# Sampling and Analysis Plan and Quality Assurance Project Plan

# Bear/Evans Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load Study

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# and Quality Assurance Project Plan

# Bear/Evans Watershed
# Temperature and Dissolved Oxygen
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September 2006

**2004 303(d) Listings Addressed in this Study:**

Bear Creek (BA64JJ, EW54VY, NC11TV, WR69YU) – Temperature, Dissolved Oxygen
Cottage Lake Creek (NO74JS) – Temperature, Dissolved Oxygen
Evans Creek (MI67EG) – Temperature, Dissolved Oxygen

Waterbody Number:  WA-08-1095 (All Segments of Bear/Evans)

Project Code: 05-065-01

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# Abstract

Monitoring of temperature and/or dissolved oxygen by the King County Department of Natural Resources, the City of Redmond, Northeast Sammamish Sewer and Water District (NES), and Union Hill Water Association (UHWA) indicates that there are segments of streams in the Bear/Evans watershed that do not meet the water quality standards for temperature or dissolved oxygen for varying periods of time between June and October. These segments are listed under Section 303(d) of the Clean Water Act as impaired waters. The present study is designed to organize and evaluate existing data and to supplement and integrate King County, Redmond, NES, and UHWA data collection to ensure that the density of the monitoring sites and the frequency and duration of data collection are adequate to develop a water quality model that provides well calibrated outputs. Water quality models will be used to develop pollutant load reduction amounts needed to bring the stream segments into compliance with the state water quality standards. Data collection and model development represent a cooperative approach between King County, Redmond, NES, UHWA, and the Department of Ecology to develop Total Maximum Daily Load reduction targets for the Bear/Evans system.

# What is a Total Maximum Daily Load, or TMDL?

## Federal Clean Water Act Requirements

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

Every two years, states are required to prepare a list of waterbodies--lakes, rivers, streams or marine waters--that do not meet water quality standards. This list is called the 303(d) list or water quality assessment. To develop the list, Ecology compiles its own water quality data along with data submitted by local, state, and federal governments; tribes; industries; and citizen monitoring groups. All data are reviewed to ensure that they were collected using appropriate scientific methods before they are used to develop the 303(d) list.

## TMDL Process Overview

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the waterbodies on the 303(d) list. A TMDL identifies how much pollution needs to be reduced or eliminated to achieve clean water. Then the local community works with Ecology to develop a strategy to control the pollution and a monitoring plan to assess effectiveness of the water quality improvement activities.

## Elements Required in a TMDL

The goal of a TMDL is to ensure the impaired water will attain water quality standards. A TMDL includes a written, quantitative assessment of water quality problems and of the pollutant sources that cause the problem. The TMDL determines the amount of a given pollutant that can be discharged to the waterbody and still meet standards (the loading capacity) and allocates that load among the various sources.

If the pollutant comes from a discrete source (referred to as a point source) such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse sources (referred to as a nonpoint source) 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 loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

## Water Quality Assessment/Categories 1-5

The 303(d) list identifies polluted waters in Washington. The Water Quality Assessment is a list that tells a more complete story about the condition of Washington's water. This list divides waterbodies into one of five categories:

Category 1. Meets tested standards for clean water.

Category 2. Waters of concern.

Category 3. No data available, so will be largely empty.

Category 4. Polluted waters that do not require a TMDL since the problems are being solved in one of three ways:
- 4a. Has a TMDL approved and is being implemented.
- 4b. Has a pollution control plan in place that should solve the problem.
- 4c. Impaired by a non-pollutant such as low water flow, dams, culverts.

Category 5. Polluted waters that require a TMDL--or the 303d list.

## Total Maximum Daily Load Analyses

Identification of the contaminant loading capacity for a waterbody is an important step in developing a TMDL. EPA defines the loading capacity as *the greatest amount of loading that a waterbody can receive without violating water quality standards*. (EPA, 2001) The loading capacity provides a reference for calculating the amount of pollution reduction needed to bring a waterbody into compliance with standards. The portion of the receiving water's loading capacity assigned to a particular source is a load or wasteload allocation. By definition, a TMDL is the sum of the allocations, which must not exceed the loading capacity.

# Introduction

Data collected by King County and the City of Redmond demonstrate that segments of Bear Creek, Cottage Lake Creek, and Evans Creek do not meet the water quality standards for temperature and dissolved oxygen. On the basis of those data, Ecology included these segments in the 2004 303(d) list of impaired waters.

Ecology, King County, City of Redmond, and others initiated this cooperative effort to develop water quality cleanup plans for temperature and dissolved oxygen in the Bear/Evans system. The cooperative effort will supplement existing data collection programs to provide water quality model input and output data. This document summarizes the short-term data collection and modeling efforts that will be used to develop pollutant load reduction targets necessary to bring stream segments into compliance with the water quality standards.

King County provides regional services throughout both incorporated and un-incorporated areas. These services include sewage treatment, land-use regulations, stormwater management, and water quality monitoring. King County has monitored water quality in local lakes, rivers, and streams for over 30 years and this investigation furthers King County's interests in maintaining and enhancing regional water quality. King County is supporting this investigation through in-kind laboratory analysis and through field activities.

The lowest reaches of both Bear and Evans creeks drain west to the Sammamish River through the City of Redmond (population 47,000; Figure 1). The lowest mile of Bear Creek is tightly constrained within a narrow corridor between State Route 520 and Marymoor Park to the south, and the Redmond Town Center, one of Redmond's largest shopping centers and business parks, to the north. In addition to the creek's mainstem, a dozen or more small catchments (sub-watersheds) located on the city's eastside, carry tributary stream flow and stormwater runoff directly into Bear and Evans creeks. Approximately 40% of Redmond's drinking water supply comes from groundwater wells that are at least partially replenished from aquifers beneath Bear and Evans creeks' valleys. Redmond's Public Works/Natural Resources Division maintains a surface water quality monitoring network across the city and is supporting this program through in-kind field sampling and laboratory analysis.

The Northeast Sammamish Sewer and Water District (NESSWD) provides water for 10,160 people and sewer service for 15,000 people east of Lake Sammamish. NESSWD has five wells and two reservoirs in the area. NESSWD and others developed the Redmond-Bear Creek Valley Ground Water Management Plan for water quantity and quality in the region. The utility district maintains a groundwater, surface water, and atmospheric monitoring network in the Bear/Evans system.

Data collected under the programs described in the present document will be used to develop models of the Bear/Evans system. The models will be used to understand factors contributing to elevated temperature and low dissolved oxygen in the system and to develop load reduction targets necessary to meet the water quality standards throughout the system. Figure 2 presents the study area location.

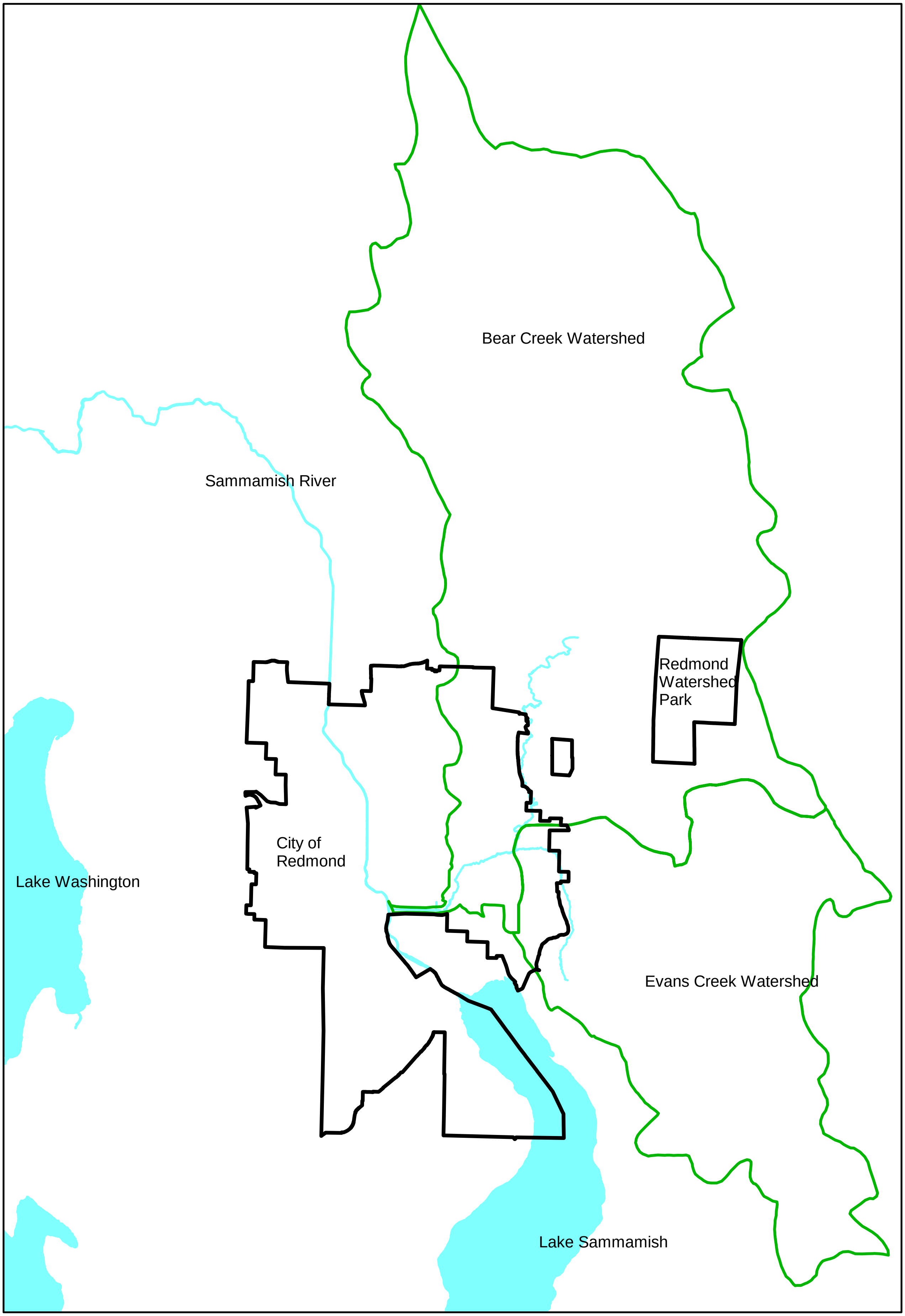


Figure 1.  City of Redmond and the Bear Creek and Evans Creek watersheds.

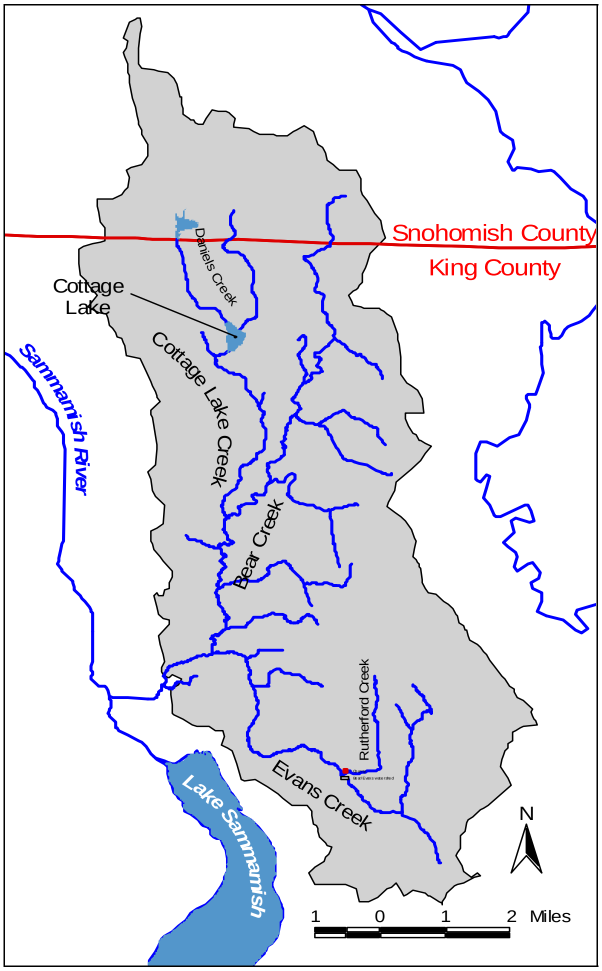


Figure 2. Bear/Evans system.

# Background

## Project Objectives

The project objectives are to collect data and to develop temperature and dissolved oxygen models for the Bear/Evans system during critical low-flow conditions. The data will supplement the ambient monitoring programs conducted by King County, City of Redmond, NESSWD, UHWA, and others. Following are specific tasks:

- Characterize stream temperatures and processes governing the thermal regime in Bear Creek, Cottage Lake Creek, and Evans Creek during critical conditions.
- Develop predictive temperature models of the Bear/Evans system under critical conditions. Apply the models to determine load allocations for effective shade and other surrogate measures to meet temperature water quality standards. Identify the areas influenced by lakes and wetlands and, if necessary, estimate the natural temperature regime.
- Conduct supplemental critical-period surveys for physical, chemical, and biological measures relevant to dissolved oxygen levels in the system. Characterize nutrient levels in the system.
- Develop predictive dissolved oxygen models and use the results to establish pollutant load reduction targets.

## Study Area Description

The Bear/Evans watershed, consisting of about 130 $km^2$ (32,100 acres), includes portions of King and Snohomish counties as well as the cities of Redmond, Sammamish, and Woodinville. The headwaters of the three primary branches originate about 55 m (180 ft) above sea level and discharge to the Sammamish River. Within the Bear Creek watershed, Cottage Lake Creek represents one branch and flows from Cottage Lake to the confluence with Bear Creek in approximately 10.8 km (6.7 miles). Bear Creek flows about 20.0 km (12.4 miles) to the confluence with Evans Creek. Evans Creek runs about 13.2 km (8.2 miles) from its headwater to the confluence with Bear Creek.

Land use in the watershed has changed markedly in the past 150 years as development in the area has increased. What was once primarily forest has become a mix of forest, grass, and impervious surfaces.

Cold Creek affects water temperature in Bear Creek. Cold Creek is a cold-water spring with water temperatures 5 to 7°C colder than the rest of the system.

King County designated Bear Creek and Cottage Lake Creek as Regionally Significant Resource Areas in the Bear Creek Basin Plan (King County, 1990). The system exhibits high aquatic habitat and salmonid diversity and abundance and a demonstrated contribution to the regional fishery resource. Freshwater mussels and sponges are found extensively in the basin. Both King

County and the City of Redmond have facilitated construction of numerous stream restoration projects identified in the Bear Creek Basin Plan.

Numerous salmonids have been found in the Bear/Evans system: chinook, sockeye, coho, kokanee, coastal cutthroat, and steelhead.

Monitoring data indicate a decline in overall water quality in terms of both temperature and dissolved oxygen:

- All sites within the Bear/Evans system, with the exception of Cottage Lake Creek, exhibit a statistically significant increase in baseflow temperatures between 1979 and 1999. Cottage Lake Creek data also indicate an increase, but the increase was not statistically significant. Daily maximum temperature did not meet the water quality standards in 19% of the Bear Creek mouth results, 5% of the mid-basin results, 8% of the upstream basin results, 2% of the Cottage Lake Creek results, and 2% of the Evans Creek results.

- Data indicate a statistically significant decrease in baseflow dissolved oxygen concentrations measured at the mouth of Evans Creek. Upstream data, however, suggest a non-statistically significant decrease. Dissolved oxygen levels did not meet water quality standards in 27% of the upstream and 33% of the downstream measurements on Evans Creek. In Bear Creek, 13% of the dissolved oxygen measurements did not meet water quality standards.

- There has been a significant decrease in baseflow orthophosphorus concentrations at all sites at the Bear/Evans system between 1979 and 1999. Baseflow total phosphorus also decreased significantly in three Bear Creek sites and at the mouth of Evans Creek. However, average baseflow ammonia and nitrate levels at the Cottage Lake Creek station have shown an increasing trend. Average baseflow ammonia concentrations at the mouth of Bear Creek and in the middle basin were much higher than the median range for all King County stream sites. Baseflow nitrate concentrations decreased significantly at the mouth of Evans Creek and increased significantly at the upstream Bear Creek site.

## Water Quality Impairments

The Department of Ecology develops and maintains the list of impaired waters, as directed under the federal Clean Water Act Section 303(d). The 2004 303(d) list, the most recent list approved by the Environmental Protection Agency, includes several waterbodies within the Bear/Evans watersheds. Table 1 summarizes the listings.

