representative subset of the macrophyte samples will be removed from the large bag and placed in 1000 mL amber bottle(s).
- The large bags containing all the macrophytes collected from each site will be sent to Ecology's aquatic plant specialist for measurement of dry weight, using a large oven located in the Central Regional Office in Yakima (MEL does not have an oven large enough to dry the full sample).
- The bottles containing the macrophyte sub-samples will be sent to the MEL for measurement of percent solids, dry weight, ash-free dry weight (AFDW), nutrient content (total nitrogen, total phosphorus and total carbon) and chlorophyll *a*.

Since macrophyte sampling is relatively new for the field staff involved, we plan on doing a "mock" or dry run of the field component described above in early June to test how easy it is extract representative macrophyte sub-samples and place these into 1000 mL bottles. This will allow us to refine our method as needed for consistency and representativeness.

The biomass samples will give us an estimate of biomass per area (e.g., in $g/m^2$). These data will be combined with the percent cover estimates to estimate overall macrophyte biomass for each reach of the water quality model.

**Riparian Vegetation Survey**

- Effective shade estimates of the aerial density of vegetation shading the stream, including:
  - Hemispherical images of the sky, overhanging vegetation, and topography at stream center. These photographs will be taken at each mainstem network site and at a few

reference reaches to verify existing riparian vegetation compared to aerial photos. The digital images will be processed and analyzed using the HemiView© software program.

  - Effective shade data at each site using a Solar Pathfinder™ that uses a polished, transparent, convex plastic dome to estimate shade from a given obstacle to the stream at different hours of the day and months of the year.

- Taking a few spot measurements of riparian vegetation heights within 150 ft of both banks, using a laser range/height finder. Detailed riparian data are not needed because of the availability of LiDAR and other spatial GIS data sets throughout the study area. These spot measurements will help ground-truth the vegetation heights determined from the LiDAR top-of-surface elevation model.

### 7.1.3 Parameters to be determined

The parameters to be determined via field data collection are discussed in Section 7.1.2. Additional parameters needed by the model will be calculated based on measured parameters (e.g., different forms of nitrogen and phosphorus).

For developing modeling scenarios and comparing observations with modeled output, we will also calculate the following: 7-DAD-Max temperatures; daily maximum, minimum, and average temperatures, daily maximum, minimum, and average DO; and 7Q10 flows.

## 7.2 Maps or diagram

A map of proposed monitoring locations are presented in Figure 7, section 7.1.1.

## 7.3 Assumptions underlying design

**Data Collection Assumptions**

- Data collected in 2015 in combination with other external data sources will be sufficient to develop continuous time-varying boundary conditions for the model.
- Data from at least one of the three synoptic surveys will capture the critical period during summer 2015.

**Modeling Assumptions**

- The QUAL2Kw model is one dimensional, which means that it assumes that the modeled sections of the Sammamish River are vertically and laterally well-mixed.
- Conservative assumptions that will be used in the development and application of the model will be sufficient to implicitly build a margin of safety into the model.

## 7.4 Relation to objectives and site characteristics

The study and field data collection is specifically designed to meet project objectives.

## 7.5 Characteristics of existing data

In 2003, King County conducted a summer diel temperature, pH, and DO study of the Sammamish River. The data from this effort provides us with some understanding of the temperature and DO dynamics in the river over the summer of 2003.

Maximum temperatures were found to be highest in late July (24 °C - 25°C), followed by June and August. Temperatures tend to get cooler moving downstream (Figure 9). This suggests that the warmer temperature of the water at the outlet of Lake Sammamish has a prolonged influence on temperature along the entire length of the Sammamish River.

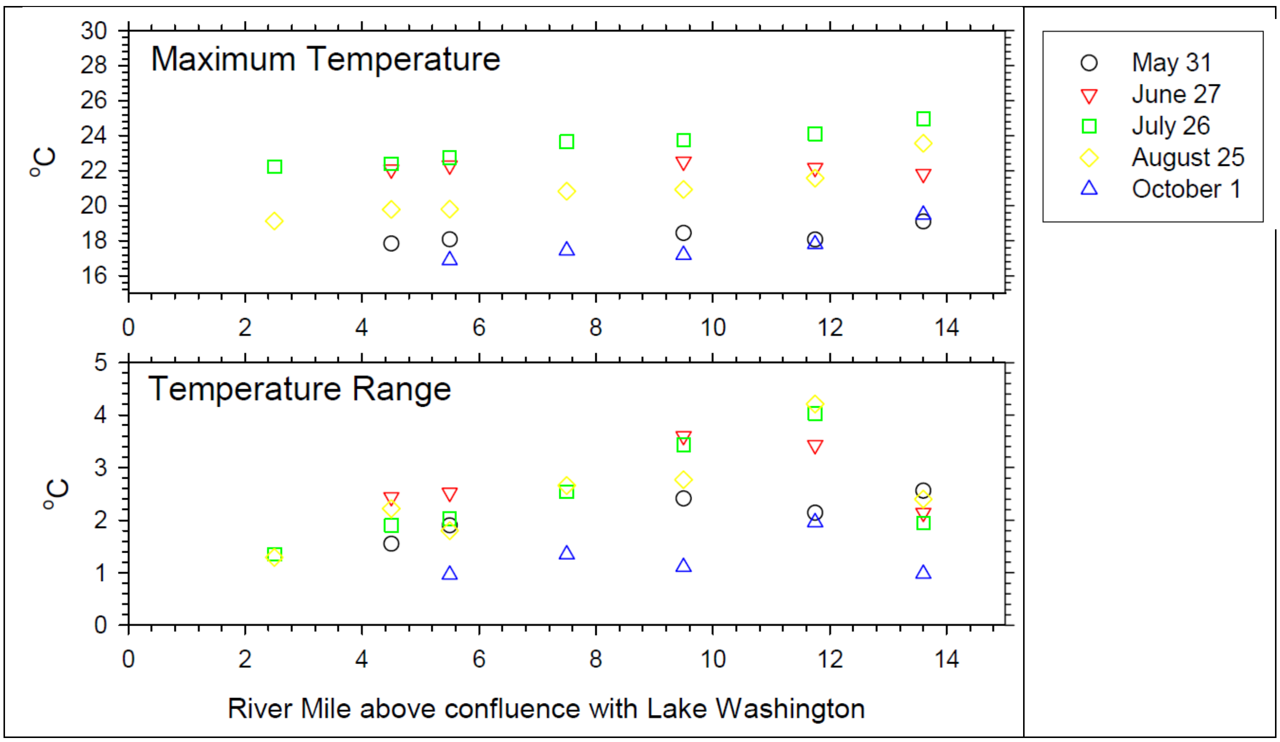



Figure 9. Longitudinal profile of Sammamish River maximum temperature and temperature range for selected days in 2003 (adapted from King County, 2005b).

Minimum DO concentrations were also at their lowest (approximately 6 mg/L) in late July and in the upper reaches of the river between RM 9 through 12. The lowest DO concentrations were found in the same reaches that have the largest daily DO range (Figure 10).

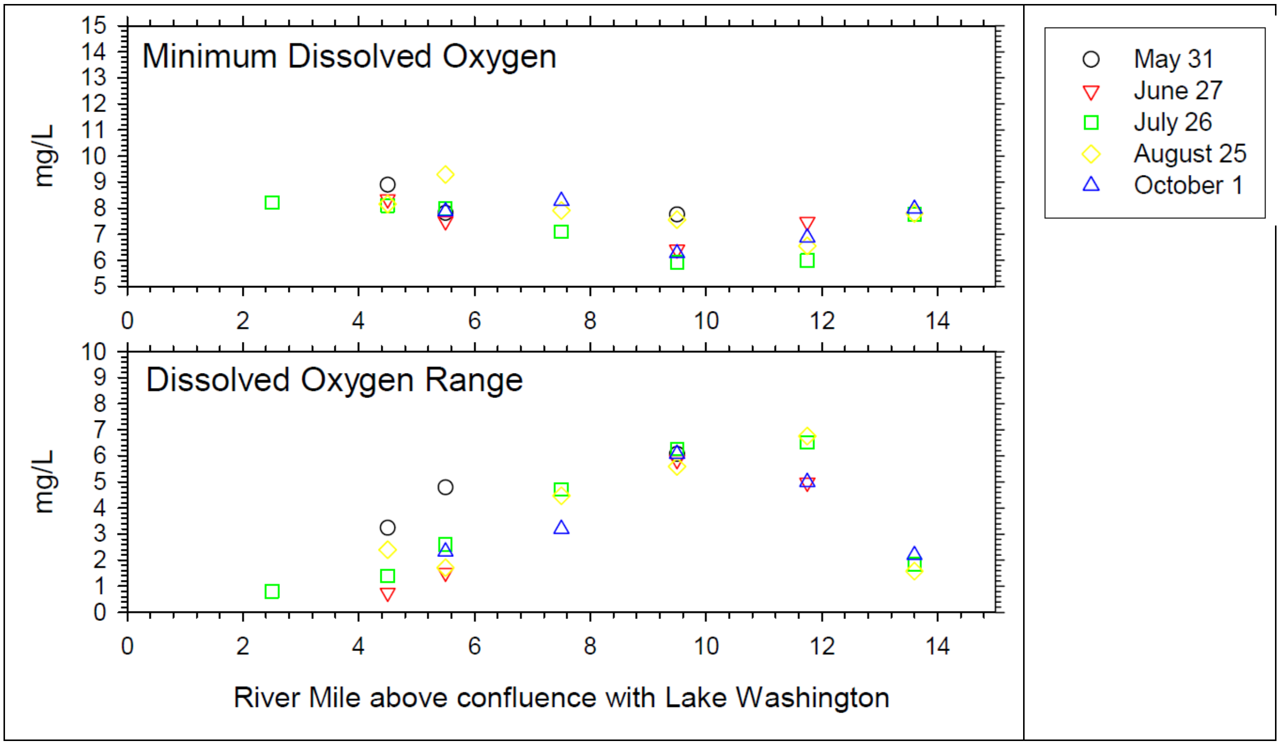



Figure 10. Longitudinal profile of Sammamish River minimum dissolved oxygen and dissolved oxygen range for selected days in 2003 (adapted from King County, 2005b).

Figure 11 shows temperature, DO concentration, and DO saturation data from continuous deployment of YSI meters at several locations along the Sammamish River during the last week of July 2003. The 116th St. location had the highest temperatures, the lowest DO concentrations, and the largest DO range of about 6 mg/L, indicating this reach to be highly productive. The DO range is smaller downstream at 145th St, at about 4 mg/L, and then decreases again further downstream with a range of about 1 mg/L at Blyth Park.