Table 1. Clean Water Act Section 303(d) listings (2004).

| Name | Listing ID | Parameter | Township | Range | Section | New WBID | KC/Redmond ID |
|---|---|---|---|---|---|---|---|
| **Category 5 Listing** | | | | | | | |
| Bear Creek | 4804 | Temperature | 25N | 05E | 12 | WR69YO | KC 484, RM1.0 |
| Bear Creek | 42095 | Temperature | 25N | 06E | 31 | EW54VY | Red36, KC J484 |
| Bear Creek | 4811 | Temperature | 25N | 06E | 06 | BA64JJ | KC C484 |
| Bear Creek | 4813 | Temperature | 26N | 06E | 30 | EW54VY | |
| Cottage Lake Creek | 4814 | Temperature | 26N | 06E | 18 | NO74JS | KC N484 |
| Evans Creek | 4809 | Temperature | 25N | 06E | 06 | MI67EG | KC S484 |
| Bear Creek | 42094 | DO | 25N | 06E | 31 | EW54VY | Red36, KC J484 |
| Bear Creek | 42087 | DO | 25N | 05E | 12 | NC11TV | Red21 |
| Bear Creek | 12687 | DO | 25N | 06E | 06 | BA64JJ | KC C484 |
| Evans Creek | 12689 | DO | 25N | 06E | 18 | MI67EG | KC S484 |
| Evans Creek | 12685 | DO | 25N | 06E | 06 | MI67EG | KC S484 |
| Cottage Lake Creek | 12688 | DO | 26N | 06E | 18 | NO74JS | KC N484 |
| **Category 2 Listing** | | | | | | | |
| Bear Creek | 12635 | pH | 26N | 06E | 30 | NO74JS | |
| Bear Creek | 12672 | DO | 26N | 06E | 30 | EW54VY | |
| Evans Creek | 4815 | Temperature | 25N | 06E | 18 | MI67EG | |
| Evans Creek | 12634 | pH | 25N | 06E | 18 | MI67EG | |

## Water Quality Standards and Parameters of Concern

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code, include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state. Table 2 lists the classifications of waterbodies within the study area. Waterbodies are not explicitly listed in the Washington Administrative Code but receive classifications as discharges to Lake Washington.

Table 2. Waterbody classification for the Bear/Evans system.

| Name | Classification |
|---|---|
| Bear Creek | Core rearing (formerly Class AA) |
| Cottage Lake Creek | Core rearing (formerly Class AA) |
| Evans Creek | Core rearing (formerly Class AA) |
| Cottage Lake | Lake[1] |

[1] The Cottage Lake Phosphorus TMDL was developed and submitted to EPA (Whiley, 2004).

Stream reaches identified as core rearing are for the protection of spawning, core rearing, and migration of salmon and trout, and other associated aquatic life. Characteristic uses for Class AA waterbodies include water supply (domestic, industrial, and agricultural), stock watering, fish and shellfish (salmonid and other fish migration, rearing, spawning, and harvesting), wildlife habitat, recreation (primary contact recreation, sport fishing, boating, and aesthetic enjoyment), and commerce and navigation. Numeric criteria for specific water quality parameters are intended to protect designated uses.

Ecology revised the state water quality standards in July 2003; however, EPA disapproved the aquatic life designations and associated temperature criteria in March 2006 (Gearheard, 2006). In the Bear/Evans systems, there was no change to the designated aquatic life use of core rearing (EPA, 2006).

## Temperature (Core Rearing, Class AA)

Freshwater temperature shall not exceed 16.0°C due to human activities. When natural conditions exceed 16.0°C, no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°C. … Incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C when the temperatures are less than the standard.

The July 2003 temperature standards do not use the class distinction but depend on whether streams are, or could be, salmonid or trout core-rearing or non-core-rearing waterbodies. However, streams that were previously identified as Class AA are designated as salmonid or trout spawning, core rearing, and migration streams which must not exceed a seven-day average maximum temperature of 16°C. (The previous standard also used 16°C but as the instantaneous maximum temperature.)

In addition, portions of the Bear/Evans system must not exceed 13°C between September 15 and May 15. This project is designed to evaluate summer peak temperatures; other conditions are not evaluated explicitly. Figure 3 presents the extent of the revised classification.

## Dissolved Oxygen (Core Rearing, Class AA)

Freshwater dissolved oxygen shall exceed 9.5 mg/L. When natural conditions … occur causing the dissolved oxygen to be depressed near or below the levels described above by class, natural dissolved oxygen levels may be degraded by no more than 0.2 mg/L by the combined effect of all human-caused activities.

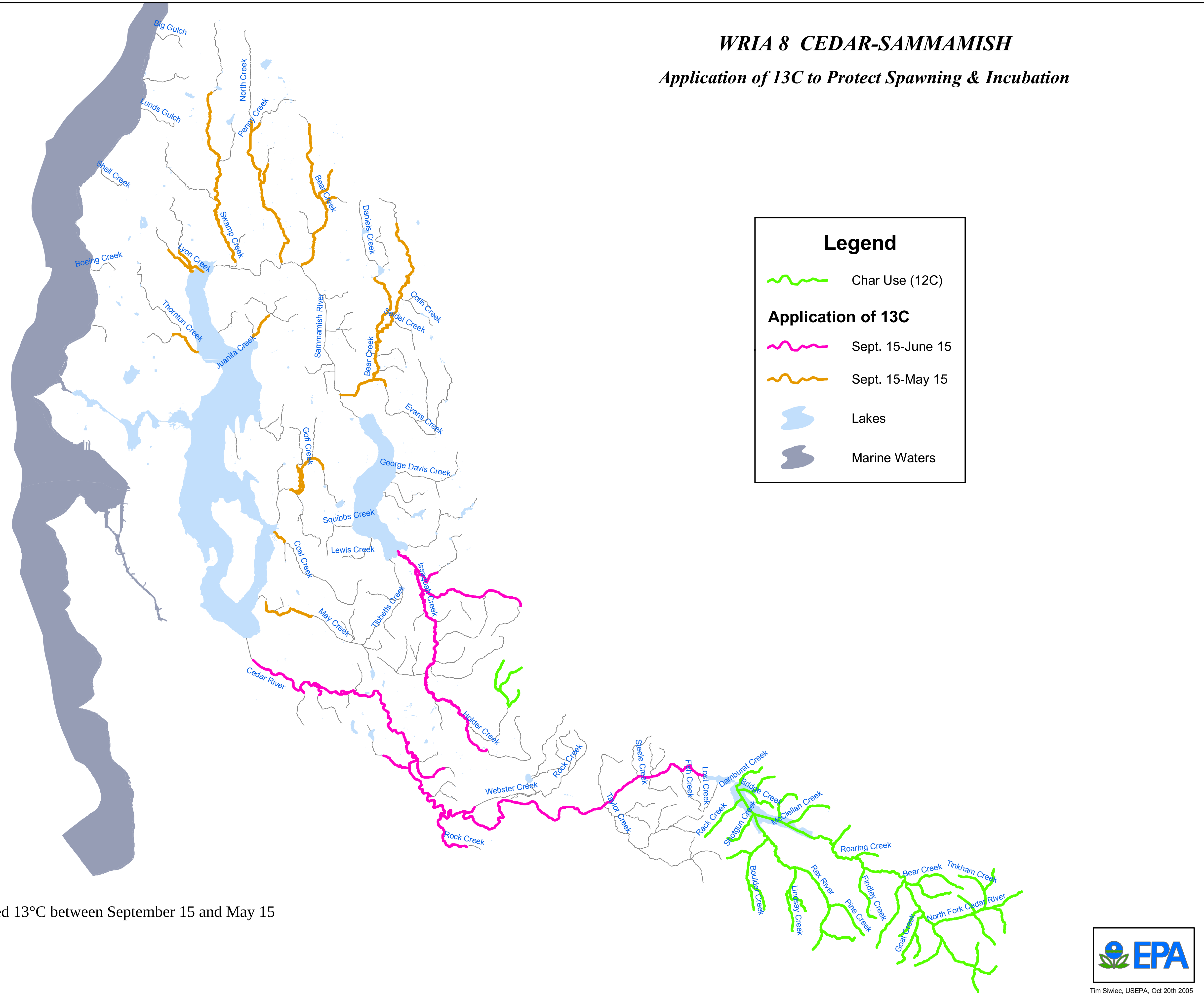


Figure 3. Stream segments that must not exceed 13°C between September 15 and May 15
(Source: EPA)

## Potential Sources and Permit Holders

### Temperature

The temperature TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. The transport and fate of heat in natural waters has been the subject of extensive study. Edinger et al. (1974) provide an excellent and comprehensive report of this research. Thomann and Mueller (1987) and Chapra (1997) have summarized the fundamental approach to the analysis of heat budgets and temperature in natural waters that will be used in this TMDL. Figure 4 shows the major heat energy processes or fluxes across the water surface or stream bed, described further in Pelletier et al. (2005).

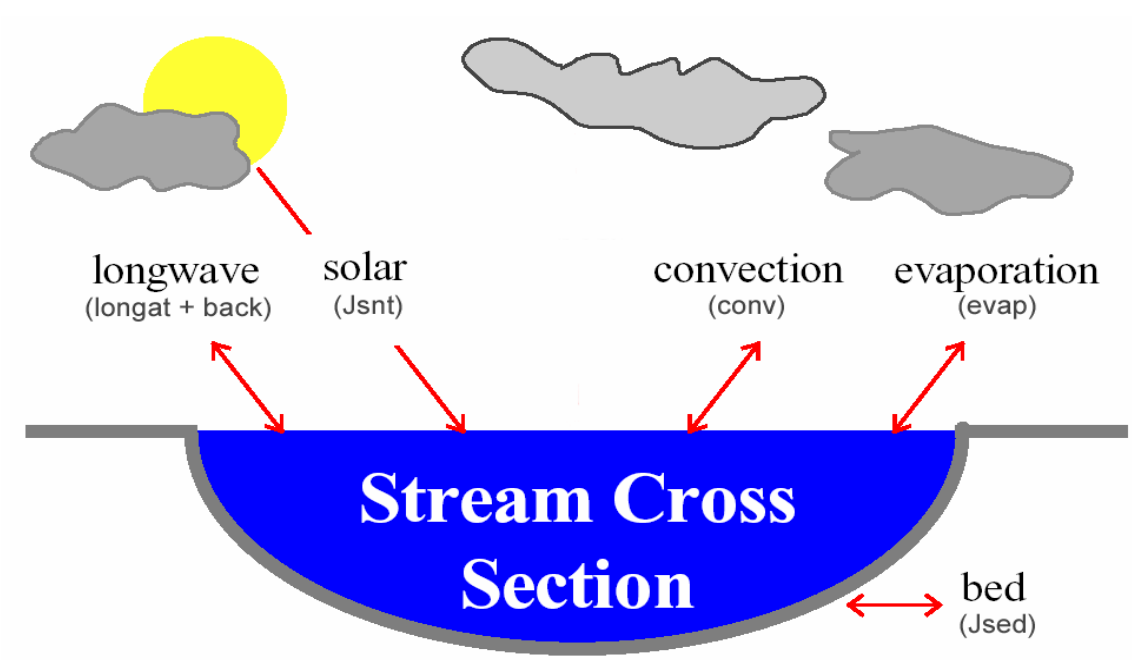


Figure 4. Surface heat transfer processes that affect water temperature.

Adams and Sullivan (1989) reported that the following environmental variables are the most important drivers of water temperature in forested streams:

- *Stream Depth*. Stream depth is the most important variable of stream size for evaluating energy transfer. Stream depth affects both the magnitude of the stream temperature fluctuations and the response time of the stream to changes in environmental conditions.

- *Air Temperature*. Daily average stream temperatures are strongly influenced by daily average air temperatures. When the sun is not shining, the water temperature in a volume of water tends toward the dewpoint temperature (Edinger et al., 1974).

- *Solar Radiation and Riparian Vegetation*. Net radiation is dominated by the amount of direct-beam solar radiation that reaches the stream surface and this, in turn, is affected by the amount of shade producing vegetation near the stream. The daily *maximum* temperatures in a stream are strongly influenced by removal of riparian vegetation because of diurnal patterns of solar heat flux. Daily *average* temperatures are less affected by removal of riparian vegetation. Discharge is an important variable that determines the temperature response to solar radiation.

- *Groundwater*. Inflows of groundwater can have an important cooling effect on stream temperature. This effect will depend on the rate of groundwater inflow relative to the flow in the stream and the difference in temperatures between the groundwater and the stream.

The heat exchange processes with the greatest magnitude are as follows (Edinger et al., 1974):

- *Shortwave Solar Radiation*. Shortwave solar radiation is the radiant energy that passes directly from the sun to the earth. Shortwave solar radiation is contained in a wavelength range between 0.14 µm and about 4 µm. The peak values during daylight hours are typically about three times higher than the daily average. Shortwave solar radiation constitutes the major thermal input to an unshaded body of water during the day when the sky is clear.

- *Longwave Atmospheric Radiation*. The longwave radiation from the atmosphere ranges in wavelength from about 4 µm to 120 µm. Longwave atmospheric radiation depends primarily on air temperature and humidity and increases as both of those increase. It constitutes the major thermal input to a body of water at night and on warm, cloudy days. The daily average heat flux from longwave atmospheric radiation typically ranges from about 300 to 450 $W/m^2$ at mid latitudes.

- *Longwave Back Radiation from the Water to the Atmosphere*. Water sends heat energy back to the atmosphere in the form of longwave radiation in wavelengths ranging from about 4 µm to 120 µm. Back radiation accounts for a major portion of the heat loss from a body of water. Back radiation increases as water temperature increases. The daily average heat flux out of the water from longwave back radiation typically ranges from about 300 to 500 $W/m^2$.

The role of riparian vegetation in maintaining a healthy stream condition and water quality is well documented and accepted in the scientific literature. Summer stream temperature increases due to the removal of riparian vegetation are well documented (for example Holtby, 1988; Lynch et al., 1984; Rishel et al., 1982; Patric, 1980; Swift and Messer, 1971; Brown et al., 1971; and Levno and Rothacher, 1967). These studies generally support the findings of Brown and Krygier (1970) that loss of riparian vegetation results in larger daily temperature variations and elevated monthly and annual temperatures. Adams and Sullivan (1989) also concluded that daily maximum temperatures are strongly influenced by the removal of riparian vegetation because of the effect of diurnal fluctuations in solar heat flux.

Summaries of the scientific literature on the thermal role of riparian vegetation in forested and agricultural areas are provided by Belt et al. (1992); Beschta et al. (1987); Bolton and Monohan (2001); Castelle and Johnson (2000); CH2MHill (2000); GEI (2002); Ice (2001); and Wenger (1999). All of these summaries of the scientific literature indicate that riparian vegetation plays an important role in controlling stream temperature. The important benefits that riparian vegetation has upon the stream temperature include:

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.

- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.

- Bank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land cover type and condition by affecting floodplain and instream roughness, contributing coarse woody debris and influencing sedimentation, stream substrate composition, and stream bank stability.

Rates of heating to the stream surface can be dramatically reduced when high levels of shade are produced and heat flux from solar radiation is minimized. There is a natural maximum level of shade that a given stream is capable of attaining, which is a function of species composition, soils, climate, and stream morphology.

Lakes and wetlands can be sources of heat to the receiving stream or river. Shallow lakes and wetlands occupy the headwaters of Bear Creek, Cottage Lake Creek, and Evans Creek. The stream is cooled in the downstream direction via groundwater inflow, input from cooler spring-fed tributaries, and hyporheic exchange. The amount of downstream cooling depends on groundwater and tributary inflow temperatures and volume, and the amount of riparian vegetation available to reduce solar radiation and prevent additional heating.

The distinction between reduced heating of streams and actual cooling is important. Shade can significantly reduce the amount of heat flux that enters a stream. Whether there is a reduction in the amount of warming of the stream, maintenance of inflowing temperatures, or cooling of a stream as it flows downstream depends on the balance of all of the heat exchange and mass transfer processes in the stream.

Mass transfer processes refer to the downstream transport and mixing of water throughout a stream system and inflows of surface water and groundwater. The downstream transport of dissolved/suspended substances and heat associated with flowing water is called advection. Dispersion results from turbulent diffusion that mixes the water column. Due to dispersion, flowing water is usually well mixed vertically. Stream water mixing with inflows from surface tributaries and subsurface groundwater sources also redistributes heat within the stream system. These processes (advection, dispersion, and mixing of surface and subsurface waters) redistribute the heat of a stream system via mass transfer. Turbulent diffusion can be calculated as a function of stream dimensions, channel roughness, and average flow velocity. Dispersion occurs in both the upstream and downstream directions. Tributaries and groundwater inflows can change the temperature of a stream segment when the inflow temperature is different from the receiving water.

The TMDL technical assessment for the Bear/Evans system will use riparian shade as a surrogate measure of heat flux to fulfill the requirements of Section 303(d). Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade accounts for the interception of solar radiation by vegetation and topography.

Heat loads to the stream will be calculated in the TMDL in a heat budget that accounts for surface heat flux and mass transfer processes. Heat loads are of limited value in guiding management activities needed to solve identified water quality problems. Shade will be used as a surrogate to thermal load as allowed under EPA regulations [defined as *other appropriate measure* in 40 CFR §130.2(i)]. A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Other factors influencing the distribution of the solar heat load also will be assessed including increases in the wetted width-to-depth ratios of stream channels. The effect of both varying streamflow levels and groundwater inflows will be assessed in this study.