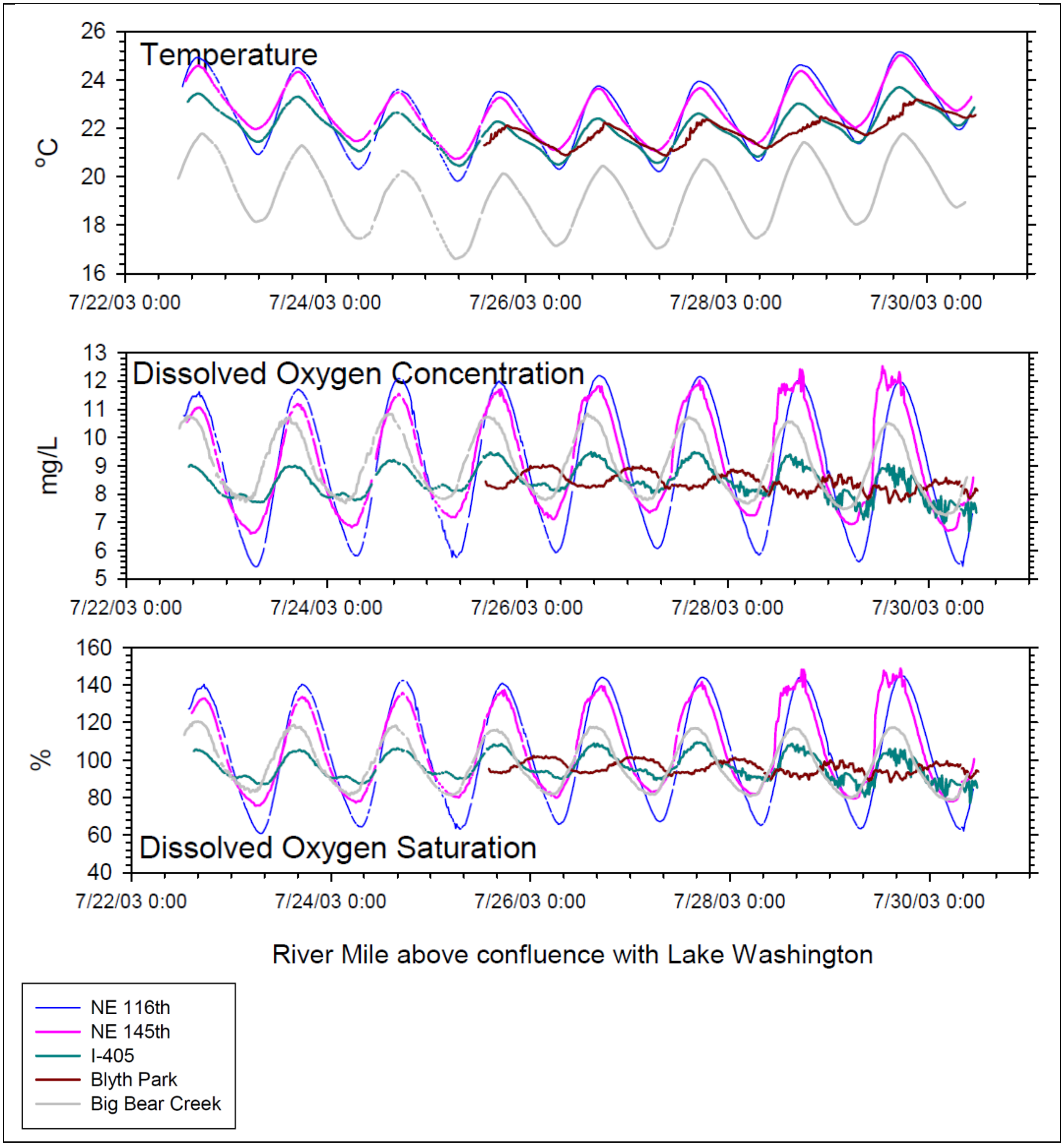



Figure 11. YSI deployment from 7/22/2003 through 7/30/2003 (adapted from King County, 2005b).

The pie charts in Figure 12 show annual average contributions of flow, total phosphorus, and total nitrogen to the Sammamish River from Lake Sammamish (weir), major tributaries, and other distributed inputs (i.e., groundwater and smaller tributaries) between 1995-2003. The Sammamish River gets almost half of its flow from Lake Sammamish. Bear Creek (referred to as "Big Bear" in the figure) and North Creek are the largest contributors of nutrients to the river, each contributing 20-30% of the total phosphorus and total nitrogen load to the Sammamish River.

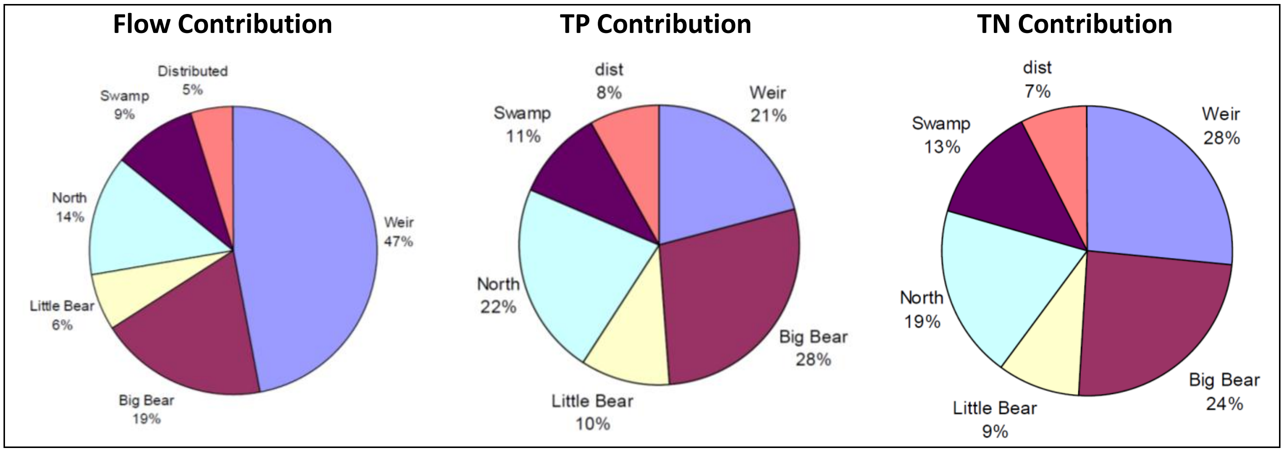



Figure 12. Estimated annual average inflow and total phosphorus (TP) and total nitrogen (TN) load contributions from the weir/Lake Sammamish, major tributaries, and distributed tributary inputs to the Sammamish River, 1995-2003 (adapted from King County, 2009).

Our current sampling plan is designed to adequately capture flow and nutrient contributions from Lake Sammamish, all major and minor tributaries, as well as groundwater. In King County (2009), "better quantification of ungauged surface and groundwater inputs, primarily of heat (i.e., temperature), dissolved solids (measured as specific conductance) and nutrients" was identified as a critical area to focus on in a future effort. The synoptic surveys planned for 2015 include measuring nutrient contributions from both groundwater (from piezometers) and ungauged surface inputs. This will help refine and corroborate the results from King County (2009), while providing more site-specific groundwater data. The longitudinal specific conductance profile will also aid in further understanding the influence of groundwater interactions along the river.

## 7.5.1 External data sources

**In addition to the data that will be collected during the 2015 field effort described above, data from other sources and organizations will also be used to fill any data gaps. These are described below.**

**Meteorology Data**

A number of data sources for meteorological data exist within the vicinity of the Sammamish River. The ones that may be used in this study are listed in Table 14.

Table 14. Available meteorological data near the Sammamish River.

| Data Source | Station | Air Temp | Dew Point | Relative Humidity | Cloud Cover | Wind Speed | Solar Radiation |
|---|---|---|---|---|---|---|---|
| AgWeatherNet | Seattle | X | X | X | | X | X |
| AgWeatherNet | Woodinville | X | X | X | | X | X |
| MesoWest | Seattle Boeing Field | X | X | X | | X | |
| MesoWest | Renton Municipal Airport | X | X | X | | X | |
| NOAA NCDC | Sea-Tac Airport | X | X | | X | X | |
| NOAA ISIS | Sand Point, Lake WA | | | | | | X |
| King County | S. Lake Sammamish Buoy | X | | X | | X | X |
| King County | Lake Washington Buoy | X | | X | | X | X |

NOAA: National Oceanic and Atmospheric Administration
NCDC: National Climatic Data Center
ISIS: Integrated Surface Irradiance Study

## Streamflow Data

King County has several current gages within the Sammamish River and tributaries that are part of their Hydrologic Monitoring Program (http://green2.kingcounty.gov/hydrology/default.aspx). Table 15 lists the King County and other gage data that might be used in our study (this list does not include all King County gages in the Sammamish Watershed). These gages will primarily be used to develop (1) continuous tributary boundary conditions for the model by developing relationships between the streamflow data that will be collected by Ecology in 2015 and continuous gage data and (2) low-flow statistics for critical conditions.

Table 15. Selected streamflow gages that might be used in this study.

| Organization/ Agency | Station ID | Station Description | Gage Type | Period of Record |
|---|---|---|---|---|
| **Mainstem** | | | | |
| King County | 51M | Sammamish River @ Marymoor Weir | Active – real time (stage + flow) | 2001 - present |
| King County | Samm_TZ_3 | Sammamish River above Bear Creek | Active (stage only) | 2011 - present |
| King County | Samm_TZ_4 | Sammamish River below Bear Creek | Active (stage only) | 2011 - present |
| King County | SAMM_90 | Sammamish River above 90th | Active (stage only) | 2011 - present |
| King County | 51T | Sammamish River at USGS gage 12125200 | Active (stage + flow) | 2005 - present |
| USGS | 12125200 | Sammamish River near Woodinville | Retired | 1965 - 2005 |
| King County | SAMM_124 | Sammamish River at 124th | Active (stage only) | 2012 - present |
| **Tributary** | | | | |
| King County | 02a | Bear Creek @ Union Hill RD | Active – real time | 1988 - present |
| King County | 30AN | Little Bear @ NE 195th | Active – real time | 2013 - present |
| Snohomish Co. | NCLD | North Creek @ County line | Retired | 1988 - 2011 |

### Water Quality Data

King County's Streams Monitoring Program (http://green2.kingcounty.gov/StreamsData/Default.aspx) conducts monthly monitoring at several locations within the Sammamish River watershed. Data from stations that might be used in our study are included in Table 16 below. All stations in this table include monitoring for the following parameters: temperature, DO, specific conductance, pH, nitrate-nitrite, ammonia, total nitrogen, orthophosphate, total phosphorus, turbidity, and TSS. These data may be used to compare with data collected by Ecology in 2015, to fill any data gaps between synoptic surveys, to develop model boundary initial conditions, or to analyze longer-term trends in nutrient concentrations.