The *Report of the Federal Advisory Committee on the Total Maximum Daily Load (TMDL) Program* (EPA, 1998) includes the following guidance on the use of surrogate measures for TMDL development:

*When the impairment is tied to a pollutant for which a numeric criterion is not possible, or where the impairment is identified but cannot be attributed to a single traditional 'pollutant,' the state should try to identify another (surrogate) environmental indicator that can be used to develop a quantified TMDL, using numeric analytical techniques where they are available, and best professional judgment (BPJ) where they are not.*

## Dissolved Oxygen, Nutrients, and pH

### Nonpoint Sources

A variety of nonpoint sources may contribute to dissolved oxygen or pH impairments. Depressed DO may result from increased nutrient loads that stimulate algae growth, referred to as productivity. The decomposition of dead algae and other organic matter consumes dissolved oxygen. Productivity may be limited by a specific nutrient, generally phosphorus in streams and nitrogen in marine waterbodies, by the absence of light to fuel photosynthesis, or by retention time in a waterbody.

Activities or mechanisms that produce nutrients or enhance nutrient transport include the following:

- Septic systems.
- Stormwater runoff from paved and pervious lands.
- Improper manure storage or disposal from commercial and non-commercial agriculture.
- Vegetation removal without erosion control and resulting discharge of sediment from construction areas or forest harvest.
- Channel bank erosion or bed scour due to high flows or constrained reaches.
- Poor fertilizer and irrigation water management.
- Removal of riparian zone vegetation, which otherwise removes nutrients from overland flow.

In addition to natural filtering of pollutants through riparian vegetation, streamside trees also reduce solar radiation reaching the stream surface, which may limit algal growth.

The diel cycle of algal growth adds dissolved oxygen (DO) during the daylight hours as the plants photosynthesize, but reduces DO levels to a natural minimum around daybreak as respiration occurs. Enhanced growth increases the daily variation resulting in lower levels of DO than would have resulted under natural conditions. These same processes affect pH.

Algae and other aquatic plants consume $CO_2$ during photosynthesis reducing the amount of $CO_2$ and bicarbonate in the water. Alkalinity stays essentially constant while pH responds by increasing. This process is exacerbated as more sunlight reaches the stream and as temperatures and nutrient concentrations increase. The pH in streams with high algal productivity typically increases during the daylight hours to its maximum around mid-to-late-afternoon and returns to near-background levels at night when plants are respiring and not taking carbon out of the water. This diel swing, like DO, can be dramatic enough to increase the daily high and/or decrease the daily low pH of streams and lakes beyond state standards.

In addition, the pH of rain in western Washington is 4.8 to 5.1 (NADP/NATN, 2004). Therefore, stormwater may have a low pH due to regional atmospheric rather than local watershed conditions. Wetland systems also affect pH by enhancing natural decomposition processes, which results in acidic pH levels.

Anthropogenic activities can lower pH as well. For example, decomposing organic material such as that found in logging slash and even acid deposition can lower pH below state standards. Some streams have a naturally low-buffering capacity, which makes them more susceptible to pH changes. These streams can have both low and high pH in the same stretch, though often during different times of the year.

Natural sources and mechanisms affect DO and pH as well. The high residence time and high organic matter loading in wetlands, for example, produce low DO and pH levels. Many wetland complexes, potentially enhanced by beaver activity, exist within the Bear/Evans system and may contribute to the low levels recorded in the mainstem and the tributaries.

**Point Sources**

No point sources discharge to the Bear/Evans system under individual NPDES permits, except those covered by stormwater. Several general permits for sand and gravel and industrial stormwater/construction have been issued for the Bear/Evans watershed, and these are listed in Table 3. The watershed is also covered by both the municipal stormwater Phase I (King County) and municipal stormwater Phase II (Redmond, Woodinville) permits, as shown in Figure 5. Highways within the Phase I area are covered by Washington State Department of Transportation's stormwater permit.

Table 3. Facilities covered under permits within the Bear/Evans system.

| Permit No. | Type | Permittee |
|---|---|---|
| **Individual Permits** | | |
| | Phase I stormwater | King County |
| | Phase I stormwater | Department of Transportation |
| | Phase II stormwater | City of Redmond |
| | Phase II stormwater | City of Sammamish |
| | Phase II stormwater | City of Woodinville |
| **General Permits** | | |
| | Sand and Gravel | (Varies over time) |
| | Construction Stormwater | (Varies over time) |

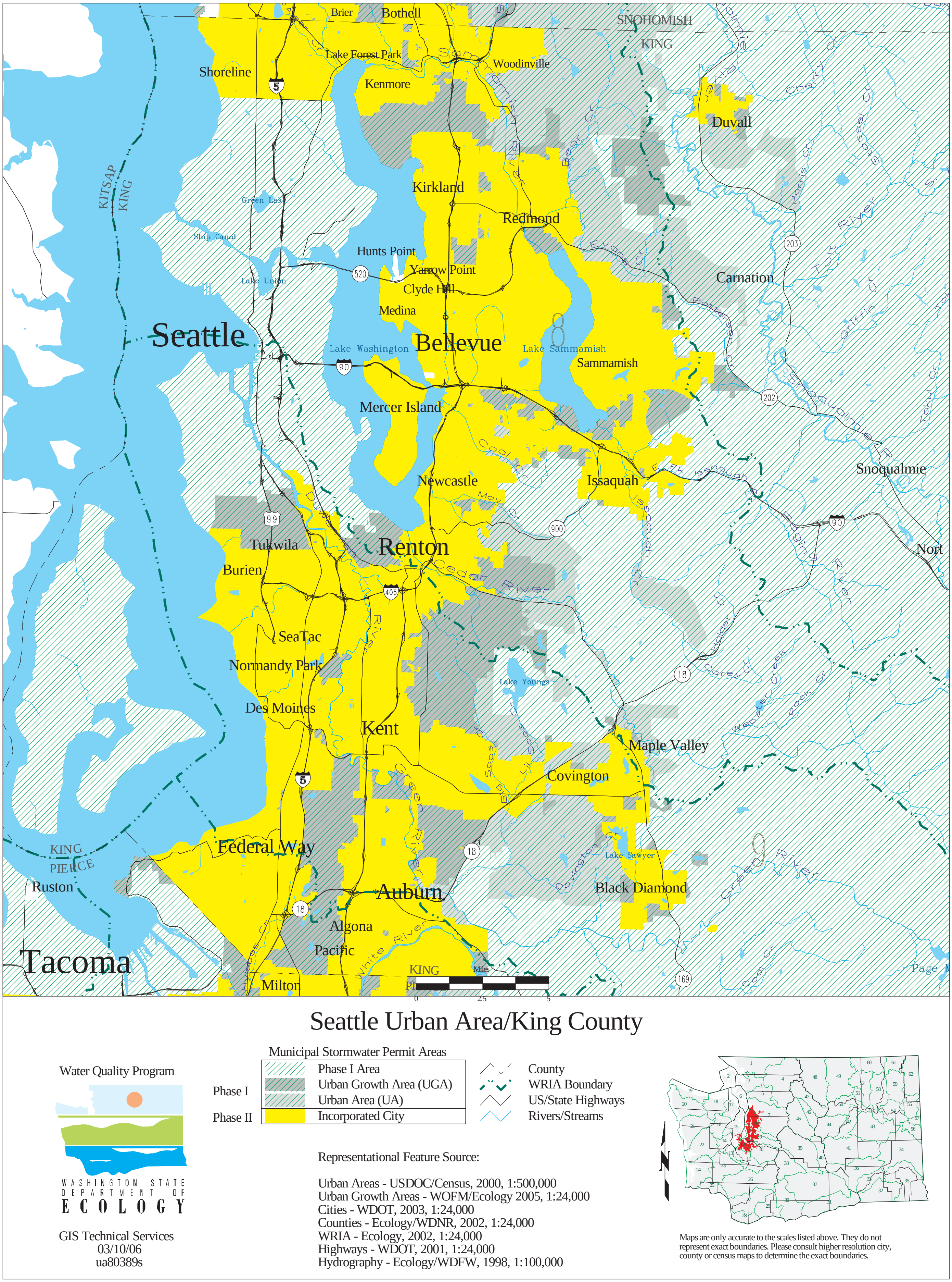


Figure 5. Stormwater permit coverage for the greater Seattle area, including the Bear/Evans watershed.

# Historical Data Review

Several agencies have collected data within the Bear/Evans system. Data are summarized here to provide context for the current programs.

## King County

King County has sampled water quality in the Bear Creek area since the early-to-mid-1970s. These efforts have produced a variety of monitoring data from multiple locations. In aggregate, over 55 different locations in the watershed have been sampled.

Since 1971 to 1976, King County has been conducting monthly baseline water quality monitoring at six sites in the Bear/Evans system. Figure 6 presents sampling locations. Station 0484 is located at the mouth of Bear Creek where it enters the Sammamish River (the first railroad bridge south of Redmond Fall City Road). Two sites are located on the mainstem of Bear Creek: station C484 is located at bridge number 119A on 95th Avenue (east of Avondale Road) and station J484 is the furthest upstream site located at the bridge on Seidel Road (100 yards east of Bear Creek Road). Two sites are located on Evans Creek: station B484, co-located with Hydrologic Information Center station 18a is located where Evans Creek meets Bear Creek at the bridge on Union Hill Rd (100 yards west of 188th Avenue NE) and station S484 is located upstream at 50th Street near the junction with Highway 202. One station (N484) is located on Cottage Lake Creek at the downstream side of the bridge on Avondale Road (near NE 51st Street).

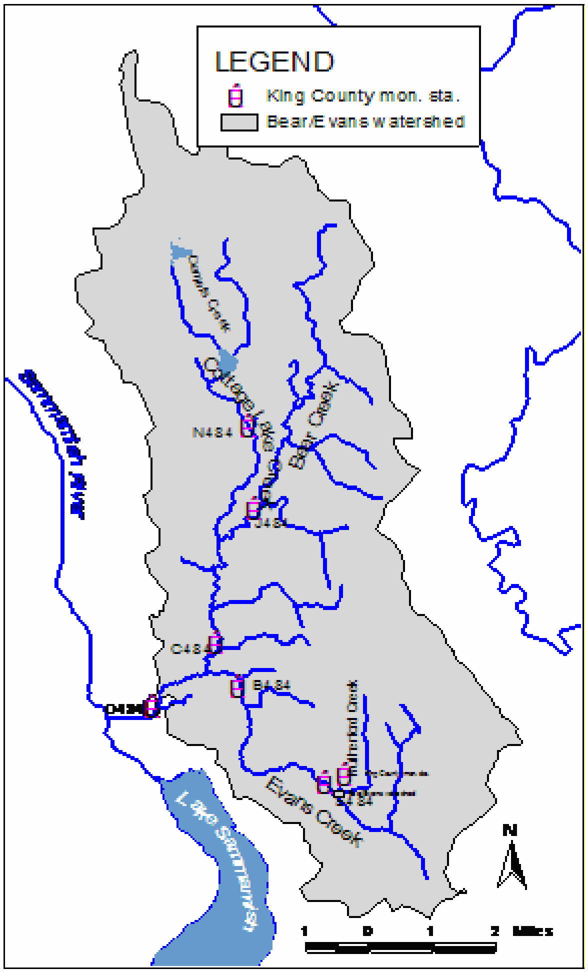


Figure 6. King County monitoring locations.

Station 0484 has been monitored monthly by King County since 1971. The temperature at this location typically exceeds water quality standards during the months of July and August, with rare exceedances in June and September. Figure 7 shows the historical temperature record for station 0484. The box plots used graphically represent the maximum and minimum values as well as the $75^{th}$ and $25^{th}$ percentiles and the median value. Figure 8 identifies the components of a boxplot.

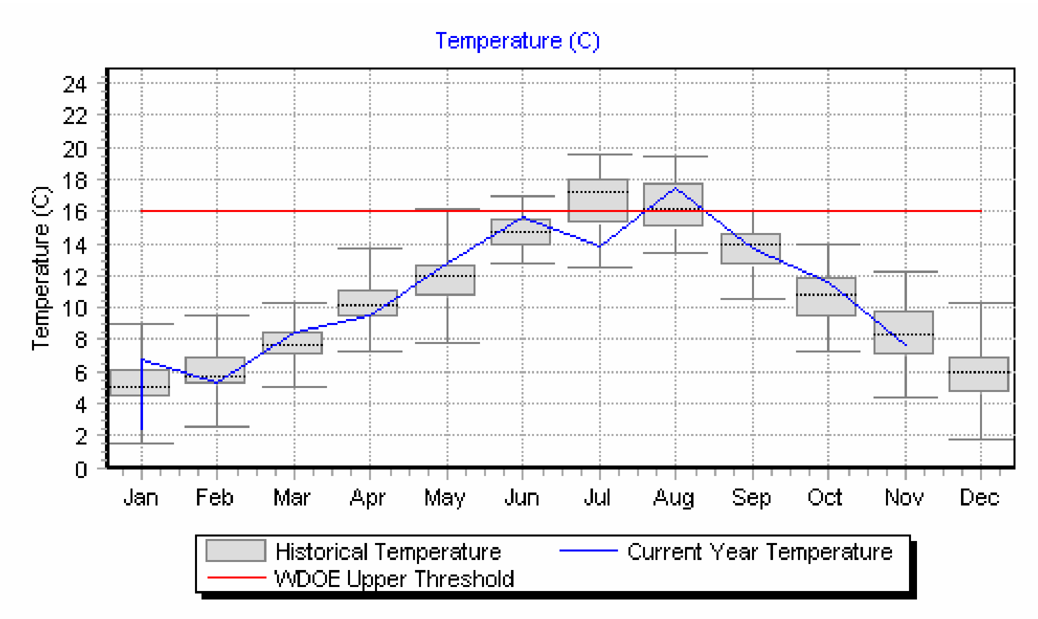


Figure 7. Station 0484, Bear Creek mouth, temperature record for 1971 to 2005.

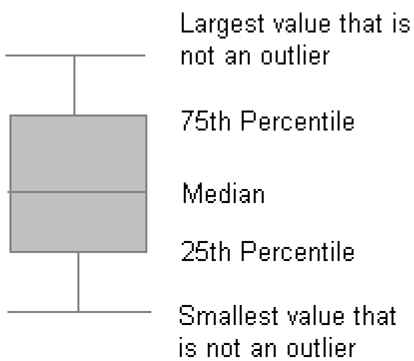


Figure 8. Components of a box plot.

Dissolved oxygen at station 0484 also typically violates water quality standards during the months of July and August although the violations continue with occasional drops in DO into November. Figure 9 illustrates the average dissolved oxygen concentrations throughout the 35-year period of record.

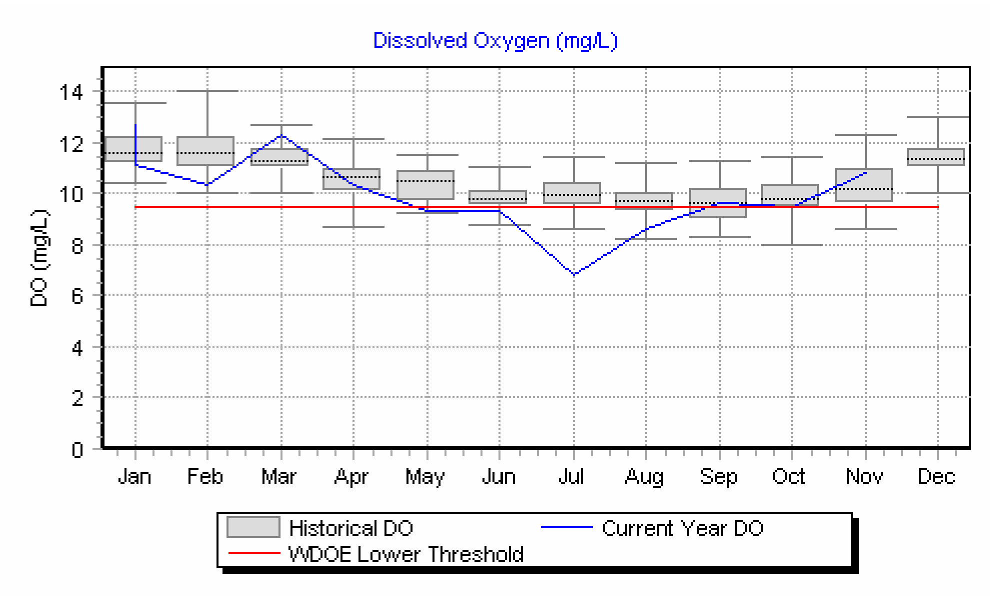


Figure 9. Station 0484, Bear Creek Mouth, dissolved oxygen record for 1971 to 2005.