Table 16. Selected King County water quality monitoring stations that might be used in this study.

| Station ID | Station Description | Period of Record |
|---|---|---|
| 0486 | Sammamish River @ Marymoor Park | 1976 – present |
| 0450CC | Sammamish River @ 145th | 2009 – present |
| 0484 | Bear Creek near mouth | 1972 – present |
| 0478 | Little Bear Creek near mouth | 1971 – present |
| 0474 | North Creek at mouth | 1974 – present |

The City of Redmond also conducts monthly monitoring for the following water quality parameters within our study area: temperature, pH, DO, conductivity, nitrite-nitrate, total phosphorus, turbidity, and TSS. Data from stations that might be used in our study are included in Table 17.

Table 17. Selected City of Redmond water quality monitoring stations that might be used in this study.

| Station ID | Station No. | Station Description | Years of Data |
|---|---|---|---|
| 5050WL | 27 | 505 @ W. Lk. Samm Pkwy | 2004-2005, 2012-2015 |
| PCOUT | 7 | Peters Creek Outfall | 2004-2006 |
| PCNE87 | 32 | Peters Creek @ 87$^{th}$ Street | 2004-2005 |
| PC151 | 134 | Peters Creek @ 151$^{st}$ | 2008-2015 |
| WLCKOL | 133 | Willows Creek @ Overlake Church | 2008-2015 |

**Groundwater Data**

Characterizing the quality of groundwater in the Sammamish River Valley has been an area of active study since the adoption of the Redmond-Bear Creek Valley Groundwater Management Area (GWMA) Plan in early 1999. Between May 2001 and October 2002, King County measured 16 wells in the Redmond-Bear Creek GWMA for a wide array of constituents including volatile and semi-volatile organic compounds, chlorinated herbicides, metals, as well as conventional and microbiological parameters (Golder, 2001; King County, 2004). Based on this sampling area, nitrate concentrations averaged 1.22 mg/L and ranged from <0.02 to 6.65 mg/L. Nitrate concentrations tended to be higher in shallow wells than deep wells, suggesting near surface sources such as septic systems or fertilizer application. Total phosphorus concentrations in these wells ranged from an estimated value of 0.0074 to 2.7 mg/L and averaged 0.29 m/L. Fecal coliform bacteria were not detected in any of the sampled wells.

In 2003-04, King County evaluated groundwater quality from 21 wells in three subareas of the Sammamish River Valley between Marymoor Park and Woodinville (King County, 2005a). Nitrate concentrations in water from these wells ranged from an estimated value of 0.02 to 16.2 mg/L and averaged value of 0.88 mg/L. Total phosphorous concentrations ranged from an estimated value of 0.004 mg/L to 1.1 mg/L and averaged 0.112 mg/L.

As part of its well-head protection program, the City of Redmond has sampled groundwater from a number of wells in the Sammamish River and lower Bear Creek Valleys (Parametrix, 1997). Groundwater samples collected from these wells between 2007 and 2014 had nitrate concentrations ranging from less than 0.05 to 4.9 mg/l and averaging 0.93 mg/L. Total phosphorus concentrations ranged from less than 0.005 to 0.828 mg/L and averaged 0.113 mg/L.

### 7.5.2. External data quality

All external data quality will be assessed before and during model development. The ability of these data to meet a level of quality sufficient to meet study objectives will be documented in the final report. Typical data assessment techniques for these sources include: exploratory data analysis, plotting and visually assessing quality, and comparison/correlation to other data sources collected at nearby locations. Table 18 presents what we know about whether the external data that we may use in this project was peer reviewed, followed a systematic project plan or QAPP, and used SOPs.

Table 18. Known and unknown data quality characteristics of external data.

| Organization/ Agency | Data Type | Data Peer Reviewed? | Systematic Planning/ QA/QC? | SOP? | Web link to data quality information (if available online) |
|---|---|---|---|---|---|
| AgWeatherNet (WA State University) | meteorological | unknown | YES | unknown | |
| MesoWest (University of Utah) | meteorological | unknown | YES | unknown | http://mesowest.utah.edu/html/help/qc.html |
| NOAA | meteorological | YES | YES | YES | http://www.cio.noaa.gov/services_programs/info_quality.html, http://www.cio.noaa.gov/services_programs/IQ_Guidelines_011812.html |
| USGS | streamflow/ stage height | YES | YES | YES | http://www.usgs.gov/info_qual/ http://www.usgs.gov/datamanagement/qaqc.php |
| King County | streamflow/ stage height | unknown | YES | YES | http://green2.kingcounty.gov/hydrology/About.aspx |
| King County | meteorological buoys | unknown | unknown | YES | https://green2.kingcounty.gov/lake-buoy/parameters.aspx |
| King County | water quality data | unknown | YES | YES | |
| King County | groundwater well data | unknown | YES | YES | |
| Snohomish County | streamflow/ stage height | unknown | unknown | unknown | |
| City of Redmond | water quality data | unknown | unknown | unknown | |

QA/QC: Quality Assurance/Quality Control
SOP: Standard Operation Procedures
WSU: Washington State University

The lack of data peer review, SOP, or QAPP does not necessarily mean that data collected by these entities are of poor quality. Section 14.1 describes, in more detail, how the quality and usability of external data from entities that do not have peer review, SOP, or QA/QC procedures in place will be assessed for this study.

# 8.0 Sampling Procedures

## 8.1 Field measurement and field sampling SOPs

Field sampling and measurement protocols will follow standard operating procedures (SOPs) developed by EAP for TMDL development (Table 19). Field measurements for pH, DO, specific conductance, and temperature will primarily be collected using a calibrated Hydrolab® sonde (Datasonde or Minisonde; Series 4 or 5).

Field staff will collect grab samples directly into pre-cleaned/sterilized containers supplied by Manchester Environmental Laboratory (MEL) and described in the MEL *Lab Users Manual* (MEL, 2008). Field staff will store samples for laboratory analysis on ice and deliver to MEL within 24 hours of collection via either the Ecology courier or direct drop-off after sampling. MEL follows standard analytical methods outlined in its users manual.

Table 19. Field sampling and measurement methods and protocols

| Parameter/Field Activity | Measurement/ Sample Type/Equipment | Field Protocol/SOP |
|---|---|---|
| Water Quality Grab Samples (see Table 9 for list) | Grab Samples | EAP015 (Joy, 2006) |
| Dissolved Oxygen | Winkler (displacement sample) | EAP023 (Ward and Mathieu, 2011) |
| DO, pH, Specific Conductance, Chl *a*, and Temperature | Hydrolab® multi-parameter sonde | EAP033 (Swanson, 2010) |
| Flow | Instantaneous | EAP024 (Sullivan, 2007); EAP055 (Shedd et al., 2013); EAP056 (Shedd, 2014), EAP058 (Burks, 2009) |
| Continuous Temperature | Thermistor/ Logger | EAP044 (Bilhimer et al., 2013) |
| Well Depth, Water Level | In situ | EAP052 (Marti, 2009); EAP061 (Sinclair and Pitz, 2010) |
| Periphyton Biomass | Biomass estimation | EAP085 (Mathieu et al., 2013) |
| Macrophyte Biomass | Biomass estimation | *Aquatic Plant Sampling Protocols* Publication No. 01-03-017 (Parsons, 2001) |
| Riparian Habitat Survey | Vegetation characteristics, substrate measurements, and shade data | EAP084 (Swanson, 2013); EAP045 (Stohr and Bilhimer, 2008) |
| Time of Travel | Hydrolab® multi-parameter sonde | EAP037 (Carroll, 2012) |
| Longitudinal Float/Profile | Hydrolab® multi-parameter sonde | EAP096 (Stuart and Mathieu, 2015) |

SOP: Standard Operating Procedure. All SOPs can be found here: http://www.ecy.wa.gov/programs/eap/quality.html (Ecology, 2014)

## 8.2 Containers, preservation methods, holding times

Table 20 lists the sample containers, measurement method, preservation, and holding times required to meet the goals and objectives of this project.

Table 20. Sample containers, preservation, and holding times.

| Parameter | Measurement Method | Container | Preservative | Holding Time |
|---|---|---|---|---|
| Alkalinity | SM 2320B | 500 mL poly –<br>NO Headspace | Cool to 0-6ºC;<br>Fill bottle *completely*; Don't agitate sample. | 14 days |
| Ammonia | SM4500NH3H | 125 mL clear poly | H2SO4 to pH<2 ;<br>Cool to 0-6°C. | 28 days |
| Biochemical Oxygen Demand 5-day (BOD5) | SM5210B | 1 gallon container | Cool to ≤6°C;<br>Keep in dark. | 48 hours |
| Chloride | EPA300.0 | 500 mL w/m poly bottle | Cool to ≤6°C. | 28 days |
| Chlorophyll a - water | SM100200H(3) | 500mL amber poly bottle | Cool to ≤6°C;<br>keep in dark. | 24 hr pre-filtration;<br>28 day post. |
| Chlorophyll a - plant tissue | SM100200H(3 | 1000 mL amber poly bottle | Cool to ≤6°C;<br>keep in dark. | 24 hr pre-filtration;<br>28 day post. |
| Ash-Free Dry Weight - plant tissue | SM10300C(5) | 1000 mL amber poly bottle | Cool to ≤6°C;<br>keep in dark. | 24 hr pre-filtration;<br>28 day post. |
| Total Carbon & Nitrogen - plant tissue | EPA440.0 | 1000 mL amber poly bottle | Cool slurry to ≤4°C;<br>keep in dark;<br>dry filter at 103-105°C & store in desiccator | 24 hr pre-filtration;<br>100 days post |
| Total Phosphorus - plant tissue | EPA200.7 | 1000 mL amber poly bottle | Cool to ≤6°C;<br>keep in dark. | 14 days pre-acidification;<br>6 months post |
| Dissolved Organic Carbon | SM5310B | 60 mL poly with: 0.45 um pore size filters[1] | Field filter with 0.45 um pore size filter;<br>1:1 HCl to pH<2;<br>Cool to 0-6°C. | 28 days |
| Nitrate/Nitrite | SM4500NO3I | 125 mL clear poly | H2SO4 to pH<2;<br>Cool to 0-6°C. | 28 days |
| Total Persulfate Nitrogen | SM4500NO3 B | 125 mL clear poly | H2SO4 to pH<2;<br>Cool to 0-6°C. | 28 days |
| Orthophosphate | SM4500PG | 125 mL amber poly w/ 0.45 um pore size filters[2] | Filter in field with 0.45 um pore size filter; Cool to 0-6°C. | 48 hours |
| Total Phosphorus | SM4500PF | 60 mL clear poly | 1:1 HCl to pH<2;<br>Cool to 0-6°C. | 28 days |

| Parameter | Measurement Method | Container | Preservative | Holding Time |
|---|---|---|---|---|
| Total Organic Carbon | SM5310B | 60 mL clear poly | 1:1 HCl to pH<2;<br>Cool to 70-6°C. | 28 days |
| Total Suspended Solids | SM2540D | 1000 mL clear poly bottle | Cool to ≤6°C | 7 days |
| Total Non-Volatile Suspended Solids | SM 540B & E | 1000 mL clear poly bottle | Cool to ≤6°C | 7 days |
| Turbidity | SM2130 | 500 mL w/m poly bottle | Cool to ≤6°C | 48 hours |

All samples taken from piezometers will be filtered.
[1] Whatman Puradisc TM 25 pp or equivalent, with a polypropylene media filter designed for aqueous and organic solutions containing high debris levels and for hard-to-filter solutions
[2] Whatman GD/X 25 mm or equivalent, with a cellulose acetate filter membrane. A glass microfiber prefilter may be used for "hard to filter" OP samples.

## 8.3 Invasive species evaluation

Field staff will follow EAP's SOP EAP070 on minimizing the spread of invasive species (Parsons et al., 2012). The Sammamish River study area is near an area of extreme concern for invasive species. Areas of extreme concern have or may have invasive species like New Zealand mud snails that are particularly hard to clean off equipment and are especially disruptive to native ecological communities. For more information, please see Ecology's website on minimizing the spread of invasive species at www.ecy.wa.gov/programs/eap/InvasiveSpecies/AIS-PublicVersion.html.

## 8.4 Equipment decontamination

After conducting field work, field staff will:

- Inspect and clean all equipment by removing any visible soil, vegetation, vertebrates, invertebrates, plants, algae or sediment. If necessary a scrub brush will be used then rinsed with clean water either from the site or brought for that purpose. The process will be continued until all equipment is clean.

- Drain all water in samplers or other equipment that may harbor water from the site. This step will take place before leaving the sampling site or at an interim site. If cleaning after leaving the sampling site, no debris will leave the equipment and potentially spread invasive species during transit or cleaning.

## 8.5 Sample ID

MEL will provide the field lead with work order numbers for all scheduled sampling dates. The work order number will be combined with a field ID number that is given by the field lead. This combination of work order number and field ID number constitute the sample ID. All sample IDs will be recorded in field logs and in an electronic spreadsheet for tracking purposes.

## 8.6 Chain-of-custody, if required

Once collected, samples will be stored in coolers in the sampling vehicle. When field staff are not in the sampling vehicle, it will be locked to maintain chain-of-custody. Upon return to the Operations Center, the chain-of-custody portion of the Laboratory Analysis Required (LARs) sheet will be filled out and the coolers will be placed in the walk-in cooler.

## 8.7 Field log requirements

A field log will be maintained by the field lead and used during each sampling event. The following information will be recorded during each visit to each site:

- Name and location of project
- Field staff
- Any changes or deviations from the QAPP
- Environmental conditions
- Date, time, sample ID, samples collected, identity of QC samples
- Field measurement results
- Pertinent observations
- Any problems with sampling

## 8.8 Other activities

Any field staff new to the type of sampling being conducted for this study will be trained by senior field staff or the project manager, following relevant Ecology SOPs. Any maintenance needed for the Hydrolab® Sondes will be performed by trained field staff, following Ecology's SOP EAP033 and manufacturer instructions and recommendations. Before sampling begins, staff will send MEL a schedule of sampling events. This will allow the lab to plan for the arrival of samples. All samples will be collected between Monday and Wednesday so that holding times will be met for all orthophosphate, turbidity, tissue, and Chlorophyll *a* samples. The lab will be notified immediately if there will be any deviations from the scheduled date of sampling. To ensure that the appropriate number and type of required sample containers are available, the field lead will work with the laboratory courier to develop a schedule for delivery of sampling containers.

# 9.0 Measurement Methods

## 9.1 Field procedures table/field analysis table

Table 21. Field procedures and measurement methods for surface water and groundwater (piezometer) sampling.

| Analyte | Sample Matrix | # of Samples | Expected Range of Results | Method/ Equipment Type | Method Detection Limit |
|---|---|---|---|---|---|
| Velocity | Water | 156 | <0.1 – 10 ft/s | Instantaneous Marsh McBirney, StreamPro ADCP, or OTT MF Pro | 0.01 ft/s |
| Water Level | Water | 12 | N/A | Calibrated E-tape | 0.01 foot |
| Water Temperature | Water | 411 | 1.0 - 35°C | Thermistor/ Logger and thermometer | N/A |
| Specific Conductance | Water | 411 | 50 – 500 umhos/cm | Hydrolab® sonde | 0.1 umhos |
| pH | Water | 411 | 6.0 – 9.0 s.u. | Hydrolab® sonde | N/A |
| Dissolved Oxygen | Water | 411 | 1.0 – 12 mg/L | Hydrolab® sonde and Winkler | 0.01 mg/L |

## 9.2 Lab procedures table

Table 22. Lab procedures and measurement methods for surface water and groundwater (piezometer) sampling.

| Analyte | Sample Matrix | # of field samples | Expected Range of Results | Method | Method Detection Limit |
|---|---|---|---|---|---|
| Alkalinity | Water | 72 | 30-90 mg/L (up to 500 mg/L for groundwater) | SM 2320B | 5 mg/L |
| Ammonia | Water | 411 | <0.01 – 30 mg/L | SM4500NH3H | 0.01 mg/L |
| Biochemical Oxygen Demand 5-day (BOD5) | Water | 36 | 2-210 mg/L | SM5210B | 2 mg/L |
| Chloride | Water | 72 | 0.3 – 100 mg/L | EPA300.0 | mg/L |
| Chlorophyll a- water | Water | 36 | 1 – 1000 $mg/m^2$ | SM10200H(3) | 0.05 ug/L |
| Chlorophyll a- plant tissue | Tissue | 12 | 1 – 1000 $mg/m^2$ | SM10200H(3) | 0.05 ug/L |
| Ash-Free Dry Weight- plant tissue | Tissue | 12 | 0.05 – 5 mg | SM10300C(5) | 0.05 mg |
| Total Carbon- plant tissue | Tissue | 12 | 1 – 20 % | EPA440.0 | 0.1% of DW |
| Total Nitrogen- plant tissue | Tissue | 12 | Not noted | EPA440.0 | 0.01% of DW |
| Total Phosphorus- plant tissue | Tissue | 12 | Not noted | EPA200.7 | 0.01% of DW |
| Dissolved Oxygen (Winkler) | Water | 411 | 1.0 – 12 mg/L | SM4500OC | 0.05 mg/L |
| Dissolved Organic Carbon | Water | 72 | <1 – 20 mg/L | SM5310B | 1 mg/L |
| Nitrate/Nitrite | Water | 411 | <0.01 – 30 mg/L | SM4500NO3I | 0.01 mg/L |
| Total Persulfate Nitrogen | Water | 411 | 0.5 – 50 mg/L | SM4500NO3 B | 0.025 mg/L |
| Orthophosphate | Water | 411 | 0.01 – 5.0 mg/L | SM4500PG | 0.003 mg/L |
| Total Phosphorus | Water | 411 | 0.01 – 10 mg/L | SM4500PF | 0.005 mg/L |
| Total Organic Carbon | Water | 36 | <1 – 20 mg/L | SM5310B | 1 mg/L |
| Total Suspended Solids | Water | 36 | <1 – 2000 mg/L | SM2540D | 1 mg/L |
| Total Non-Volatile Suspended Solids | Water | 36 | <1 – 2000 mg/L | SM 540B & E | 1mg/L |
| Turbidity | Water | 36 | 0-1000 NTU | SM2130 | 0.5 NTU |

## 9.3 Sample preparation method(s)

There are no additional sample preparations that have not already been described.

## 9.4 Special method requirements

There are no special methods that will be used for this study.

## 9.5 Lab(s) accredited for method(s)

All chemical analysis, except plant tissue total nitrogen and carbon content, will be performed at MEL, which is accredited for all methods. The plant samples for measurement of total nitrogen and carbon content will be sent to a contract lab that is accredited for the method.

# 10.0 Quality Control (QC) Procedures

## 10.1 Table of field and lab QC required

Table 23. Table of field and lab quality control requirements.

| Parameter | Field Blanks | Field Replicates | Lab Check Standard | Lab Method Blanks | Lab Replicates | Matrix Spikes |
|---|---|---|---|---|---|---|
| **Field Procedures** | | | | | | |
| Velocity | n/a | 10% | n/a | n/a | n/a | n/a |
| Water Temperature | n/a | 10% | n/a | n/a | n/a | n/a |
| Specific Conductance | n/a | 10% | n/a | n/a | n/a | n/a |
| pH | n/a | 10% | n/a | n/a | n/a | n/a |
| Dissolved Oxygen | n/a | 10% | n/a | n/a | n/a | n/a |
| **Lab Procedures** | | | | | | |
| Alkalinity | 6/project | 10% | 1/run | 1/run | 1/20 samples | n/a |
| Ammonia | 8/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Biochemical Oxygen Demand 5-day (BOD5) | 3/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Chloride | 6/project | 10% | 1/run | 1/run | 1/20 samples | n/a |
| Chlorophyll a - water | 3/project | 10% | n/a | n/a | 1/20 samples | n/a |
| Chlorophyll a - periphyton | n/a | 10% | n/a | n/a | 1/20 samples | n/a |
| Chlorophyll a - plant tissue | n/a | 10% | n/a | n/a | 1/20 samples | n/a |
| Ash-Free Dry Weight - plant tissue | n/a | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Carbon - plant tissue | n/a | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Nitrogen - plant tissue | n/a | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Phosphorus - plant tissue | n/a | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Dissolved Oxygen (Winkler) | 6/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Dissolved Organic Carbon | 6/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Nitrate/Nitrite | 8/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Persulfate Nitrogen | 8/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |

| Parameter | Field Blanks | Field Replicates | Lab Check Standard | Lab Method Blanks | Lab Replicates | Matrix Spikes |
|---|---|---|---|---|---|---|
| Orthophosphate | 8/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Phosphorus | 8/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Organic Carbon | 3/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |
| Total Suspended Solids | 3/project | 10% | 1/run | 1/run | 1/20 samples | n/a |
| Total Non-Volatile Suspended Solids | 3/project | 10% | 1/run | 1/run | 1/20 samples | n/a |
| Turbidity | 3/project | 10% | 1/run | 1/run | 1/20 samples | 1/20 samples |

## 10.2 Corrective action processes

QC results may indicate problems with data during the course of the project. The lab will follow prescribed procedures to resolve the problems. Options for corrective actions might include:

- Retrieving missing information.
- Re-calibrating the measurement system.
- Re-analyzing samples within holding time requirements.
- Modifying the analytical procedures.
- Requesting additional sample collection or additional field measurements.
- Qualifying results.