The remainder of the long term Bear Creek ambient monitoring results exhibit very similar seasonal patterns and variability. Results from these locations have been included in Appendix B.

In addition to temperature and dissolved oxygen, King County monitors fecal coliforms, pH, total phosphorus, total suspended solids, total nitrogen, and turbidity at all six long-term ambient monitoring locations in the Bear/Evans system. Overall, the water quality in Bear/Evans Creek was characterized as *fair* in 1989 (King County, 1990). The water quality data indicate a decline in overall water quality from earlier years due to lower dissolved oxygen concentrations, higher temperatures, and higher bacteria concentrations. A 25-year (1979 – 2004) trend analysis was conducted with data collected from all six sites in the Bear/Evans creek. As with most streams in WRIA 8, there has been a significant increase in water temperatures over this 25-year period. Conductivity increased significantly at all six sites. Dissolved oxygen decreased at two sites on Bear Creek (J484, N484) and at both sites on Evans Creek. There have been some improvements in water quality as evidenced by the decrease in total suspended solids, phosphorus concentrations (ortho and total), and fecal coliform bacteria. Ammonia and total-nitrogen concentrations also decreased at most of the six sites in the Bear/Evans creek. Nitrate concentrations decreased at three sites (J484, 0484, and B484) but increased at N484 and C484. The pH values decreased significantly in Evans Creek. A Water Quality Index (WQI) rating system was developed by the Washington State Department of Ecology. It evaluates several water quality parameters and gives an overall rating of “high,” “moderate,” or “low” concern. In the most recent comparison conducted (2003 – 2004 water year), Bear Creek rated “moderate” concern while Evans Creek rated “high” concern.

King County maintains nine streamflow gauges in the Bear/Evans basin:

- Bear Creek at mouth (02a)
- Wetland Big Bear Creek #45 Outlet (02b)
- Bear Creek at 133rd Street NE, near Redmond (02e)
- Bear Creek at Woodinville-Duvall Road (02f)
- Cottage Lake Creek at NE 132nd Street (02g)
- Cold Creek near Cottage Creek (02h)
- Evans Creek at Union Hill Road (18a)
- Northridge Evans Creek #4 (Redmond Block South) (18b)
- Northridge Evans Creek #4 (Redmond Block Interior) (18c)

King County also maintains three water temperature gauges:

- Cottage Creek (02i)
- Bear Creek at Mouth (02j)
- Cold Creek Below Spring (02k)

King County also maintains one precipitation gauge:

- Cottage Lake Rain Gauge (02w)

Flow gauge 02a has been continuously monitored since October of 1987. These data have been complied into box plots by month and Figure 10 shows the average monthly flow in cubic feet per second.

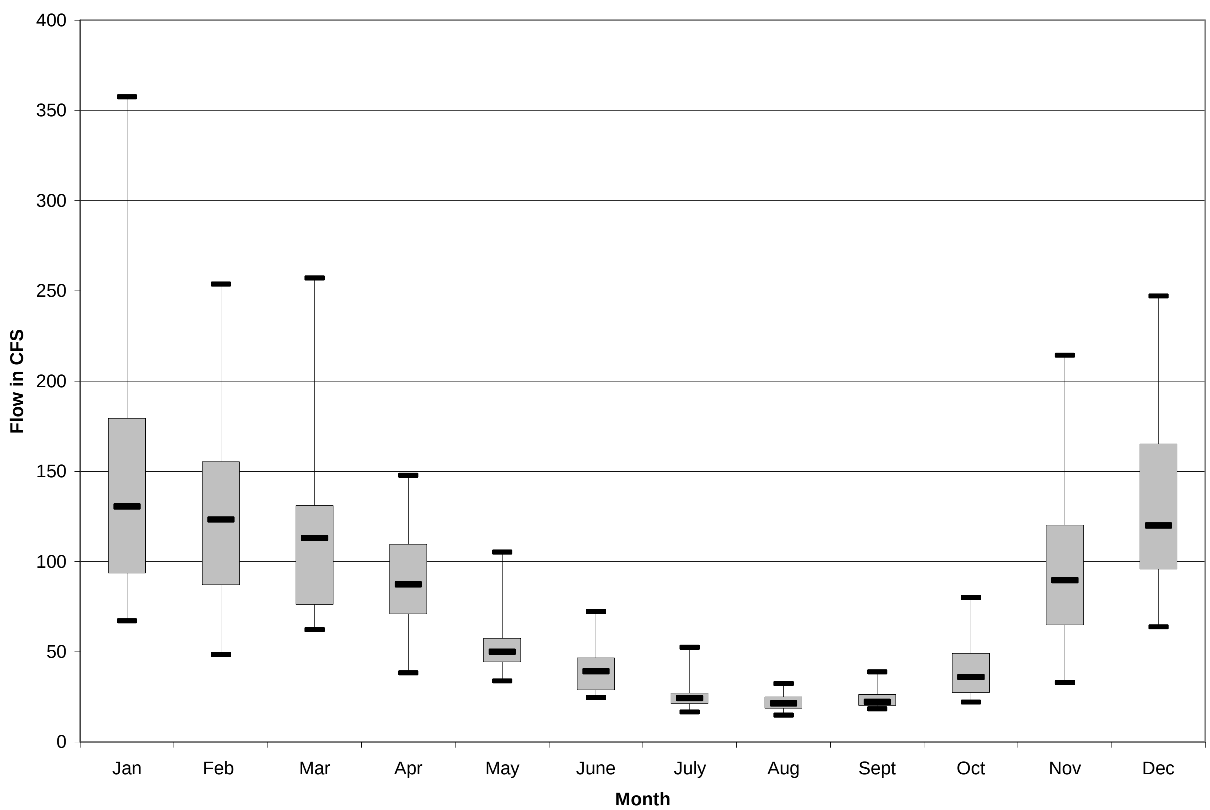


Figure 10. Average monthly flow for Station 02a, Bear Creek Mouth, 1987 to 2005.

For the TMDL study, these flow data will be augmented with the other stream gauges and the instantaneous flow measurements conducted during the synoptic survey.

## Northeast Sammamish Sewer and Water District and Union Hill Water Association

The Northeast Sammamish Sewer and Water District (NESSWD) and the Union Hill Water Association (UHWA) maintain a monitoring network throughout the Evans Creek and lower Bear Creek watersheds. NESSWD and UHWA partnered with King County to establish and maintain three discharge monitoring stations in the Evans Creek system. NESSWD and UHWA monitor air and water temperature at multiple locations, as shown in Figure 11.

RH2, under contract to NESSWD and UHWA, monitored water temperature at 34 sites in the Evans Creek basin in 2002 and 2003 (RH2 Engineering, Inc., 2005). Peak 7DADM temperatures occurred July 21-27, 2002, and July 27-August 2, 2003, as shown in Figure 12. Peak temperatures were lowest at the Rutherford Creek confluence (57.0°F = 13.9°C) and rise to 69.3°F (20.7°C) at the confluence with Bear Creek. Evans Creek is cooler than Bear Creek at the confluence. Below the Bear/Evans confluence, Bear Creek water temperature increases to 72.7°F (22.6°C) before the confluence with the Sammamish River. Figure 13 illustrates the longitudinal profile from 2003, which was similar to 2002 conditions. Riparian vegetation categories were identified by stream reach as four categories: forest, shrubs, grasses, and impervious surfaces.

Based on patterns of riparian vegetation, the study concluded that high temperatures were due to a lack of riparian shade. Recommendations included revegetating stream banks as well as increasing stream complexity and structure.

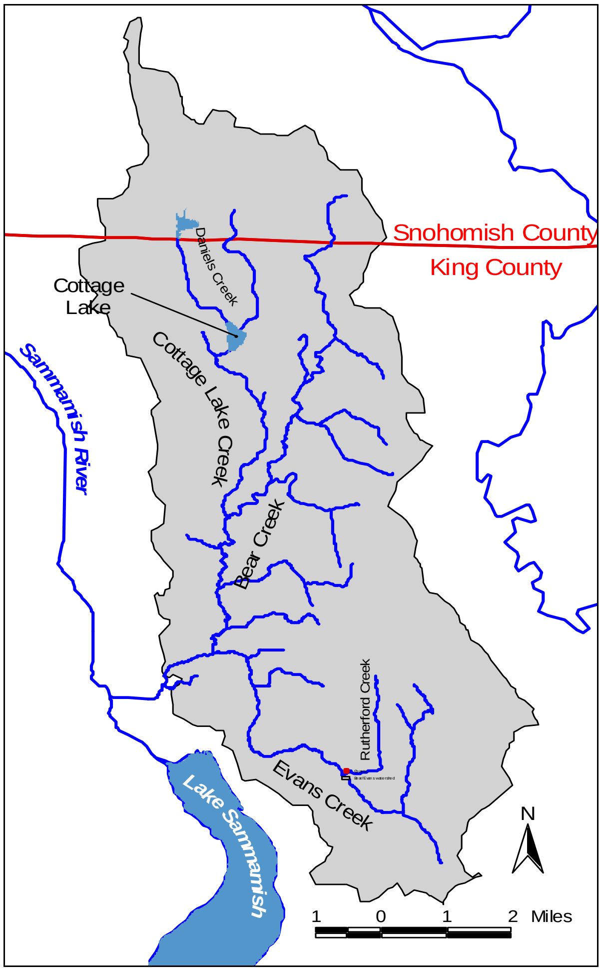


Figure 11. Discharge and water quality monitoring locations operated by Northeast Sammamish Sewer and Water District and Union Hill Water Association.


Figure 12. Peak 7DADM temperatures in the Evans Creek and lower Bear Creek system in 2003. Source: RH2 Engineering, Inc. (2005).

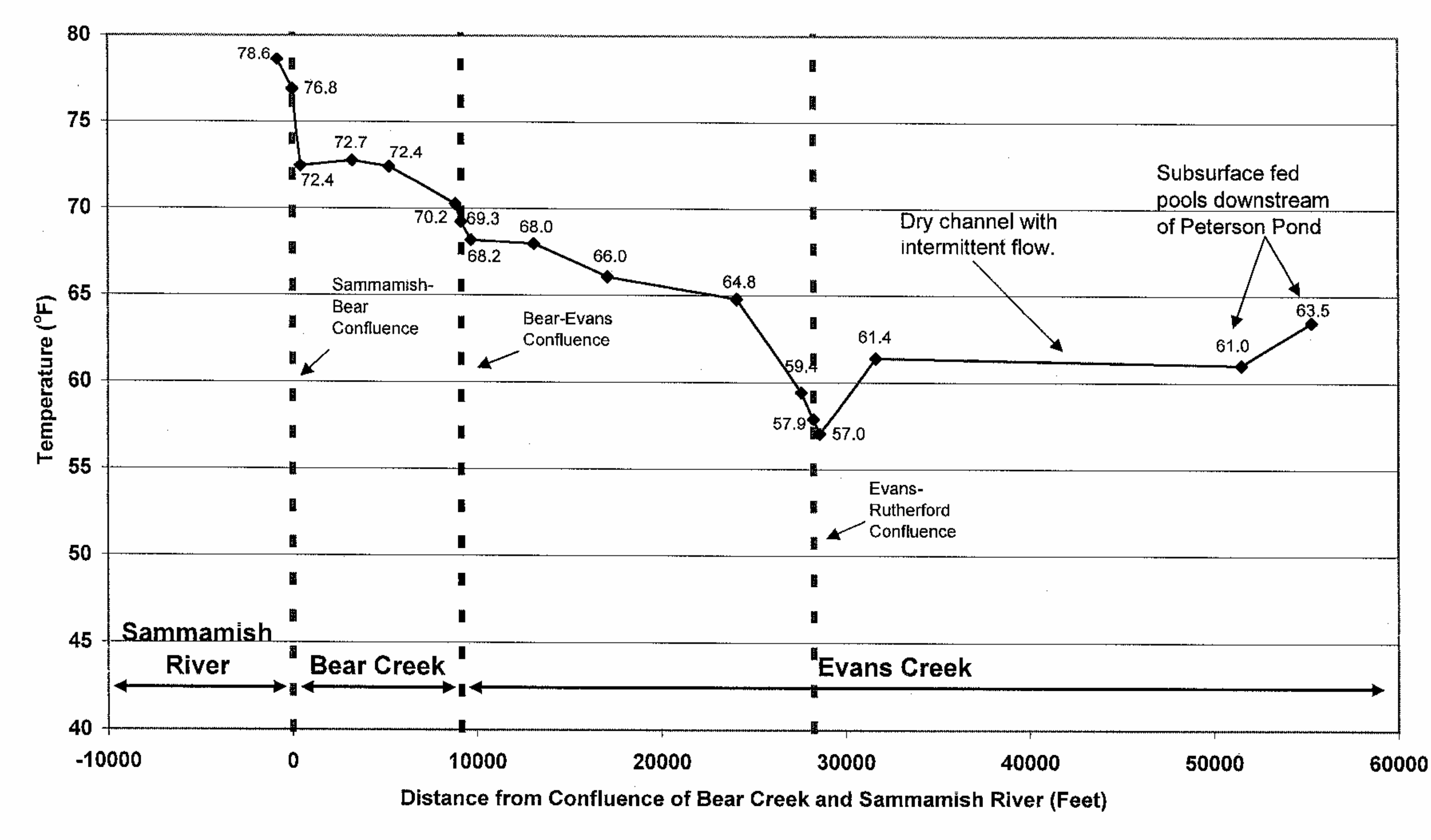


Figure 13. Longitudinal temperature profile in the Evans Creek and lower Bear Creek system in 2003. Source: RH2 Engineering, Inc. (2005).

## City of Redmond

The City of Redmond initiated a surface water quality and stream flow monitoring program in 1995. Since the larger mainstem rivers and creeks that flow through the city (Sammamish River, Bear and Evans creeks) were already being monitored by regional jurisdictions (U.S. Army Corps of Engineers, U.S. Geological Survey, and King County) the city decided to focus on monitoring the numerous smaller tributary streams that flow into these larger systems. For several years, data collection was mostly directed to the more heavily urbanized tributaries that flow to the Sammamish River, but as City development increasingly moved to the east and north, new sampling stations were added to the tributaries that drained to Bear Creek.

Redmond's historic flow data from Bear Creek watershed is limited to records from Perrigo Creek at Avondale Way (a natural tributary stream; 1995-2000) and the Redmond Way Outfall (principally stormwater; 1995-98; 2002) that discharges directly to lower Bear Creek. Water quality sampling of dissolved oxygen, water temperature, conductivity, pH, and turbidity--collected at two-week intervals--was conducted at these same stations between 1995 and 1998-1999. Quarterly water quality sampling (expanded to include total phosphorous and fecal coliform) continued at the Redmond Way Outfall between 2001 and 2003, as well as at two more northerly tributaries of Bear Creek: Avondale at NE 104 Street (principally stormwater) and Avondale at NE 116 Street (a natural tributary stream). Comprehensive analysis (2004) of Redmond's prior surface water data identified several concerns within these portions of the Bear Creek watershed. All of the sites violated state standards for fecal coliform and all of the sites except Avondale at NE 116 Street failed to meet state standards for dissolved oxygen. The Avondale at NE 104 Street site also violated state standards for high water temperature. Following this analysis, Redmond adopted Ecology's WQI methodology citywide. Specifically the city added total nitrogen and total suspended sediment to previously measured parameters and initiated sampling at six new stations on small tributary streams that drain to Bear Creek (Figure 14). Benthic invertebrate sampling has now been conducted at several of these locations.

As part of this proposed TMDL study, Redmond will install continuous recording water temperature instruments (HOBO pendant temperature data loggers, from Onset Computer Corp., Pocasset, MA) just above the mouths of Mackey Creek and four other smaller tributaries of Bear Creek, within the city's jurisdiction. A second set of HOBOs will be installed well upstream within each of these same creek systems (Figure 14) thus providing knowledge of spatial, as well as temporal, temperature gradients. These instruments will collect data over the hottest months of the late summer and early fall. The city also plans to use hand-held instruments to obtain instantaneous stream flow and dissolved oxygen measurements, at these same locations, during the time period that the basin-wide TMDL data are being collected.

## Ecology

The monitoring network of the Ecology ambient program does not include stations in the Bear/Evans system. The only water quality data are associated with a single benthic sample collected in 1999.

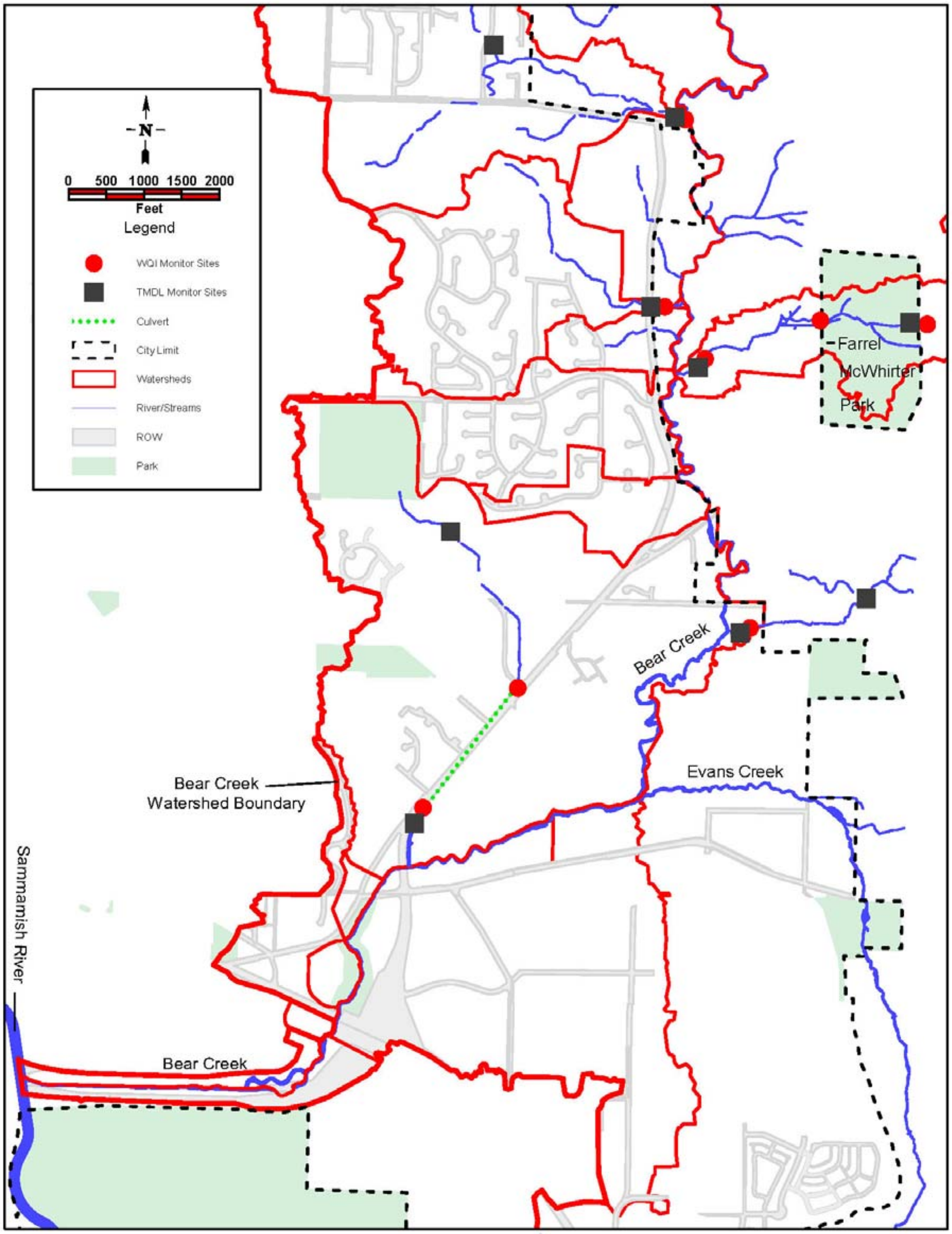


Figure 14. City of Redmond water quality monitoring stations.

# Organization and Schedule

Ecology is responsible for submitting water quality cleanup plans to EPA for approval. However, under the cooperative effort in Bear/Evans, staff from Ecology, King County, City of Redmond, and others will share monitoring program responsibility. Table 4 presents the schedule for completion and specific institutional responsibilities. Specific field programs are described under Experimental Design.

Table 4. Bear/Evans data collection, model development, and TMDL development schedule and responsibilities.

| Task | Schedule for Completion | Responsibility |
|---|---|---|
| Continuous Temperature Monitoring | July and August, 2006 | Ecology, in coordination with NESSWD/ UHWA and City of Redmond |
| Continuous Dissolved Oxygen Monitoring | July and August, 2006 | King County, with some support from Ecology |
| Synoptic Productivity Monitoring | July and August, 2006 | King County, with some support from Ecology |
| Synoptic Flow and Travel Time | August 2006 | Ecology, with some support from King County and others |
| Periphyton Monitoring | July and August, 2006 | Ecology, with optional support from field teams |
| Riparian Shade Development | July through September, 2006 | King County, with some support from Ecology |
| Temperature Model Development | Fall 2006 through Spring 2007 | Ecology, with some support from King County |
| Dissolved Oxygen Model Development | Fall 2006 through Spring, 2007 | Ecology, with some support from King County |
| Draft TMDL Technical Report | July 2007 | Ecology, with some support from King County |
| Final TMDL Technical Report | October 2007 | Ecology, with some support from King County |
| TMDL Submittal Report | October 2007 | Ecology |
| Detailed Implementation Plan | October 2008 | Ecology |
| Final EIM Data Processing | December 2006 | Ecology |

Ecology Environmental Assessment Program staff will coordinate the overall field program with teams assembled from all participating organizations.

Study Tracker Schedule

| Environmental Information System (EIM) Data Set (If Applicable) | |
|---|---|
| EIM Data Engineer | Nuri Mathieu |
| EIM User Study ID | MROB002 |
| EIM Study Name | Bear/Evans Temperature and DO TMDL |
| EIM Completion Due | 6-30-07 |
| **Final Report** | |
| Report Author Lead | Pending, WQSU |
| Schedule | |
| Report Supervisor Draft Due | December 2007 |
| Report Client/Peer Draft Due | January 2008 |
| Report External Draft Due | February 2008 |
| Report Final Due (Original) | June 2008 |

# Experimental Design

Several water quality monitoring programs will be conducted to develop temperature and dissolved oxygen model input and output data during short-term studies conducted during critical conditions.

Monitoring includes in situ continuous data and instantaneous values as well as grab samples collected for laboratory analysis.  Table 5 summarizes the experimental design.  Appendix 3 describes specific monitoring locations.

Table 5.  Station summary by monitoring program.

| Program | Parameter | Type | Equipment | Bear Creek | Evans Creek |
|---|---|---|---|---|---|
| Continuous Temperature and DO | Water temperature | Continuous | TidBit | 14 stations | 10 stations |
| | Air temperature | Continuous | TidBit | 4 stations | 2 stations |
| | Relative humidity | Continuous | RH probe | 4 stations | 2 stations |
| | DO, pH, temperature, conductivity | Continuous | YSI | 8 stations | 5 stations |
| Synoptic Productivity | DO, pH, temperature, conductivity | Instantaneous in situ | YSI and Hydrolabs | 15 stations | 10 stations |
| | Total nitrogen and total phosphorus | Grab samples, unfiltered | (laboratory) | 15 stations | 10 stations |
| | Dissolved nutrients (nitrate+nitrite, ammonia nitrogen, orthophosphorus) | Grab samples, filtered | (laboratory) | 15 stations | 10 stations |
| | Chlorophyll a | Grab samples | (laboratory) | 15 stations | 10 stations |
| | TOC, DOC, alkalinity | Grab samples | (laboratory) | 15 stations | 10 stations |
| | Periphyton | Grab samples | (see Methods) | 8 stations | 5 stations |
| Synoptic Flow and Travel Time | Discharge | Instantaneous in situ | Flow meter and wading rod | 15 stations | 10 stations |
| | Tracer concentration | Continuous | Fluorometer | 3 release and 4 monitoring stations | 3 release and 3 monitoring stations |
| Shade | Riparian shade | Instantaneous in situ | Hemiview camera | 14 stations | 5 stations |

## Continuous Temperature and Dissolved Oxygen Monitoring

Continuous temperature data will provide daily minimum and maximum values for model calibration and validation. Both air temperature and water temperature are necessary to model creek conditions. Figure 15 identifies the relative humidity, air, and water temperature monitoring locations. Because elevation differences are small within the Bear/Evans system, air temperature TidBits and relative humidity probes will be deployed at a subset of six sites. Probes will be installed on or around July 15 and removed on or around August 15.

Continuous dissolved oxygen data will provide minimum and maximum values for model calibration and validation. Figure 16 indicates monitoring locations where equipment will be deployed during two-week periods for three to four days at a time. Depending on equipment available, deployment may be staggered, with six sites monitored in the Bear Creek watershed during a different period than the five sites in the Evans Creek watershed. However, all monitoring should occur during summer low-flow conditions, likely between July 15 and August 15, 2006. Equipment will record dissolved oxygen, temperature, pH, and conductivity.

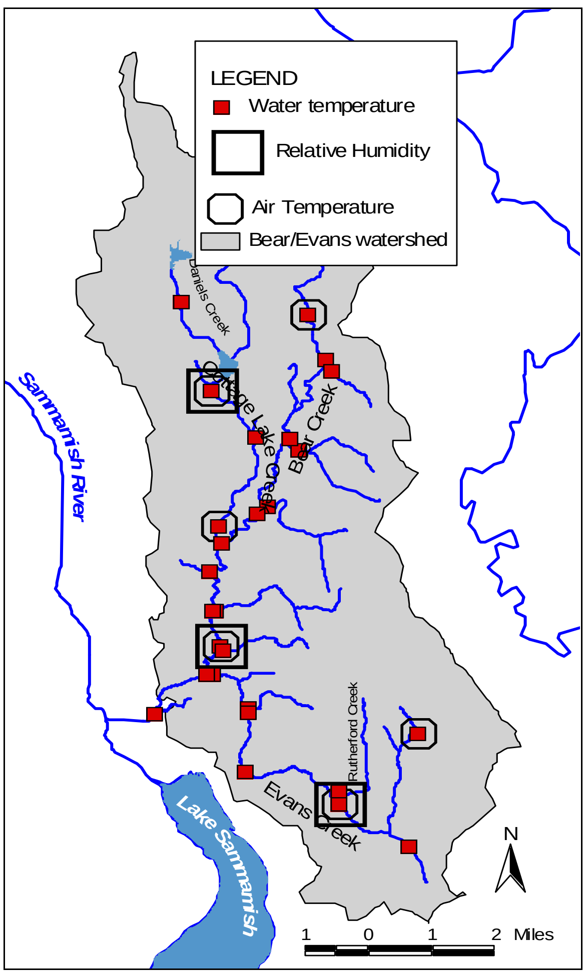


Figure 15. Monitoring locations for continuous water temperature (red squares) as well as air temperature and relative humidity (open symbols).

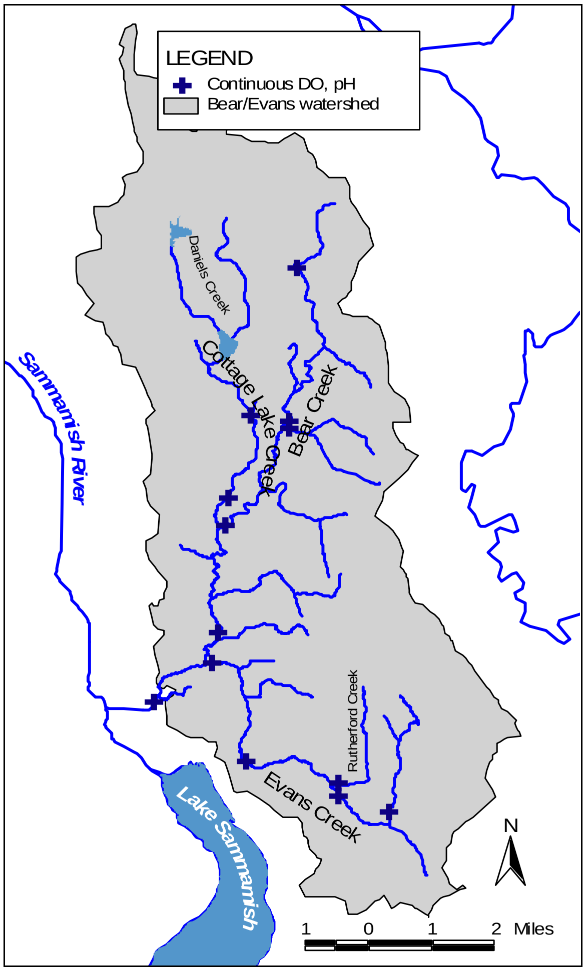


Figure 16. Monitoring locations for continuous dissolved oxygen monitoring.

## Synoptic Productivity Monitoring

River temperature and dissolved oxygen generally reach critical levels during late July or early August when discharge approaches summer low-flow conditions. A synoptic monitoring program will be conducted over a two-day period in the Bear/Evans watershed to characterize water quality parameters relevant to modeling temperature and dissolved oxygen. Figure 17 presents the proposed monitoring locations.

Field teams will record in situ parameters (temperature, dissolved oxygen, pH, and conductivity) and collect representative grab samples for laboratory analysis early in the morning and late in the afternoon on two consecutive days. Timing will depend on summer 2006 hydrologic conditions, but monitoring will be conducted near baseflow and outside periods influenced by storm events. Grab samples will be analyzed for total nitrogen, nitrate plus nitrite, ammonium, total phosphorus, soluble reactive phosphorus, total organic carbon, dissolved organic carbon, alkalinity[2], and chlorophyll a. Samples will be delivered to the laboratory once per day.

Field teams will characterize periphyton density at a subset of sites located on the main stem of both Bear and Evans creeks. Periphyton biomass will be estimated at four sites within the Bear Creek watershed and three sites within the Evans Creek watershed. Figure 18 presents the locations. Methods are described in Sampling Procedures and In Situ Measurement Procedures.

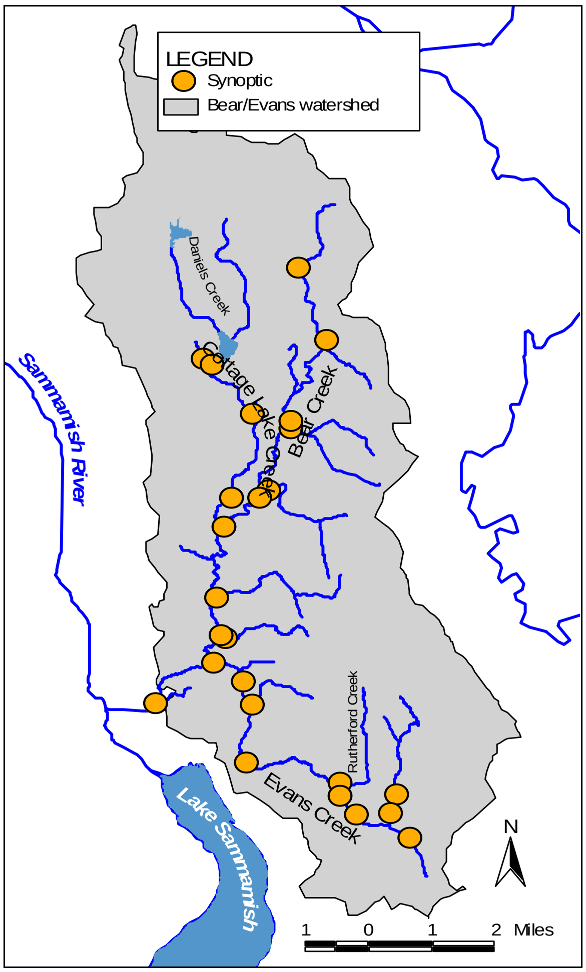


Figure 17. Synoptic monitoring locations in the Bear/Evans watershed.

[2] For pH simulation.

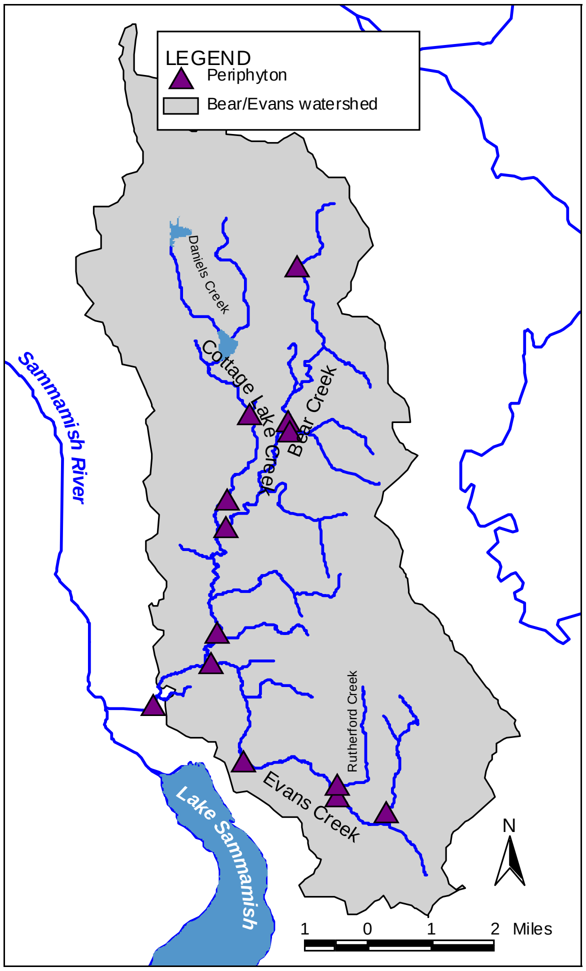


Figure 18. Periphyton monitoring locations in the Bear/Evans watershed.