# 11.0 Data Management Procedures

## 11.1 Data recording/reporting requirements

Staff will record all field data in a field notebook or an equivalent electronic collection platform. Before leaving each site, staff will check field notebooks or electronic data forms for missing or improbable measurements. Staff will enter field-generated data into Microsoft (MS) Excel® spreadsheets as soon as practical after they return from the field. If data were collected electronically, data will be backed up on Ecology servers when staff return from the field. The field assistant will check data entry against the field notebook data for errors and omissions. The field assistant will notify the field lead or project manager of missing or unusual data.

Lab results will be checked for missing and/or improbable data. MEL will send data through Ecology's Laboratory Information Management System (LIMS). The field lead will check MEL's data for omissions against the "Request for Analysis" forms. The project manager will review data requiring additional qualifiers.

## 11.2 Laboratory data package requirements

Laboratory-generated data reduction, review, and reporting will follow the procedures outlined in the MEL *Lab Users Manual* (MEL, 2008). Variability in lab duplicates will also be quantified, using the procedures outlined in the manual. Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory QA/QC results will be sent to the project manager for each set of samples.

## 11.3 Electronic transfer requirements

MEL will provide all data electronically to the project manager through the LIMS to EIM data feed. Protocol is already in place for how and what MEL transfers to EIM through LIMS.

## 11.4 Acceptance criteria for existing data

See Section 6.2 and 7.5.

## 11.5 EIM/STORET data upload procedures

All field measurement data will be entered into EIM, following all existing Ecology business rules and the EIM User's Manual for loading, data quality checks, and editing.

# 12.0 Audits and Reports

## 12.1 Number, frequency, type, and schedule of audits

No audits are planned for this study. However, there could be a field consistency review by another experienced EAP field staff during the period of this project. The aim of this review is to improve field work consistency, improve adherence to SOPs, provide a forum for sharing innovations, and strengthen our data QA program.

## 12.2 Responsible personnel

If any field audits are conducted, they will be done by experienced EAP field staff who will observe for consistency in field data collection and adherence to SOPs.

## 12.3 Frequency and distribution of report

The results of the field data collection, data quality assessment, data analysis, and modeling will eventually be presented in a TMDL report. The final report will be published according to the project schedule in Section 5.4. No interim reports are expected, though progress will be tracked using EAP Activity Tracker.

## 12.4 Responsibility for reports

- The project manager/principal investigator (still to be determined) will author the technical sections of the final TMDL report.
- Kirk Sinclair will contribute to the groundwater sections of the final TMDL report.
- Ralph Svrjcek will author the TMDL Implementation Plan for the final TMDL report.

# 13.0 Data Verification

## 13.1 Field data verification, requirements, and responsibilities

The field lead will verify initial field data before leaving each site. This process involves checking the data sheet for omissions or outliers. If measurement data are missing or a measurement is determined to be an outlier, the measurement will be repeated.

Before entering any data into EIM or using it for analysis or modeling, the field lead will compare all field data to determine compliance with MQOs. The field lead will note values that are out of compliance with the MQOs and will notify the project manager. At the conclusion of the study, the field lead will compile a summary of all out of compliance values (if any) and provide it to the project manager for a decision on usability.

## 13.2 Lab data verification

MEL staff will perform the laboratory verification following standard laboratory practices. After the laboratory verification, the field lead will perform a secondary verification of each data package. This secondary verification will entail a detailed review of all parts of the laboratory data package with special attention to laboratory QC results. The field lead will bring any discovered issues to the project manager for resolution.

## 13.3 Validation requirements, if necessary

All laboratory data that have been verified by MEL staff will be validated by a project staff member. Field measurement data that was verified by a project staff member will be validated by a different staff member.

After data entry and data verification tasks are completed, all field, laboratory, and flow data will be entered into the EIM system. EIM data will be independently reviewed by another field assistant for errors at an initial 10% frequency. If significant entry errors are discovered, a more intensive review will be undertaken.

# 14.0 Data Quality (Usability) Assessment

## 14.1 Process for determining whether project objectives have been met

### 14.1.1 Study data usability

After all laboratory and field data are verified, the field lead or project manager will thoroughly examine the data package, using statistical techniques and professional judgment, to determine if MQOs for completeness, representativeness, and comparability have been met. If the criteria have not been met (e.g., if the %RSD for sample duplicates exceeds the MQO), the project manager will decide if affected data should be qualified or whether it should be rejected. The project manager will decide how any qualified data will be used in the technical analysis, and will document this in the final TMDL report. The final report will assess all data and analysis results and provide a final determination regarding project goals and objectives.

### 14.1.2 External data usability

Any water quality data from outside this study that is used in the TMDL analysis must meet the requirements of the agency's credible data policy: (www.ecy.wa.gov/programs/wq/qa/wqp01-11-ch2_final090506.pdf). This requirement does not apply to non-quality data such as flow or meteorological data.

Some of the data sources have their own data assessment processes in place, and data that does not meet established quality criteria are often flagged with appropriate data qualifiers. Qualified data will be used with caution or discarded based on professional judgment.

The usability of data from external sources that do not have readily available information on whether the data were peer reviewed or followed QA/QC procedures or SOPs will also be assessed by exploratory data analysis, plotting and visually assessing quality, and comparison/correlation to other data sources collected at nearby locations.

The final report will include (1) an assessment of data quality for any outside data used for TMDL analysis and (2) certification that the data meets a level of quality acceptable for use in TMDL development. The data quality assessment will include one or more of the following elements:

- Reference to a peer-reviewed and published QAPP.
- Demonstration that the collected data yielded results of comparable quality to the study (based on data quality objectives and requirements in this QAPP).
- Documentation that the objectives of the QAPP or equivalent quality assurance procedures were met and that the data are suitable for water quality-based actions. The assessment of

the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at time of sampling.

- Documentation of the planning, implementation, and assessment strategies used to collect the information, including:
    - Documentation of the original intended use of the gathered information (e.g., chemical/physical data for TMDL analyses)
    - Description of the limitations on use of the data (e.g., these measurements only represent storm-event conditions).
    - Data sets must be complete, that is, not censored to include only part of the data results from the project.

## 14.2 Data analysis and presentation methods

Data will be analyzed before they are used for modeling, and any relevant and interesting data analysis will be presented in the final TMDL report using a combination of tables and plots of various kinds, such as time series plots, histograms, and box plots.

The technical analysis will also include the evaluation of model quality to assess model uncertainty and ensure that the achievement of project goals is appropriately supported by the quality of the model results. Model results will also be presented in the final TMDL report. A combination of tables and plots of various kinds, such as time series plots, histograms, and box plots will be used and will include comparisons of observed data and modeled results.

## 14.3 Treatment of non-detects

Any non-detects will be included in the study analysis. Depending on the circumstances and the parameter, non-detects will be treated in one of two ways:

- Non-detect may be replaced with half the detection limit
- Non-detect may be treated as an indeterminate value between zero and the detection limit. For example when comparing model predictions to observed data where the observed data is a non-detect, any predicted value less than the detection limit would be considered an exact match.

## 14.4 Sampling design evaluation

The sampling design described in this QAPP is based on the data needs of the modeling and analytical tools that will be used to complete the TMDL analysis. These primarily include input and calibration data to feed the QUAL2Kw water quality model as well as data needed for the Shade model and RMA modeling tool.

The combination of data collected during this project and existing data is expected to be sufficient for the selected modeling tools. The process of using the data to develop and calibrate the model(s) will automatically involve the evaluation of the sampling design. It is expected that these modeling tools, used with the data collected during this project and existing data, will be sufficient to meet project goals and objectives.

## 14.5 Documentation of assessment

In the final TMDL report, the project manager will include a summary of the data quality assessment and model quality evaluation findings. This summary is usually included in the data quality section of reports.

# 15.0 References

Bilhimer. D., A. Stohr, and S. Brock. 2013. Standard Operating Procedure for Continuous Temperature Monitoring of Fresh Water Rivers and Streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature. Version 3.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP044. www.ecy.wa.gov/programs/eap/quality.html

Booth, D.B. 1994. Glaciofluvial infilling and scour of the Puget Lowland, Washington, during ice-sheet glaciation. *Geology* 22:695-698.

Burks, T.W. 2009. Standard Operating Procedure for the Operation of SonTek® FlowTracker® Handheld ADV®. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP058. www.ecy.wa.gov/programs/eap/quality.html

Carey, B. 2003. Groundwater/surface water interactions in the upper Sammamish River: A preliminary analysis. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-015.

Carroll, J. 2012. Standard Operating Procedure for Time-of-Travel Studies in Freshwater using a Dye Tracer. Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP037. www.ecy.wa.gov/programs/eap/quality.html

Casola, J.H., J.E. Kay, A.K. Snover, R.A. Norheim, L.C. Whitely Binder, and the Climate Impacts Group. 2005. Climate Impacts on Washington's Hydropower, Water Supply, Forests, Fish, and Agriculture. A report prepared for King County (Washington) by the Climate Impacts Group (Center for Science in the Earth System, Joint Institute for the Study of the Atmosphere and Ocean, University of Washington, Seattle).

Chapra, S.C. 1997. Surface Water-Quality Modeling. McGraw-Hill, New York, N.Y.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter. 1998a. Stream temperature simulation of forested riparian areas: I. watershed-scale model development. Journal of Environmental Engineering. April 1998. pp. 304-315.

Chen, Y.D., R.F. Carsel, S.C. McCutcheon, and W.L. Nutter. 1998b. Stream temperature simulation of forested riparian areas: II. model application. Journal of Environmental Engineering. April 1998. pp. 316-328.

Chrzastowski, M. 1983. Historical changes to Lake Washington and route of the Lake Washington Ship Canal, King County, WA. U.S. Geological Survey, Water Resources Investigation Open File Report 81-1182.

Collins, B.D., D.R. Montgomery, and A.J. Sheikh. 2003. Reconstructing the Historical Riverine Landscape of the Puget Lowland. In: Montgomery, D. R., Bolton, S., Booth, D. B., and Wall, L., (editors) Restoration of Puget Sound Rivers, University of Washington Press, Seattle and London, pp. 79-128.

Ecology. 2003. Shade.xls - a tool for estimating shade from riparian vegetation. Washington State Department of Ecology, Olympia, WA. http://www.ecy.wa.gov/programs/eap/models.html

Ecology. 2014. Standard Operating Procedures. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA http://www.ecy.wa.gov/programs/eap/quality.html

FEMA (Federal Emergency Management Agency). 1978. Flood Insurance Study, King County, Washington and Incorporated Areas.

Fresh, K.L., E. Warner, R. Tabor, and D. Houck. 1999. Migratory Behavior of Adult Chinook Salmon Spawning in the Lake Washington Watershed in 1998 as Determined with Ultrasonic Telemetry. Draft Progress Report. Copy received from Nancy Rapin (Muckleshoot Indian Tribe) on June 12, 2015.

Golder Associates Inc. 2001, Sampling and Analysis Plan for Redmond-bear Creek Valley Groundwater Management Area. Prepared for King County Department of Natural Resources, Seattle, Washington. 27 p.

Hallock, D. 2009. Quality Assurance Monitoring Plan: Continuous Monitoring for Oxygen, Temperature, pH, and Conductivity in Statewide Rivers and Streams. Washington State Department of Ecology, Olympia, WA. Publication No. 09-03-122. https://fortress.wa.gov/ecy/publications/SummaryPages/0903122.html

Hamlet A.F. and D.P. Lettenmaier. 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. Journal of the American Water Resources Association, 35(6):1597-1623.

Herrera Environmental Consultants. 2013. Project Report: Sammamish River Brazilian Elodea Removal. Prepared for King County River and Floodplain Section Water and Land Resources Division, Seattle, WA.

Hobson A.J., B.T. Neilson, N. von Stackelberg, M. Shypryt, J, Ostermiller, G. Pelletier and S.C. Chapra. 2014. Development of a Minimalistic Data Collection Strategy for QUAL2Kw. Journal of Water Resources Planning and Management. 04014096(13).

Joy, J. 2006. Standard Operating Procedure for Grab sampling – Fresh water, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP015. www.ecy.wa.gov/programs/eap/quality.html

Kerwin, J. 2001. Salmon and Steelhead Habitat Limiting Factors Report for the Cedar – Sammamish Basin (Water Resource Inventory Area 8). Washington Conservation Commission. Olympia, WA. http://www.pugetsoundnearshore.org/supporting_documents/WRIA_8_LFR_FINAL.pdf

Kilpatrick, F.A. and J.F. Wilson Jr. 1982. Measurement of Time-Of-Travel in Streams by Dye Tracing. U.S. Geological Survey. Techniques of Water-Resources Investigations, Book 3, Chapter A9.

King County. 1995. Lake Sammamish total phosphorus model. Prepared by W.W. Perkins for METRO-King County Surface Water Management.

King County. 2004. Ambient Groundwater Monitoring, 2001-2004 results. Prepared by Anchor Environmental and King County Dept of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington. 21 p.

King County. 2005a. Sammamish River Valley Groundwater Study 2003-2004 data report. Prepared by King County Department of Natural Resources and Parks, Water and Land Resources Division. Seattle, Washington.

King County. 2005b. Sammamish River Diel pH and Dissolved Oxygen Study. Prepared by Curtis DeGasperi, Water and Land Resources Division. Seattle, Washington.

King County. 2009. Development of a Laterally Averaged 2-Dimensional Water Quality Model of the Sammamish River (CE-QUAL-W2 Version 3.2). Prepared by Curtis DeGasperi, Water and Land Resources Division, Seattle, Washington.

King County. 2014. Lake Sammamish Water Quality Response to Land Use Change. Prepared by Dr. Eugene B. Welch, Emeritus Professor, University of Washington, and Consulting Limnologist, and Debra Bouchard, Science and Technical Support Section, King County Water and Land Resources Division, Seattle, WA.

Liesch, B.A., C.E. Price, and K.L. Walters. 1963. Geology and ground-water resources of Northwestern King County, Washington. U.S. Geological Survey, Ground-water Branch, Water Supply Bulletin No. 20.

Lombard, S. and C. Kirchmer. 2004. Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-030. https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html

Marti, P.B. 2009. Standard Operating Procedure for Manual Well-Depth and Depth-to-Water Measurements. Washington State Department of Ecology, Olympia, WA. SOP Number EAP052. www.ecy.wa.gov/programs/eap/quality.html

Martz, M., M. Valentine, and C. Fitzgerald. 1999. Sammamish River temperature study, 1998. Results from temperature modeling and literature review of temperature effects on fish. U.S. Army Corps of Engineers, Seattle District.

Mathieu, N. 2006. Replicate Precision for Twelve Total Maximum Daily Load (TMDL) Studies and Recommendations for Precision Measurement Quality Objectives for Water Quality Parameters. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-044. https://fortress.wa.gov/ecy/publications/SummaryPages/0603044.html

Mathieu, N., S. Collyard, and T. Mohamedali. 2011. Standard Operating Procedure for Collection of Periphyton Samples for TMDL studies. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP085. www.ecy.wa.gov/programs/eap/quality.html

MEL. 2008. Manchester Environmental Laboratory Lab Users Manual, Ninth Edition. Manchester Environmental Laboratory, Washington State Department of Ecology, Manchester, WA.

Mote, P.W., E. Salathé, and C. Peacock. 2005. Scenarios of future climate for the Pacific Northwest, Climate Impacts Group, University of Washington, Seattle, WA. 13 pp.

NHC (Northwest Hydraulic Consultants). 2010. Floodplain Mapping Study for the Sammamish River. Prepared for King County River and Floodplain Management Section, Water and Land Resources Division, Department of Natural Resources and Parks. NHC Project #21683. Seattle, WA.

Parametrix, Inc. 1997. Wellhead Protection Report, City of Redmond, Department of Public Works. https://fortress.wa.gov/ecy/publications/publications/1203212.pdf

Parsons, J., 2001. Aquatic Plan Sampling Protocols. Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-017. https://fortress.wa.gov/ecy/publications/publications/0103017.pdf

Parsons J., D. Hallock, K. Seiders, B. Ward, C. Coffin, E. Newell, C. Deligeannis, K. Welch. 2012. Standard Operating Procedure to Minimize the Spread of Invasive Species. Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP070. www.ecy.wa.gov/programs/eap/quality.html

Pelletier, G., S. Chapra, and H. Tao, 2006. QUAL2Kw – A framework for modeling water quality in streams and rivers using a genetic algorithm for calibration. Environmental Modelling and Software 21 (2006) 419-425.

Pelletier, G. and S. Chapra. 2008. QUAL2Kw theory and documentation (version 5.1) A modeling framework for simulating river and stream water quality. Washington State Department of Ecology, Olympia, WA.

Pelletier, G. 2013. RMA.xls – River metabolism analyzer for continuous monitoring data. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models

R2 Resource Consultants. 1999. Habitat Survey, Sammamish River, King County, Washington, 1999 Data Report--Final, prepared for U.S. Army Corps of Engineers, Seattle District.

R2 Resource Consultants. 2010. Assessment of Summer Temperatures and Feasibility and Design of Improved Adult Chinook Salmon Thermal Refuge Habitat in the Sammamish River. Prepared for Muckleshoot India Tribe Fisheries Division.

R2 Resource Consultants. 2013. On the Feasibility of Constructing Suitable Juvenile Salmonid Off-Channel Habitat on the Sammamish River, City of Bothell. Prepared for City of Bothell, WA in collaboration with Pacific Groundwater Group, Seattle, WA.

Sanderson, T. and P. Pickett. 2014. A Synopsis of Model Quality from the Department of Ecology's Total Maximum Daily Load Technical Studies. Publication No. 14-03-042, Washington State Department of Ecology, Olympia, WA. https://fortress.wa.gov/ecy/publications/SummaryPages/1403042.html

Shedd, J.R., C. Springer, and C.J. Clishe. 2013. Standard Operating Procedure of the Teledyne RD Instruments Stream-Pro Acoustic Doppler Current Profiler. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP055. www.ecy.wa.gov/programs/eap/quality.html

Shedd, J.R. 2014. Standard Operating Procedure for Measuring and Calculating Stream Discharge. Version 1.2. Washington State Department of Ecology, Olympia, WA. SOP Number EAP056. www.ecy.wa.gov/programs/eap/quality.html

Sinclair, K. and C. Pitz. 2010. Standard Operating Procedure for installing, measuring, and decommissioning hand-driven in-water piezometers. Version 1.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP061. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_061Piezometers_v1_1.pdf

Stickney, A.E. and L. McDonald. 1977. Squak Slough 1870-1920. Early Days on the Sammamish River Woodinville-Bothell-Kenmore. Evergreen Printing Co., Seattle, WA.

Stohr, A. and D. Bilhimer. 2008. Standard Operating Procedure for hemispherical digital photography field surveys conducted as part of temperature TMDL or Forests and Fish Unit technical study. Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP045. www.ecy.wa.gov/programs/eap/quality.html

Stuart, T. and N. Mathieu. 2015. Standard Operating Procedure for Collection of Longitudinal Stream Depth Profiles. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP096. www.ecy.wa.gov/programs/eap/quality.html

Sullivan, L. 2007. Standard Operating Procedure for Estimating Streamflow, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP024. www.ecy.wa.gov/programs/eap/quality.html

Swanson, T. 2010. Standard Operating Procedure for Hydrolab® DataSonde® and MiniSonde® Multiprobes, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP033. www.ecy.wa.gov/programs/eap/quality.html

Swanson, T. 2013. Standard Operating Procedure for Conducting Riparian Vegetation and Stream Channel Surveys in Wadeable Streams for Temperature TMDL studies. Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP084. www.ecy.wa.gov/programs/eap/quality.html

U.S. Army Corps of Engineers. 1962. Channel Improvement: Sammamish River, Washington, General Design Memorandum. U.S. Army Engineer District, Seattle, WA.

U.S. Army Corps of Engineers. 2010. HEC-RAS River Analysis System User's Manual. Version 4.1. Davis, CA. http://www.hec.usace.army.mil/software/hec-ras/documentation/HEC-RAS_4.1_Users_Manual.pdf

WAC 173-201A. Water Quality Standards for Surface Waters in the State of Washington Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/laws-rules/ecywac.html

Wagner, R.J., R.W. Boulger, Jr., C.J. Oblinger, and B.A. Smith. 2006. Guidelines and standard procedures for continuous water-quality monitors: station operation, record computation, and data reporting. U.S. Geological Survey Techniques and Methods 1-D3.