## Synoptic Flow and Travel Time

How water moves around strongly influences water quality in the system. Knowledge of the fine-scale distribution of flows within a watershed enables the calculation of groundwater inputs, which will influence temperature and dissolved oxygen. Travel time provides a fundamental model calibration and validation parameter and also enhances understanding of the system.

The flow distribution will be established during synoptic flow studies conducted during summer low-flow conditions. The fine-scale data at several sites will complement the long-term monitoring data at King County flow monitoring locations[3]. Figure 19 presents the monitoring locations where discharge will be recorded. If the number of field teams is limited, the survey can extend over two days; however, surveys must occur when baseflow conditions are present. Replicate flows will be collected to verify the comparability of field measurements at three sites,

[3] Instantaneous flow will be recorded at the King County gaging locations to compare with the stage-discharge relationship. Because small differences in flows will be significant, the gaging record cannot substitute for detailed flow monitoring throughout the watershed.

as described in Sampling Procedures and In Situ Measurement Procedures. The synoptic flow survey should coincide with the synoptic water quality monitoring survey described above.

In addition, a tracer study will be conducted simultaneously and will be led by Ecology field teams. The shallow water depths preclude the use of drogues. Thus, dissolved tracers will provide the best information on travel time and dispersion, both important parameters for modeling. Field protocols are included with Sampling Procedures and In Situ Measurement Procedures. Figure 20 summarizes the release locations and downstream monitoring stations within the Bear/Evans system. Final travel time estimates between each release and monitoring station will be calculated based on the time of arrival of peak concentration and length of stream reach. Dispersion will be calculated from the spread of the plume.

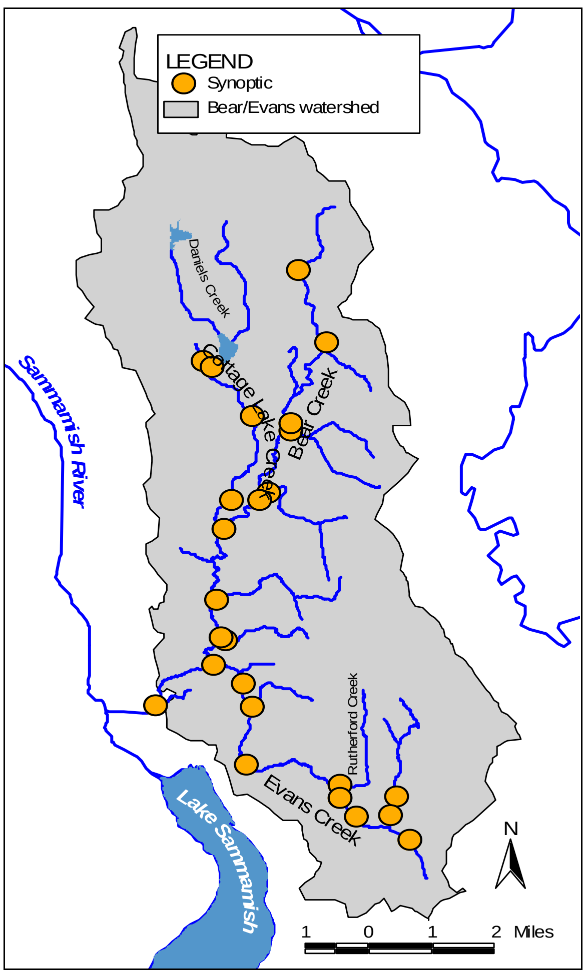


Figure 19. Synoptic flow monitoring locations within the Bear/Evans watershed.

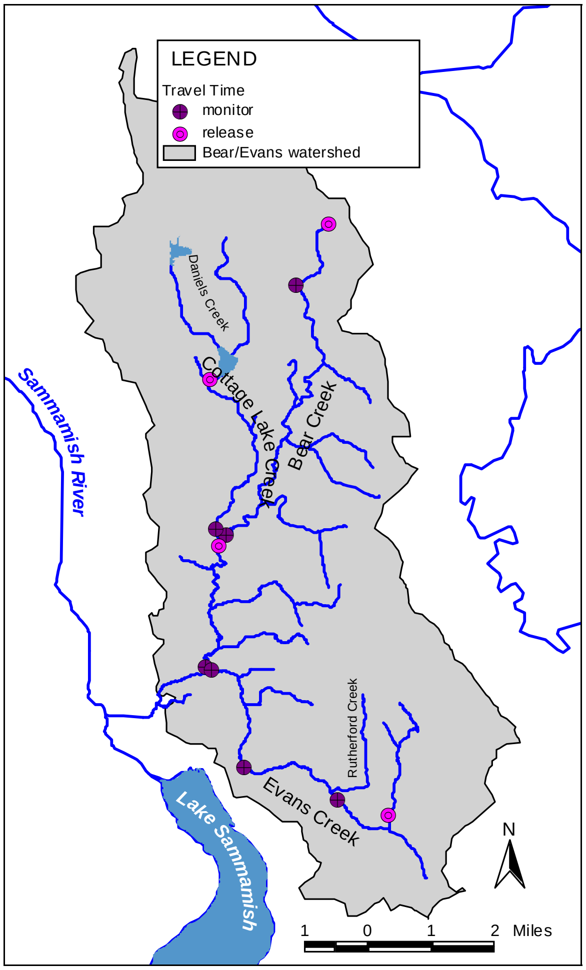


Figure 20. Tracer study release and monitoring locations within the Bear/Evans watershed.

Initial rough estimates of travel times between stations are presented in Table 6. The values are estimated from Manning's equation using a hydraulic radius of 0.15 m (0.5 ft), a Manning's coefficient of 0.1, and valley slopes estimated from a 10-m digital elevation model (DEM). Results indicate that at least three releases will be necessary to characterize travel time in the Bear Creek system. Because of the low gradients of the Evans Creek system, the tracer study may be subdivided into two separate releases to minimize the amount of dye used.

Table 6. Approximate travel time characteristics.

| From | Elevation (m) | To | Elevation (m) | Length (mi) | Slope | Velocity (ft/s) | Travel Time (hr) |
|---|---|---|---|---|---|---|---|
| Cottage Lake | 70 | Cottage Lake Creek/ Bear Creek confluence | 27 | 3 | 0.009 | 0.9 | 5 |
| Paradise Lake | 145 | Bear Creek valley bottom | 78 | 1 | 0.042 | 2 | 0.8 |
| Bear Creek valley bottom | 78 | Cottage Lake Creek/ Bear Creek confluence | 27 | 4 | 0.008 | 0.8 | 7 |
| Cottage Lake Creek/ Bear Creek confluence | 27 | Bear Creek/ Evans Creek confluence | 15 | 2.5 | 0.003 | 0.5 | 7 |
| Peterson Pond | 140 | Evans Creek valley bottom | 34 | 1.5 | 0.044 | 2 | 1.1 |
| Evans Creek valley bottom | 34 | Bear Creek/ Evans Creek confluence | 15 | 5.5 | 0.002 | 0.4 | 19 |

## Riparian Shade Development

Ongoing efforts by King County will determine whether available Light Distance and Ranging (LiDAR) data can be used to estimate riparian shade in small streams (DeGasperi, personal communication with Mindy Roberts). If the LiDAR data are not available or cannot be used, a small-scale riparian shade study will be conducted. However, if the LiDAR-based method provides sufficient shade estimates, the proposed study will not be conducted. The LiDAR-based method will be documented in subsequent publications by King County staff, based in part on DeGasperi (2004).

Riparian vegetation characteristics will be developed from imagery and field observations. Riparian vegetation patterns within 150 meters of the stream channel will be digitized from orthophotos. Vegetation classes, consisting of height and density, will be assigned based on orthophotos and field observations, possibly using the methods described in Roberts (2003). Hemispherical photography will be used to measure shade in situ at monitoring locations shown in Figure 21.

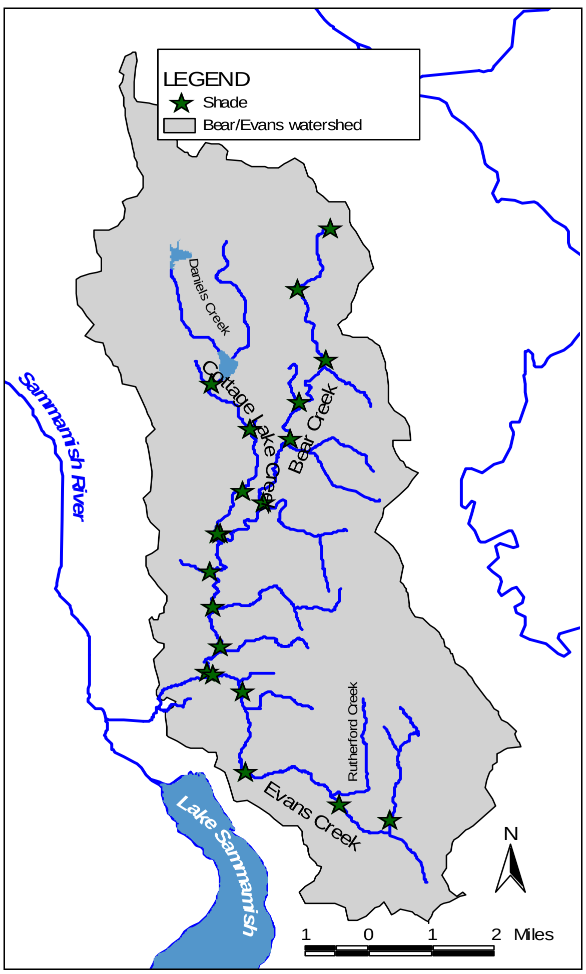


Figure 21. Locations for in situ riparian shade measurements using hemispherical photography in the Bear/Evans system.

# Quality Control

## Measurement Quality Objectives

Measurement quality objectives (MQOs) refer to the performance or acceptance criteria for individual data quality indicators such as precision, bias, and lower reporting limit. MQOs provide the basis for determining the procedures that should be used for sampling and analysis.

Field studies are designed to generate data adequate to reliably estimate the temporal and spatial variability of that parameter. Sampling, laboratory analysis, and data evaluation steps have several sources of error that should be addressed by MQOs. Accuracy in laboratory measurements can be more easily controlled than field sampling variability. Analytical bias needs to be as low and precision as high as possible in the laboratory. Sampling variability can be controlled somewhat by strictly following standard procedures and collecting quality control samples, but natural spatial and temporal variability can contribute greatly to the overall variability in the parameter value. Resources limit the number of samples that can be taken at one site spatially or over various time intervals. Finally, laboratory and field errors are further amplified by estimate errors in loading calculations and model results.

Precision is the degree of agreement between replicate analyses of a sample under identical conditions and is a measure of the random error associated with the analysis, usually expressed as Relative Percent Difference (RPD) or Relative Standard Deviation (RSD). Accuracy is the measure of the difference between an analytical result and the true value, usually expressed as percent. The accuracy of a result is affected by both systematic errors (bias) and random errors (imprecision). Bias is the systematic or persistent distortion of a measurement process that causes errors in one direction. Precision, accuracy, and bias for water quality data may be measured by one or more of the following quality control procedures: method blanks, matrix spikes, certified reference materials, replicates, positive controls, and negative controls. These are discussed under Sampling Procedures and In Situ Measurement Procedures.

Representativeness expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at the sampling point, or an environmental condition. Samples for analysis will be collected from stations with pre-selected coordinates to represent specific site locations. Sample collection procedures are assigned to minimize variations, potential contamination, and other types of degradation in the chemical and physical composition of the water. Following standard field protocols will ensure that samples are representative. Laboratory representativeness is achieved by proper preservation and storage of samples along with appropriate subsampling and preparation for analysis.

Completeness is defined as the total number of samples analyzed for which acceptable analytical data are generated, compared to the total number of samples collected. Sampling at stations with known position coordinates in favorable conditions and at the appropriate time points, along with adherence to standardized sampling and testing protocols, will aid in providing a complete data set for this project. The goal for completeness is 100%.

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared with another. This goal is achieved through using standardized techniques to collect and analyze representative samples, along with standardized data validation and reporting procedures.

# Sampling Procedures and In situ Measurement Procedures

## Discharge and Water Quality Monitoring

Field procedures will follow standard operating procedures (King County Environmental Lab, 2002a, 2002b, 2004, 2005a-f). Collecting replicate samples will assess total variation for field sampling and laboratory analysis and thereby provide an estimate of total precision. Table 7 summarizes the field and laboratory quality control program.

Table 7. Summary of field and laboratory quality control samples.

| Analysis | Field Replicates | Lab Check Standard | Lab Method Blank | Lab Duplicate | Matrix Spikes |
|---|---|---|---|---|---|
| **Field Measurements** | | | | | |
| Velocity/Discharge | 1/day | N/A | N/A | N/A | N/A |
| Temperature | 1/10 | N/A | N/A | N/A | N/A |
| Dissolved Oxygen | 1/10 | N/A | N/A | N/A | N/A |
| Specific Conductivity | 1/10 | 1/run | N/A | N/A | N/A |
| pH | 1/10 | 1/10 | N/A | N/A | N/A |
| **Laboratory Analyses** | | | | | |
| Dissolved Oxygen (Winkler) | 1/10 samples | N/A | N/A | N/A | N/A |
| Chlorophyll a | 1/10 samples | N/A | N/A | 1/20 samples | N/A |
| Total Organic Carbon | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Dissolved Organic Carbon | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Alkalinity | 1/10 samples | 1/day | N/A | 1/20 samples | N/A |
| Total Nitrogen | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Ammonia Nitrogen | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Nitrate plus Nitrite Nitrogen | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Orthophosphate | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |
| Total Phosphorus | 1/10 samples | 1/day | 1/day | 1/20 samples | 1/20 samples |

### In situ Measurements

Field sheets are printed on *Rite in the Rain* paper. Each station has a set of field observation parameters that must be filled in by field personnel prior to or during sampling. Any field observations should be written on field sheets at the time of observation.

A field measurement replicate is defined as a separate in situ measurement made following all procedures typically done between individual measurements. The probe typically would be removed from the waterbody and then returned to the same depth and position used in the original measurement.

One field replicate per ten samples should be analyzed to assess precision of the temperature, dissolved oxygen, conductivity, and pH sensors. If any of the parameters are found to be outside of control limits, the sensors must be recalibrated before further use. Upon returning to the lab, a post-run analysis of dissolved oxygen, conductivity, and pH should be completed and documented in the YSI Quality Control (QC) notebook. If QC results are found to be outside of control limits, results may be qualified according to standards documented in the King County Environmental Laboratory's (KCEL) Quality Assurance Manual (King County Environmental Laboratory, 2006).

**Continuous Temperature and Dissolved Oxygen Monitoring**

The Onset StowAway TidBits will be pre- and post-calibrated by Ecology in accordance with standard Ecology protocols (Ward et al., 2001)[4] to document instrument bias and performance at representative temperatures. A National Institute of Standards and Technology (NIST) certified reference thermometer will be used for the calibration. At the completion of monitoring, the raw data will be adjusted for instrument bias, based on the pre- and post-calibration results, if the bias is greater than +0.2°C. Variation for field sampling of instream temperatures will be addressed with a field check of the data loggers with a hand-held alcohol thermometer at all sites upon deployment, download events, and at TidBit removals at the end of the study period. Field sampling and measurements will follow standard Ecology quality control protocols.

Extended deployment YSI measurements will be performed consistently with the protocols defined in KCEL Standard Operating Procedures (SOP) #02-01-008-001 YSI Multiprobe Operation (in draft). Following calibration, each YSI sonde will be taken into the field and deployed at selected locations for three to four days. Sondes will be secured by steel cable, locked to a permanent structure, and placed in the thalweg at each site. Every effort will be made to secure the sondes from vandalism. The sondes will collect temperature, dissolved oxygen, specific conductivity, and pH readings at 15 minute intervals throughout deployment. After the deployment period, the sondes will return to the lab for a post deployment end check and data upload.

Once in the field, conductivity and pH check standards will be run to assess accuracy and instrument drift. A field replicate for a YSI measurement is: a) placing a second sonde in the water and allowing it to equilibrate, b) waiting for a measurement time to roll over (15- minute increment) on both YSIs, and c) downloading the replicate YSI at the end of the day and matching time-stamped measures with their appropriate location and primary sonde measurement. Acceptance limits for the YSI parameters are described in KCEL (2002a) and summarized in Table 8.

YSI QC sheets are intended for documentation of YSI QC samples. This includes initial calibration, continuing calibration verification replicates, duplicates, and post-run calibration check. The analyst will include the calibration and analysis date; standard lot numbers and concentrations; and instrument readings, recovery calculations, and initials.

[4] Revised protocol is to calibrate with equipment set to 1-minute intervals instead of 5-minute intervals.