Ward W.J. and N. Mathieu. 2011. Standard Operating Procedure for the Collection and Analysis of Dissolved Oxygen (Winkler Method). Version 2.3. Washington State Department of Ecology, Olympia, WA. SOP Number EAP023. www.ecy.wa.gov/programs/eap/quality.html

Western Region Climate Center (WRCC). 2015. Washington Climate Summaries for Seattle Sail Sand Pt., WSFO, Washington (457470). http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?wa7470

# 16.0 Figures

The figures in this QAPP are inserted after they are first mentioned in the text.

# 17.0 Tables

The tables in this QAPP are inserted after they are first mentioned in the text.

# 18.0 Appendix. Glossaries, Acronyms, and Abbreviations

## Glossary of General Terms

**Ambient:** Background or away from point sources of contamination. Surrounding environmental condition.

**Baseflow:** The component of total streamflow that originates from direct groundwater discharges to a stream.

**Char:** Fish of genus *Salvelinus* distinguished from trout and salmon by the absence of teeth in the roof of the mouth, presence of light colored spots on a dark background, absence of spots on the dorsal fin, small scales, and differences in the structure of their skeleton. (Trout and salmon have dark spots on a lighter background.)

**Clean Water Act:** A federal act passed in 1972 that contains provisions to restore and maintain the quality of the nation's waters. Section 303(d) of the Clean Water Act establishes the TMDL program.

**Conductivity:** A measure of water's ability to conduct an electrical current. Conductivity is related to the concentration and charge of dissolved ions in water.

**Critical condition:** When the physical, chemical, and biological characteristics of the receiving water environment interact with the effluent to produce the greatest potential adverse impact on aquatic biota and existing or designated water uses. For steady-state discharges to riverine systems, the critical condition may be assumed to be equal to the 7Q10 flow event unless determined otherwise by the department.

**Designated uses:** Those uses specified in Chapter 173-201A WAC (Water Quality Standards for Surface Waters of the State of Washington) for each water body or segment, regardless of whether or not the uses are currently attained.

**Diel:** Of, or pertaining to, a 24-hour period.

**Dissolved oxygen (DO):** A measure of the amount of oxygen dissolved in water.

**Diurnal:** Of, or pertaining to, a day or each day; daily. (1) Occurring during the daytime only, as different from nocturnal or crepuscular, or (2) Daily; related to actions which are completed in the course of a calendar day, and which typically recur every calendar day (e.g., diurnal temperature rises during the day, and falls during the night).

**Effective shade:** The fraction of incoming solar shortwave radiation that is blocked from reaching the surface of a stream or other defined area.

**Effluent:** An outflowing of water from a natural body of water or from a human-made structure. For example, the treated outflow from a wastewater treatment plant.

**Hyporheic:** The area beneath and adjacent to a stream where surface water and groundwater intermix.

**Load allocation:** The portion of a receiving water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

**Loading capacity:** The greatest amount of a substance that a water body can receive and still meet water quality standards.

**Margin of safety:** Required component of TMDLs that accounts for uncertainty about the relationship between pollutant loads and quality of the receiving water body.

**Municipal separate storm sewer systems (MS4):** A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade channels, or storm drains): (1) owned or operated by a state, city, town, borough, county, parish, district, association, or other public body having jurisdiction over disposal of wastes, stormwater, or other wastes and (2) designed or used for collecting or conveying stormwater; (3) which is not a combined sewer; and (4) which is not part of a Publicly Owned Treatment Works (POTW) as defined in the Code of Federal Regulations at 40 CFR 122.2.

**National Pollutant Discharge Elimination System (NPDES):** National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, large factories, and other facilities that use, process, and discharge water back into lakes, streams, rivers, bays, and oceans.

**Nonpoint source:** Pollution that enters any waters of the state from any dispersed land-based or water-based activities, including but not limited to atmospheric deposition, surface-water runoff from agricultural lands, urban areas, or forest lands, subsurface or underground sources, or discharges from boats or marine vessels not otherwise regulated under the NPDES program. Generally, any unconfined and diffuse source of contamination. Legally, any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act.

**Nutrient:** Substance such as carbon, nitrogen, and phosphorus used by organisms to live and grow. Too many nutrients in the water can promote algal blooms and rob the water of oxygen vital to aquatic organisms.

**pH:** A measure of the acidity or alkalinity of water. A low pH value (0 to 7) indicates that an acidic condition is present, while a high pH (7 to 14) indicates a basic or alkaline condition. A pH of 7 is considered to be neutral. Since the pH scale is logarithmic, a water sample with a pH of 8 is ten times more basic than one with a pH of 7.

**Phase I stormwater permit:** The first phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to medium and large municipal separate storm sewer systems (MS4s) and construction sites of five or more acres.

**Phase II stormwater permit:** The second phase of stormwater regulation required under the federal Clean Water Act. The permit is issued to smaller municipal separate storm sewer systems (MS4s) and construction sites over one acre.

**Point source:** Source of pollution that discharges at a specific location from pipes, outfalls, and conveyance channels to a surface water. Examples of point source discharges include municipal wastewater treatment plants, municipal stormwater systems, industrial waste treatment facilities, and construction sites where more than 5 acres of land have been cleared.

**Pollution:** Contamination or other alteration of the physical, chemical, or biological properties of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or are likely to, create a nuisance or render such waters harmful, detrimental, or injurious to (1) public health, safety, or welfare, or (2) domestic, commercial, industrial, agricultural, recreational, or other legitimate beneficial uses, or (3) livestock, wild animals, birds, fish, or other aquatic life.

**Reach:** A specific portion or segment of a stream.

**Riparian:** Relating to the banks along a natural course of water.

**Salmonid:** Fish that belong to the family *Salmonidae*. Any species of salmon, trout, or char.

**Sediment:** Soil and organic matter that is covered with water (for example, river or lake bottom).

**Stormwater:** The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or snow melt. Stormwater can also come from hard or saturated grass surfaces such as lawns, pastures, playfields, and from gravel roads and parking lots.

**Streamflow:** Discharge of water in a surface stream (river or creek).

**Surface waters of the state:** Lakes, rivers, ponds, streams, inland waters, salt waters, wetlands and all other surface waters and water courses within the jurisdiction of Washington State.

**Synoptic survey:** Data collected simultaneously or over a short period of time.

**System potential:** The design condition used for TMDL analysis.

**Thalweg:** The deepest and fastest moving portion of a stream.

**Total Maximum Daily Load (TMDL):** A distribution of a substance in a water body designed to protect it from not meeting (exceeding) water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a margin of safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

**Total suspended solids (TSS):** Portion of solids retained by a filter.

**Turbidity:** A measure of water clarity. High levels of turbidity can have a negative impact on aquatic life.

**Wasteload allocation:** The portion of a receiving water's loading capacity allocated to existing or future point sources of pollution. Wasteload allocations constitute one type of water quality-based effluent limitation.

**Watershed:** A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

**1-DMax or 1-day maximum temperature:** The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less.

**303(d) list:** Section 303(d) of the federal Clean Water Act, requiring Washington State to periodically prepare a list of all surface waters in the state for which beneficial uses of the water – such as for drinking, recreation, aquatic habitat, and industrial use – are impaired by pollutants. These are water quality-limited estuaries, lakes, and streams that fall short of state surface water quality standards and are not expected to improve within the next two years.

**7-DADMax or 7-day average of the daily maximum temperatures:** The arithmetic average of seven consecutive measures of daily maximum temperatures. The 7-DADMax for any individual day is calculated by averaging that day's daily maximum temperature with the daily maximum temperatures of the three days before and the three days after that date.

**7Q10 flow:** A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average. The 7Q10 flow is commonly used to represent the critical flow condition in a water body and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q10 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

**$90^{th}$ percentile:** An estimated portion of a sample population based on a statistical determination of distribution characteristics. The $90^{th}$ percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

## Acronyms and Abbreviations

Following are acronyms and abbreviations used in this report.

| | |
|---|---|
| DO | Dissolved oxygen |
| Ecology | Washington State Department of Ecology |
| e.g. | For example |
| EIM | Environmental Information Management database |
| EPA | U.S. Environmental Protection Agency |
| et al. | And others |
| GIS | Geographic Information System software |
| GPS | Global Positioning System |
| i.e. | In other words |
| MEL | Manchester Environmental Laboratory |
| MQO | Measurement quality objective |
| NPDES | (See Glossary above) |
| QA | Quality assurance |
| RM | River mile |
| RPD | Relative percent difference |
| RSD | Relative standard deviation |
| SOP | Standard operating procedures |
| TMDL | (See Glossary above) |
| TOC | Total organic carbon |
| Trib | Tributary |
| TSS | (See Glossary above) |
| USFS | United States Forest Service |
| USGS | United States Geological Survey |
| WAC | Washington Administrative Code |
| WDFW | Washington Department of Fish and Wildlife |
| WQA | Water Quality Assessment |
| WRIA | Water Resource Inventory Area |
| WSDOT | Washington State Department of Transportation |
| WSFO | Weather Service Forecast Office |

*Units of Measurement*

| | |
|---|---|
| °C | degrees centigrade |
| cfs | cubic feet per second |
| ft | feet |
| g | gram, a unit of mass |
| km | kilometer, a unit of length equal to 1,000 meters |
| m | meter |
| mm | millimeter |
| mg | milligram |
| mg/L | milligrams per liter (parts per million) |
| mL | milliliter |
| NTU | nephelometric turbidity units |

| | |
|---|---|
| s.u. | standard units |
| ug/L | micrograms per liter (parts per billion) |
| um | micrometer |
| umhos/cm | micromhos per centimeter |
| uS/cm | microsiemens per centimeter, a unit of conductivity |

## Quality Assurance Glossary

**Accreditation:** A certification process for laboratories, designed to evaluate and document a lab's ability to perform analytical methods and produce acceptable data. For Ecology, it is "Formal recognition by (Ecology)…that an environmental laboratory is capable of producing accurate analytical data." [WAC 173-50-040] (Kammin, 2010)

**Accuracy:** The degree to which a measured value agrees with the true value of the measured property. USEPA recommends that this term not be used, and that the terms precision and bias be used to convey the information associated with the term accuracy. (USGS, 1998)

**Analyte:** An element, ion, compound, or chemical moiety (pH, alkalinity) which is to be determined. The definition can be expanded to include organisms, e.g., fecal coliform, Klebsiella. (Kammin, 2010)

**Bias:** The difference between the population mean and the true value. Bias usually describes a systematic difference reproducible over time, and is characteristic of both the measurement system, and the analyte(s) being measured. Bias is a commonly used data quality indicator (DQI). (Kammin, 2010; Ecology, 2004)

**Blank:** A synthetic sample, free of the analyte(s) of interest. For example, in water analysis, pure water is used for the blank. In chemical analysis, a blank is used to estimate the analytical response to all factors other than the analyte in the sample. In general, blanks are used to assess possible contamination or inadvertent introduction of analyte during various stages of the sampling and analytical process. (USGS, 1998)

**Calibration:** The process of establishing the relationship between the response of a measurement system and the concentration of the parameter being measured. (Ecology, 2004)

**Check standard:** A substance or reference material obtained from a source independent from the source of the calibration standard; used to assess bias for an analytical method. This is an obsolete term, and its use is highly discouraged. See Calibration Verification Standards, Lab Control Samples (LCS), Certified Reference Materials (CRM), and/or spiked blanks. These are all check standards, but should be referred to by their actual designator, e.g., CRM, LCS. (Kammin, 2010; Ecology, 2004)

**Comparability:** The degree to which different methods, data sets and/or decisions agree or can be represented as similar; a data quality indicator. (USEPA, 1997)

**Completeness:** The amount of valid data obtained from a project compared to the planned amount. Usually expressed as a percentage. A data quality indicator. (USEPA, 1997)

**Continuing Calibration Verification Standard (CCV):** A QC sample analyzed with samples to check for acceptable bias in the measurement system. The CCV is usually a midpoint calibration standard that is re-run at an established frequency during the course of an analytical run. (Kammin, 2010)

**Control chart:** A graphical representation of quality control results demonstrating the performance of an aspect of a measurement system. (Kammin, 2010; Ecology 2004)

**Control limits:** Statistical warning and action limits calculated based on control charts. Warning limits are generally set at +/- 2 standard deviations from the mean, action limits at +/- 3 standard deviations from the mean. (Kammin, 2010)

**Data Integrity:** A qualitative DQI that evaluates the extent to which a data set contains data that is misrepresented, falsified, or deliberately misleading. (Kammin, 2010)

**Data Quality Indicators (DQI):** Commonly used measures of acceptability for environmental data. The principal DQIs are precision, bias, representativeness, comparability, completeness, sensitivity, and integrity. (USEPA, 2006)

**Data Quality Objectives (DQO):** Qualitative and quantitative statements derived from systematic planning processes that clarify study objectives, define the appropriate type of data, and specify tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions.
(USEPA, 2006)

**Data set:** A grouping of samples organized by date, time, analyte, etc. (Kammin, 2010)

**Data validation:** An analyte-specific and sample-specific process that extends the evaluation of data beyond data verification to determine the usability of a specific data set. It involves a detailed examination of the data package, using both professional judgment, and objective criteria, to determine whether the MQOs for precision, bias, and sensitivity have been met. It may also include an assessment of completeness, representativeness, comparability and integrity, as these criteria relate to the usability of the data set. Ecology considers four key criteria to determine if data validation has actually occurred. These are:

- Use of raw or instrument data for evaluation.
- Use of third-party assessors.
- Data set is complex.
- Use of EPA Functional Guidelines or equivalent for review.

Examples of data types commonly validated would be:

- Gas Chromatography (GC).
- Gas Chromatography-Mass Spectrometry (GC-MS).
- Inductively Coupled Plasma (ICP).

The end result of a formal validation process is a determination of usability that assigns qualifiers to indicate usability status for every measurement result. These qualifiers include:

- No qualifier, data is usable for intended purposes.
- J (or a J variant), data is estimated, may be usable, may be biased high or low.
- REJ, data is rejected, cannot be used for intended purposes (Kammin, 2010; Ecology, 2004).

**Data verification:** Examination of a data set for errors or omissions, and assessment of the Data Quality Indicators related to that data set for compliance with acceptance criteria (MQOs). Verification is a detailed quality review of a data set. (Ecology, 2004)

**Detection limit** (limit of detection)**:** The concentration or amount of an analyte which can be determined to a specified level of certainty to be greater than zero. (Ecology, 2004)

**Duplicate samples:** Two samples taken from and representative of the same population, and carried through and steps of the sampling and analytical procedures in an identical manner. Duplicate samples are used to assess variability of all method activities including sampling and analysis. (USEPA, 1997)

**Field blank:** A blank used to obtain information on contamination introduced during sample collection, storage, and transport. (Ecology, 2004)

**Initial Calibration Verification Standard (ICV):** A QC sample prepared independently of calibration standards and analyzed along with the samples to check for acceptable bias in the measurement system. The ICV is analyzed prior to the analysis of any samples. (Kammin, 2010)

**Laboratory Control Sample (LCS):** A sample of known composition prepared using contaminant-free water or an inert solid that is spiked with analytes of interest at the midpoint of the calibration curve or at the level of concern. It is prepared and analyzed in the same batch of regular samples using the same sample preparation method, reagents, and analytical methods employed for regular samples. (USEPA, 1997)

**Matrix spike:** A QC sample prepared by adding a known amount of the target analyte(s) to an aliquot of a sample to check for bias due to interference or matrix effects. (Ecology, 2004)

**Measurement Quality Objectives** (MQOs)**:** Performance or acceptance criteria for individual data quality indicators, usually including precision, bias, sensitivity, completeness, comparability, and representativeness. (USEPA, 2006)

**Measurement result:** A value obtained by performing the procedure described in a method. (Ecology, 2004)

**Method:** A formalized group of procedures and techniques for performing an activity (e.g., sampling, chemical analysis, data analysis), systematically presented in the order in which they are to be executed. (EPA, 1997)

**Method blank:** A blank prepared to represent the sample matrix, prepared and analyzed with a batch of samples. A method blank will contain all reagents used in the preparation of a sample, and the same preparation process is used for the method blank and samples. (Ecology, 2004; Kammin, 2010)

**Method Detection Limit (MDL):** This definition for detection was first formally advanced in 40CFR 136, October 26, 1984 edition. MDL is defined there as the minimum concentration of an analyte that, in a given matrix and with a specific method, has a 99% probability of being identified, and reported to be greater than zero. (Federal Register, October 26, 1984)

**Percent Relative Standard Deviation (%RSD):** A statistic used to evaluate precision in environmental analysis. It is determined in the following manner:

$$\%RSD = (100 * s)/x$$

where s is the sample standard deviation and x is the mean of results from more than two replicate samples (Kammin, 2010)

**Parameter:** A specified characteristic of a population or sample. Also, an analyte or grouping of analytes. Benzene and nitrate + nitrite are all "parameters." (Kammin, 2010; Ecology, 2004)

**Population:** The hypothetical set of all possible observations of the type being investigated. (Ecology, 2004)

**Precision:** The extent of random variability among replicate measurements of the same property; a data quality indicator. (USGS, 1998)

**Quality Assurance (QA):** A set of activities designed to establish and document the reliability and usability of measurement data. (Kammin, 2010)

**Quality Assurance Project Plan (QAPP):** A document that describes the objectives of a project, and the processes and activities necessary to develop data that will support those objectives. (Kammin, 2010; Ecology, 2004)

**Quality Control (QC):** The routine application of measurement and statistical procedures to assess the accuracy of measurement data. (Ecology, 2004)

**Relative Percent Difference (RPD):** RPD is commonly used to evaluate precision. The following formula is used:

$$[Abs(a-b)/((a + b)/2)] * 100$$

where "Abs()" is absolute value and a and b are results for the two replicate samples. RPD can be used only with 2 values. Percent Relative Standard Deviation is (%RSD) is used if there are results for more than 2 replicate samples (Ecology, 2004).

**Replicate samples:** Two or more samples taken from the environment at the same time and place, using the same protocols. Replicates are used to estimate the random variability of the material sampled. (USGS, 1998)

**Representativeness:** The degree to which a sample reflects the population from which it is taken; a data quality indicator. (USGS, 1998)

**Sample (field):** A portion of a population (environmental entity) that is measured and assumed to represent the entire population. (USGS, 1998)

**Sample (statistical):** A finite part or subset of a statistical population. (USEPA, 1997)

**Sensitivity:** In general, denotes the rate at which the analytical response (e.g., absorbance, volume, meter reading) varies with the concentration of the parameter being determined. In a specialized sense, it has the same meaning as the detection limit. (Ecology, 2004)

**Spiked blank:** A specified amount of reagent blank fortified with a known mass of the target analyte(s); usually used to assess the recovery efficiency of the method. (USEPA, 1997)

**Spiked sample:** A sample prepared by adding a known mass of target analyte(s) to a specified amount of matrix sample for which an independent estimate of target analyte(s) concentration is available. Spiked samples can be used to determine the effect of the matrix on a method's recovery efficiency. (USEPA, 1997)

**Split Sample:** The term split sample denotes when a discrete sample is further subdivided into portions, usually duplicates. (Kammin, 2010)

**Standard Operating Procedure (SOP):** A document which describes in detail a reproducible and repeatable organized activity. (Kammin, 2010)

**Surrogate:** For environmental chemistry, a surrogate is a substance with properties similar to those of the target analyte(s). Surrogates are unlikely to be native to environmental samples. They are added to environmental samples for quality control purposes, to track extraction efficiency and/or measure analyte recovery. Deuterated organic compounds are examples of surrogates commonly used in organic compound analysis. (Kammin, 2010)

**Systematic planning:** A step-wise process which develops a clear description of the goals and objectives of a project, and produces decisions on the type, quantity, and quality of data that will be needed to meet those goals and objectives. The DQO process is a specialized type of systematic planning. (USEPA, 2006)

## References for QA Glossary

Ecology, 2004. Guidance for the Preparation of Quality Assurance Project Plans for Environmental Studies. https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html

Kammin, B., 2010. Definition developed or extensively edited by William Kammin, 2010. Washington State Department of Ecology, Olympia, WA.

USEPA, 1997. Glossary of Quality Assurance Terms and Related Acronyms. U.S. Environmental Protection Agency. http://www.ecy.wa.gov/programs/eap/quality.html

USEPA, 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process EPA QA/G-4. U.S. Environmental Protection Agency. http://www.epa.gov/quality/qs-docs/g4-final.pdf

USGS, 1998. Principles and Practices for Quality Assurance and Quality Control. Open-File Report 98-636. U.S. Geological Survey. http://ma.water.usgs.gov/fhwa/products/ofr98-636.pdf