All maintenance and instrument work should be noted in the YSI logbooks. Each entry is to be dated and signed.

Table 8. Hydrolab and YSI quality control requirements.

| **Hydrolab** | | | |
|---|---|---|---|
| Parameter | Replicate Samples | Field Calibration Check Standards | Calibration Drift End Check |
| Dissolved Oxygen | RPD ≤ 20% | Not applicable | ± 4 % |
| Temperature | ± 0.3 $^{o}$C | Not applicable | Not applicable |
| Conductivity | RPD ≤ 10% | ± 10 % | ± 10 % |
| pH | ± 0.2 pH units | ± 0.2 pH units | ± 0.2 pH units |

| **YSI** | |
|---|---|
| Parameter | Post-Deployment Calibration Check Acceptance Limits |
| Dissolved Oxygen | ±10 % |
| Temperature | Not applicable |
| Conductivity | ± 10 % |
| pH | ± 0.3 pH units |

## Flow Measurements

All flow measurements will follow standard Ecology protocols and King County Environmental Laboratory's SOP (2002b). Streamflow measurements will be conducted at each sampling location during steady, low-flow conditions. Water depth and velocity will be recorded at a minimum of five to seven cross sections using wading rods and velocity meters calibrated to manufacturer's recommendations. Field teams will use consistent techniques described at a pre-sampling meeting to minimize variability among teams.

## Sample Collection

Samples are collected by one of three methods. Grab sampling by hand-dipping sample bottles is one method that does not require decontamination techniques. The cap is removed from the bottle and it is simply dipped into the stream or river. Using a bucket with a bottom drain or a Richards bottle requires scrubbing with a brush and reverse osmosis water at the lab, followed by thoroughly rinsing three times with ambient stream water to be sampled.

Samples will be collected from the thalweg, within free-flowing stream sections, and away from channel boundaries. Where access is from a bridge, the sample will be collected from the upstream side. These procedures are described in King County Environmental Laboratory's SOP (2005e).

## Travel Time

Pulses of sufficient rhodamine dye solution will be released to achieve a measurable fluorescence at each downstream station[5]. Fluorometers will be deployed at each monitoring location to record dye concentrations at 30-minute intervals.

## Riparian Shade

HemiView images will be recorded within the stream channel at discharge monitoring locations. The images will be processed using standard Ecology procedures to determine in situ shade levels for comparison with predicted values. In addition, if the LiDAR-based shade estimates are insufficient, field observations of riparian vegetation characteristics will be recorded at flow monitoring locations or at sites selected from orthophotos.

## Periphyton Biomass

Periphyton biomass samples will be collected by scraping material from a measured surface area on representative rocks. Three samples will be collected at each site. The material will then be analyzed for chlorophyll a and ash-free dry weight (Joy, 2001).

# Laboratory Measurement Procedures

All water samples will be analyzed by the King County Environmental Laboratory using Standard Operating Procedures. Table 9 lists measurement procedures by parameters. The method detection limit (MDL) is defined as that concentration at which an analyte can be detected reliably. The reporting detection limit (RDL) is defined as that concentration at which an analyte can be quantified reliably.

Dissolved nutrient samples will be filtered within 24 hours of collection using 0.45-micron filters. Syringes will be triple rinsed prior to filtering. The first 10 to 20 mL of sample extracted through a pre-cleaned filer will be discarded.

Each sample run should include at least one field replicate for each parameter to be analyzed in the laboratory. At a minimum, 10% of the samples will be field replicates. Field replicates are collected using the same methodology as the original samples or as close temporally to the original sample as possible. The field replicate is not distinguishable from the original sample except by sample number and collection time.

Samples should be delivered to the analytical laboratory daily. This minimizes the number of people handling samples and protects sample quality and security. All samples are to be placed in a cooler with ice and a plastic barrier. This will keep the samples at or near 4°C until they arrive at the lab.

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[5] Research has shown the dye does not affect human health in any way at the very low concentrations used. Rhodamine dye is commonly used for this type of scientific study by the Department of Ecology and Department of Health.

At the analytical laboratory, the sample manager should oversee:

- Receipt of samples.
- Maintenance of sample management records.
- Maintenance of sample tracking logs.
- Distribution of samples for laboratory analyses.
- Supervision of labeling and log keeping.

Table 9. King County Environmental Laboratory measurement procedures. Units are mg/L for all but alkalinity (mg-$CaCO_3$/L) and chlorophyll a (ug/L).

| Analyte | KCEL SOP | Analytical Method | MDL | RDL | Sample Containers | Hold Time | Field Preservation Method |
|---|---|---|---|---|---|---|---|
| Total Nitrogen | 03-03-013-002 | SM4500-N-C | 0.05 | 0.1 | 125 mL HDPE CWM | 2 days | Cool to 4°C |
| Nitrate+Nitrite Nitrogen | 03-03-013-002 | SM4500-NO3-F | 0.02 | 0.04 | 125 mL HDPE CWM | 2 days | Filter and cool to 4°C |
| Ammonia-Nitrogen | 03-03-012-003 | SM4500-NH3-G | 0.01 | 0.02 | 125 mL HDPE CWM | 2 days | Filter and cool to 4°C |
| Total Phosphorus | 03-03-013-002 | SM4500-P-B,F MOD | 0.005 | 0.01 | 125 mL HDPE CWM | 2 days | Cool to 4°C |
| Orthophosphorus | 03-03-013-002 | SM4500-P-F | 0.002 | 0.005 | 125 mL HDPE CWM | 2 days | Filter and cool to 4°C |
| Total Organic Carbon | 03-04-001-004 | SM5310-B | 0.5 | 1.0 | 40 mL amber glass VOA | 2 days | Cool to 4°C |
| Dissolved Organic Carbon | 03-04-001-004 | SM5310-B | 0.5 | 1.0 | 125 mL amber HDPE CNM | 2 days | Filter and cool to 4°C |
| Alkalinity | 03-03-001-003 | SM2320-B (4C) | 0.2 | 10 | 500 mL HDPE CWM | 14 days | Cool to 4°C |
| Chlorophyll a | 03-02-002S-003 | EPA 446.0/SM 10200 H | 0.15 | 0.3 | 1 L HDPE AWM | 1 day | Cool to 4°C |

King County Environmental Services staff will maintain custody of all samples until delivery to the laboratory. Samples will be delivered on the same day as they are collected and the sample tracking logs will document the date and time of arrival of all samples. Table 10 summarizes quality control requirements.

Table 10. King County Environmental Laboratory quality control requirements.

| Analyte | Method Blank | Replicate RPD | Positive Control Recovery | Matrix Spike %Recovery |
|---|---|---|---|---|
| Total Nitrogen | <MDL | 20% | 85 – 115% | 75 – 125% |
| Nitrate+Nitrite Nitrogen | <MDL | 20% | 85 – 115% | 75 – 125% |
| Ammonia-Nitrogen | <MDL | 20% | 85 – 115% | 75 – 125% |
| Total Phosphorus | <MDL | 20% | 85 – 115% | 75 – 125% |
| Orthophosphorus | <MDL | 20% | 85 – 115% | 75 – 125% |
| Total Organic Carbon | <MDL | 20% | 85 – 115% | 75 – 125% |
| Dissolved Organic Carbon | <MDL | 20% | 85 – 115% | 75 – 125% |
| Alkalinity | N/A | 10% | 85 – 115% | N/A |
| Chlorophyll a | <MDL | 25% | 90 – 110% | N/A |

## Data Verification and Validation

Data verification involves examining the data for errors or omissions as well as examining the results for compliance with QC acceptance criteria. Laboratory results are reviewed and verified by qualified and experienced lab staff, and findings are documented in the case narrative. Field results should also be verified to ensure that data are consistent, correct, and complete, with no errors or omissions; results for QC samples accompany the sample results; established criteria for QC results were met; data qualifiers were assigned where necessary, and methods and protocols are followed.

Ecology Environmental Assessment (EA) Program staff will verify and validate field and laboratory data before entering into Ecology's Environmental Information Management (EIM) system. Ecology's verification/validation will occur after data have been received from KCEL.

Data reported by KCEL must pass a review process before final results are available to the client. A *Peer Review* process is used where a second analyst or individual proficient at the method reviews the data set. The reviewer will complete a data review checklist which will document the completeness of the data package and if any QC failures exist.

Once data review is complete and all data quality issues have been resolved or corrected, the status of the data in LIMS will be changed to *approved*. Once a data set has been approved, it is *posted* or transferred to the portion of the LIMS database known as the Environmental Data System (EDS) where all historical LIMS data are maintained. Signatures or initials of the lab lead and reviewer(s) indicate formal approval of hardcopy data or reports (non-LIMS), typically on the review checklist. A copy of this approved checklist should be stored with the final hardcopy data package. Table 11 presents laboratory data qualifiers. When data are entered into Ecology's EIM system, the standard EIM qualifiers, which differ from those used by KCEL, will be used.

For field data entered into LIMS, a copy of the LIMS data review report, workgroup report, QC report, field sheet, and Hydrolab calibration form are reviewed by a second individual familiar with the procedure before the data is approved in LIMS. For the YSI data that are collected during the extended deployments and not entered into LIMS, a second individual familiar with the procedure will review the Excel spreadsheet and verify the completeness of the data, identify any anomalies and ensure QC specifications have been met. Any questionable data will be flagged and the project manager notified. A peer-reviewed Excel spreadsheet containing the data files, a copy of the YSI QC sheet, and any field notes will be presented electronically to the project manager.

Table 11. King County Environmental Laboratory data qualifiers.

| Qualifier | Description |
|---|---|
| **General** | |
| H | Indicates that a sample handling criterion was not met in some manner prior to analysis. The sample may have been compromised during the sampling procedure or may not comply with holding times, storage conditions, or preservation requirements. The qualifier will be applied to applicable analyses for a sample. |
| R | Indicates that the data are judged unusable by the data reviewer. The qualifier is applied based on the professional judgment of the data reviewer rather than any specific set of QC parameters and is applied when the reviewer feels that the data may not or will not provide any useful information to the data user. This qualifier may or may not be analyte-specific. |
| <MDL | Applied when a target analyte is not detected or detected at a concentration less than the associated method detection limit (MDL). MDL is defined as the lowest concentration at which an analyte can be detected. The MDL is the lowest concentration at which a sample result will be reported. |
| <RDL | Applied when a target analyte is detected at a concentration greater than or equal to the associated MDL but less than the associated reporting detection limit (RDL). RDL is defined as the lowest concentration at which an analyte can reliably be quantified. The RDL represents the minimum concentration at which method performance becomes quantitative and is not subject to the degree of variation observed at concentrations between the MDL and RDL. |
| RDL | Applied when a target analyte is detected at a concentration that, in the raw data is equal to the RDL. |
| TA | Applied to a sample result when additional narrative information is available in the text field. The additional information may help to qualify the sample result but is not necessarily covered by any of the standard qualifiers. |
| **Chemistry** | |
| B | Applied to a sample result when an analyte was detected at a concentration greater than the MDL in the associated batch method blank. The qualifier is applied in Organics analyses when the sample analyte concentration is less than five times the blank concentration and is applied in Conventionals and Metals analysis when the sample concentration is less than ten times the blank concentration. The qualifier indicates that the analyte concentration in the sample may include laboratory contamination.<br>This is an analyte-specific qualifier. |
| J# | Applied to tentatively identified compounds (TIC's) reported for organics analysis. A TIC is a non-target analyte that appears on a chromatogram during sample analysis. The analyst compares the analyte peak to a reference library to obtain the best possible match. The number associated with the J qualifier is the confidence level of the analyte library match. The confidence level varies from 1 (highest confidence) to 4 (lowest confidence). The reported concentration is an estimated value. |
| P | Applied to indicate the presence of the reported analyte above the regulatory reporting limit for the test method. |
| >MR | Applied when a target analyte concentration exceeds the instrument or method capacity to measure accurately. The qualifier is primarily in the organics section. It is applied when the detected analyte concentration exceeds the upper instrument calibration limit and further dilution is not feasible. The reported value is an estimated analyte concentration. |

# Corrective Action Procedures

Individual SOPs describe specific corrective actions for each analytical procedure and QC measure. If QC samples exceed their control limits, the analysis is repeated, if possible, or documented and affected samples qualified. If samples are lost or compromised, the project manager must determine whether to re-sample or to disregard the station for the specific parameter or event.

King County Environmental Laboratory documentation and record keeping will follow standard protocols, as described in Kruger (2002). Within the analytical laboratory, each section and analytical procedure has its own documentation protocol. The minimum documentation required in the lab includes an instrument logbook, analysis log, calibration and analysis documentation, and LIMS hardcopy sheets.

For all analytical results generated by lab activities, sufficient hardcopy data must be stored such that a reviewer could verify that the requirements of the reference method and SOP were met. The format of stored data may include logbook entries, field notes, benchsheets, and printouts of instrument or data files. Storage of only the electronic version of these documents is not sufficient to meet current data storage requirements. Subcontracted tests are to be documented in a similar manner.

## Logbooks

Hand written information used as supporting documentation, which is not stored directly with the analysis results, such as standards preparation records and equipment calibration checks, must be maintained in logbooks. All logbooks must be paginated. Logbooks prepared from instrument printout or other loose pages should be permanently bound prior to storage. Logbook entries should be made using indelible black ink (no pencils) and dated and initialed. Logbooks and individual logbook entries must be uniquely identified if they are to be referenced in other documents. All deletions and corrections must be a single line cross-out, accompanied with the date and initials of the person making the correction.

## Data Packages

For each run or analysis sequence, a data package will be produced which will include all appropriate raw data for standards, samples. and QC analyses. Data packages must include the inclusive dates and times of the analyses and the identity of the analyst(s). If corrective actions were taken or a compromised sample was analyzed, the data package will contain a copy of the Corrective Action Form and/or a Compromised Sample Form (or their equivalent). Specific requirements for the contents of data packages are described in each method SOP. The analyst(s) who generated the data is responsible for compiling the data package and transferring it to the data reviewer. Prior to data review, the data packages are organized according to method SOPs. Data packages may reference other data sets or documents rather than requiring each data package to contain copies of all necessary information. All deletions and corrections to handwritten or printed documentation must be a single line cross-out, accompanied with the date and initials of the person making the correction.

## Storage of Lab Data

Procedures for the storage and disposal of hardcopy lab data are summarized in King County Environmental Laboratory's SOP #11-01-005-000 (Records Storage) which is based on King County and Washington State governmental records storage requirements. It is the policy of the lab to store all data packages, supporting documentation, and project records for a minimum of ten years, based on the date of sample, collection or field data measurement. The subcontract lab is responsible for its own records' storage which should be at least ten years.

In LIMS, the final sample and QC data are maintained indefinitely in the EDS database, which is backed up daily. Additional LIMS information specific to sample management is maintained a minimum of one-year past the date the final results were posted. Other types of electronic data, such as instrument files, may be stored but no lab-wide policy is currently available.

# Data Management Procedures

Two phases of data management will occur. KCEL follows standard data management protocols and will submit the data to Ecology. Ecology will complete data management as described below.

## King County Environmental Laboratory

Once raw data have been generated by an analytical procedure or from field measurements, the data must be transformed into a format appropriate for analysis. For chemistry and selected microbiological parameters, numerical results are entered into LIMS where additional calculations may take place such as conversion of instrumental concentrations to final sample results.

The format used to load data to LIMS and types of calculations done after loading is specified in each method SOP. The adjustment of the number of significant digits and addition of selected data qualifiers is also accomplished by LIMS. For in-lab data loaded to LIMS, automatic calculation of QC results and comparison to acceptance limits is performed by LIMS. However, data for subcontracted samples for chemistry parameters are also entered into the LIMS database. QC results for subcontracted analyses are not entered into LIMS and any data flags must be manually entered.

Data will not be distributed outside each lab unit or to clients until it has met the full definition of final data. *Final Data* is defined as approved data posted to the historical database (EDS) or is otherwise in its final reportable and stored format (if not a LIMS parameter). This implies the data has been appropriately peer reviewed, properly qualified and is in its final format in terms of units and significant figures. Not only is final data assured of a higher level of quality through peer reviewing and qualification, but it will also match any future reports since it has come from the final storage location. The standard method for clients to access final data is either through direct electronic access to LIMS (EDS database) or through hard-copy reports and/or electronic files provided by the Lab Project Manager (LPM) or their equivalent. Direct client access to the EDS database is controlled by access privileges provided by the Information Systems and Data Analysis unit for individual clients. Data reporting via hardcopy through LPMs must follow the guidelines in King County Environmental Laboratory's SOP #11-03-001-001 (Project Report Review Guidelines) before being delivered to the client. Electronic files delivered to clients must also follow King County Environmental Laboratory's SOP #08-01-001-000 (Guidelines for Delivering Electronic Lab Data to Customers).

## Department of Ecology

Field measurement data will be entered into a field book with waterproof paper in the field and then entered into spreadsheets as soon as practical after returning from the field. This database will be used for preliminary analysis and to create a table to upload data into EIM.

Sample result data received from KCEL will be exported prior to entry into EIM and added to a cumulative spreadsheet for laboratory results. This spreadsheet will be used to informally review and analyze data during the course of the project.

An EIM user study (MROB002) has been created for this TMDL study and all monitoring data will be available via the internet once the project data has been validated. The URL address for this geospatial database is: www.ecy.wa.gov/eim/index.html. All data will be uploaded to EIM by the EIM data engineer once it has been reviewed for quality assurance and finalized.

All spreadsheet files, paper field notes, and GIS products created as part of the data analysis and model building will be kept with the project data files.

# Laboratory Budget

King County Environmental Laboratory will analyze all samples. Table 12 summarizes the total number of samples and approximate costs. Ecology's Manchester Environmental Laboratory will not be used for sample analysis.

Table 12. Summary of laboratory analyses performed by King County Environmental Laboratory.

| | High Priority Only |
|---|---|
| Number of Stations | 17 |
| Number of Days | 2 |
| Number of Samples Per Day | 2 |
| **Total Number of Samples** | **68** |
| **Total Cost Per Sample** | **$173** |
| Total Nitrogen | 16 |
| NO23N, NH4N, OP, TP | 53 |
| TP | 0 |
| TOC | 29 |
| DOC | 29 |
| Chlorophyll a | 46 |
| BOD5 | 0 |
| **Total Analytical Costs** | **$11,764** |

# Data Analysis and Use

## Model Descriptions

Several models will be used to evaluate the loading capacity and to determine the wasteload and load allocations necessary to meet the water quality standards.  These are described below and will be applied to the waterbodies and parameters listed in Table 13.

Table 13.  Analyses and models used by waterbody and parameter.

| Waterbody | Parameter | Model | Reference |
|---|---|---|---|
| Bear, Cottage Lake, Evans creeks | Temperature | TTools, Shade, QUAL2K | Ecology (2003a and 2003b) |

Data collection, compilation, and assessment are based on the data requirements of the two models used in this study, which are described below.

### TTools

TTools is an ArcView extension developed by the Oregon Department of Environmental Quality (ODEQ, 2001) to develop GIS-based data from polygon coverages and grids.  The tool develops vegetation and topography perpendicular to the stream channel and samples longitudinal stream channel characteristics, such as the near-stream disturbance zone and elevation.

### Shade Model

Shade.xls was adapted from a program that was originally developed by the Oregon Department of Environmental Quality (ODEQ) as part of the HeatSource model.  Shade.xls calculates shade using one of two optional methods:

- ODEQ's original method from the HeatSource model version 6 (ODEQ, 2003).
- Chen’s method based on the Fortran program HSPF SHADE (Chen, 1996).  The method uses a slightly different approach to modeling the attenuation of solar radiation through the canopy (Chen et al., 1998a and 1998b).

All data will be assembled from field surveys.  Table 14 summarizes specific data requirements.

Table 14. Temperature model data requirements and field data collection parameters.

| | | MODEL | | Field Data Collection |
|---|---|---|---|---|
| | PARAMETER | Shade | Qual2Kw | |
| Flow | discharge - tributary | | x | x |
| | discharge (upstream & downstream) | | x | x |
| | flow velocity | | x | x |
| | groundwater inflow rate/discharge | | x | x |
| | travel time | | x | |
| General | calendar day/date | x | x | |
| | duration of simulation | x | x | |
| | elevation - downstrean | x | x | |
| | elevation - upstream | x | x | |
| | elevation/altitude | x | x | x |
| | latitude | x | x | x |
| | longitude | x | x | x |
| | time zone | x | | |
| Physical | channel azimuth/stream aspect | x | | |
| | cross-sectional area | x | x | x |
| | Manning's n value | x | x | |
| | percent bedrock | x | x | x |
| | reach length | x | x | x |
| | stream bank slope | x | | x |
| | stream bed slope | x | x | x |
| | width - bankfull | x | | x |
| | width - stream | x | x | x |
| Temperature | temperature - groundwater | | x | x |
| | temperature - tributaries | | x | x |
| | temperature - water downstream | | x | x |
| | temperatures - water upstream | | x | x |
| | temperature - air | | x | x |
| Vegetation | % forest cover on each side | x | | x |
| | canopy-shading coefficient/veg density | x | | x |
| | diameter of shade-tree crowns | x | | |
| | distance to shading vegetation | x | | |
| | topographic shade angle | x | | |
| | vegetation height | x | | x |
| | vegetation shade angle | x | | |
| | vegetation width | x | | |
| Weather | relative humidity | | x | x |
| | % possible sun/cloud cover | | x | |
| | solar radiation | | x | x |
| | temperature - air | | x | x |
| | wind speed/direction | | x | x |

## QUAL2K

QUAL2K (Q2K) is a river and stream water quality model that represents a modernized version of QUAL2E (Brown and Barnwell, 1987). QUAL2Kw is adapted from the Q2K model originally developed by Chapra (Pelletier et al., 2005; Chapra and Pelletier, 2003). Q2K is similar to QUAL2E in the following respects:

- *One Dimensional*. The channel is well-mixed vertically and laterally. Non-uniform, steady flow is simulated.
- *Diurnal Heat Budget*. The heat budget and temperature are simulated as a function of meteorology on a diurnal time scale.
- *Diurnal Water-Quality Kinetics*. All water quality variables are simulated on a diurnal time scale.
- *Heat and Mass Inputs*. Point and nonpoint loads and abstractions (withdrawals or losses) are simulated.

The QUAL2Kw framework includes the following new elements:

- *Software Environment and Interface*. Q2K is implemented within the Microsoft Windows environment. It is programmed in the Windows macro language: Visual Basic for Applications (VBA). Excel is used as the graphical user interface.
- *Model Segmentation*. Q2K can use either constant or varying segment lengths. In addition, multiple loadings and abstractions can be input to any reach.
- *Carbon Speciation*. Q2K uses two forms of carbon, rather than BOD, to represent organic carbon. These forms are a slowly oxidizing form (slow carbon) and a rapidly oxidizing form (fast carbon). In addition, non-living particulate organic matter (detritus) is simulated. This detrital material is composed of particulate carbon, nitrogen, and phosphorus in a fixed stoichiometry. Q2K will be used to simulate pH in the Deschutes River and in Capitol Lake.
- *Anoxia*. Q2K accommodates anoxia by reducing oxidation reactions to zero at low oxygen levels. In addition, denitrification is modeled as a first-order reaction that becomes pronounced at low-oxygen concentrations.
- *Sediment-Water Interactions*. Sediment-water fluxes of dissolved oxygen and nutrients from aerobic/anaerobic sediment diagenesis are simulated internally rather than being prescribed. That is, oxygen (SOD) and nutrient fluxes are simulated as a function of settling particulate organic matter, reactions within the sediments, and the concentrations of soluble forms in the overlying waters.
- *Bottom Algae*. The model explicitly simulates attached bottom algae.
- *Light Extinction*. Light extinction is calculated as a function of algae, detritus, and inorganic solids.
- *pH*. Both alkalinity and total inorganic carbon are used to simulate pH.
- *Pathogens*. A generic pathogen is simulated. Pathogen removal is determined as a function of temperature, light, and settling.
- *Hyporheic Exchange and Sediment Pore Water Quality*. Q2K also has the ability to simulate the metabolism of heterotrophic bacteria in the hyporheic zone.

## Temperature Approach

Data collected during this TMDL effort will allow the development of a temperature simulation model that is both spatially continuous and which spans full-day lengths (quasi-dynamic, steady-state diel simulations). The GIS and modeling analyses will be conducted using three software tools:

- Oregon Department of Environmental Quality's TTools extension for ArcView (ODEQ, 2001) will be used to sample and process GIS data for input to the Shade and QUAL2Kw models.
- Ecology's Shade model (Ecology, 2003a) will be used to estimate effective shade along Bear Creek, Cottage Lake Creek, and Evans Creek. Effective shade will be calculated at
- 100-m (330 ft) intervals along the streams and then averaged over 500-m (1600 ft) intervals for input to the QUAL2Kw model.
- The QUAL2Kw model (Chapra, 2001; Ecology, 2003b) will be used to calculate the components of the heat budget and simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw will be applied by assuming that flow remains constant for a given condition such as a seven-day or one-day period, but key variables are allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget described in Chapra (1997). Diurnally varying water temperatures at 500-m (1,640 ft) intervals along the streams in the basin will be simulated using a finite difference numerical method. The water temperature model will be calibrated to instream data along the creeks. Groundwater contributions will be quantified from the synoptic flow study in consultation with previous hydrologic flow modeling conducted by King County using HSPF.

All input data for the Shade and QUAL2Kw models will be longitudinally referenced, allowing spatial and/or continuous inputs to apply to certain zones or specific river segments.

## Dissolved Oxygen, Nutrients, and pH Approach

All water quality data will be entered into Ecology's EIM system. Data will be verified and a random set of 10% of the data entries will be independently reviewed for errors. If errors are detected, another 10% will be reviewed until no errors are detected. All preliminary data will be made available to reviewers after basic quality control and EIM data entry are completed.

Data analysis will include evaluation of data distribution characteristics and, if necessary, appropriate distribution transformations. Estimation of univariate statistical parameters and graphical presentation of the data (box plots, time series, regressions) will be made using EXCEL or WQHYDRO (Aroner, 1994) computer software.

Ecology will use QUAL2Kw (Ecology, 2003b) for quasi-dynamic analysis of dissolved oxygen and pH during critical conditions in critical reaches.

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# Appendix A
# Glossary of Terms

| | |
|---|---|
| 7DADM | Seven-day average of the daily maximum temperature |
| AWM | Amber wide-mouth bottle |
| CNM | Clear narrow-mouth bottle |
| CWM | Clear wide-mouth bottle |
| DO | Dissolved oxygen |
| DOC | Dissolved organic carbon |
| EDS | Environmental Data System |
| EIM | Environmental Information Management |
| EPA | Environmental Protection Agency |
| HDPE | High-density polyethylene bottle |
| KCEL | King County Environmental Laboratory |
| LiDAR | Light detection and ranging |
| LIMS | Laboratory information management system |
| MDL | Method detection limit |
| MQOs | Measurement Quality Objectives |
| NADP | National Atmospheric Deposition Program |
| NATN | National Atmospheric Trends Network |
| NESSWD | Northeast Sammamish Sewer and Water District |
| QC | Quality control |
| RDL | Reporting detection limit |
| RH | Relative humidity |
| RPD | Relative percent difference |
| RSD | Relative standard deviation |
| SOP | Standard operating procedure |
| TMDL | Total maximum daily load |
| TOC | Total organic carbon |
| UHWA | Union Hill Water Association |
| VOA | Volatile organic analysis bottle |
| WBID | Waterbody Identification |

# Appendix B
# King County Monitoring Program Historical Data

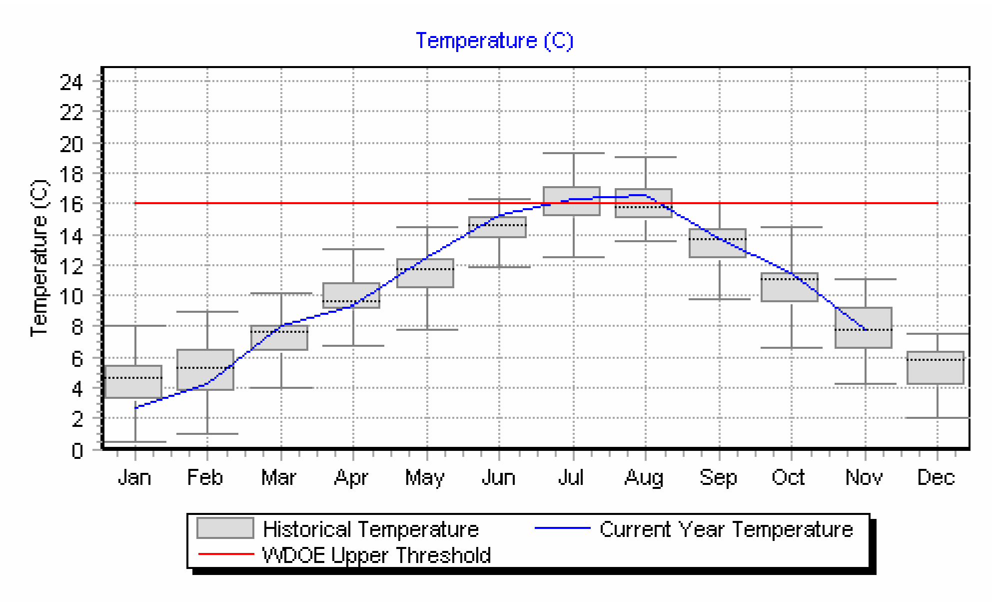


Figure A-1. Station C484, lower Bear Creek, temperature record for 1974 to 2005.

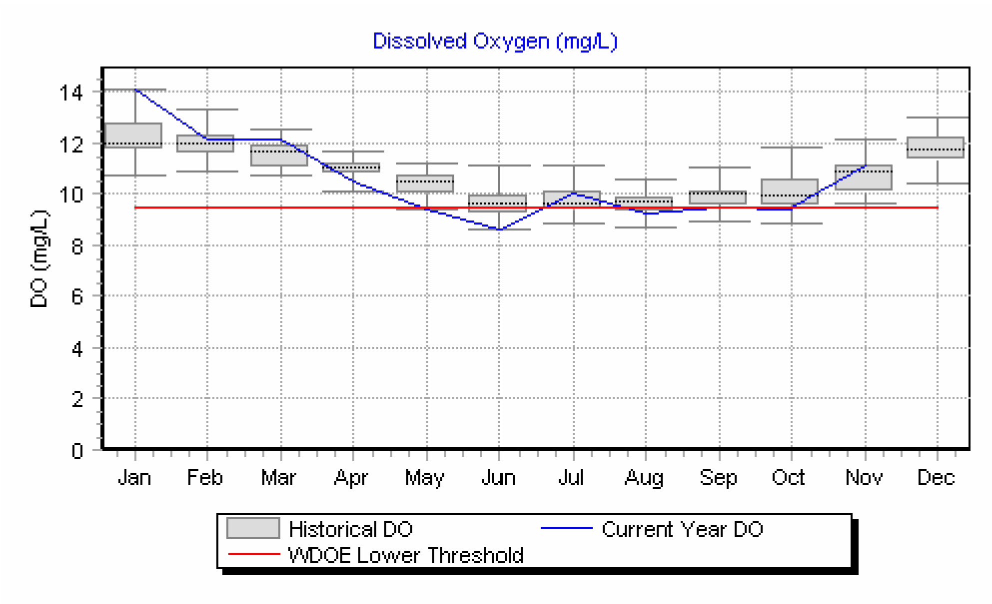


Figure A-2. Station C484, lower Bear Creek, dissolved oxygen record for 1974 to 2005.

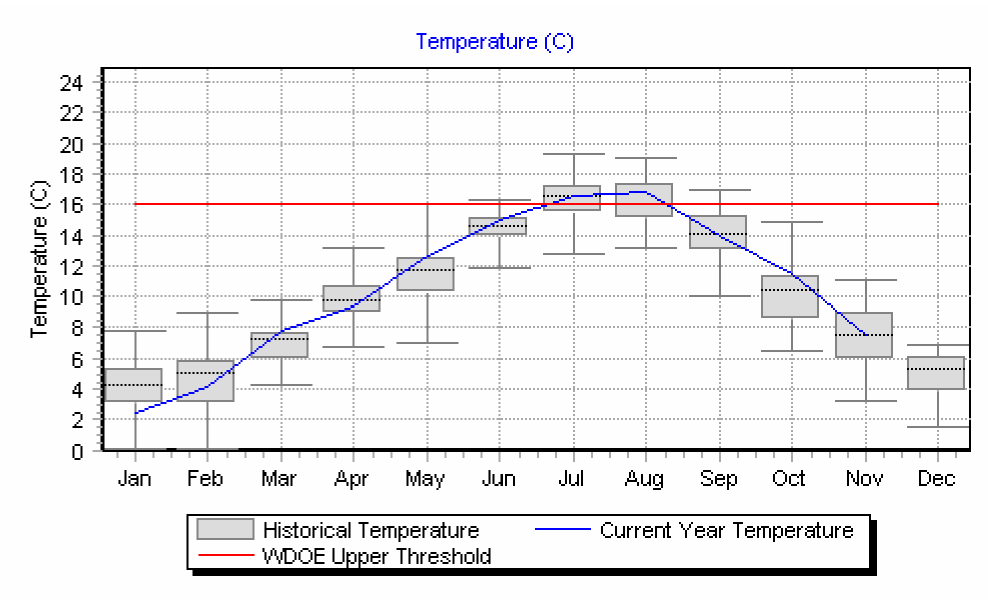


Figure A-3. Station J484, middle Bear Creek, temperature record for 1974 to 2005.

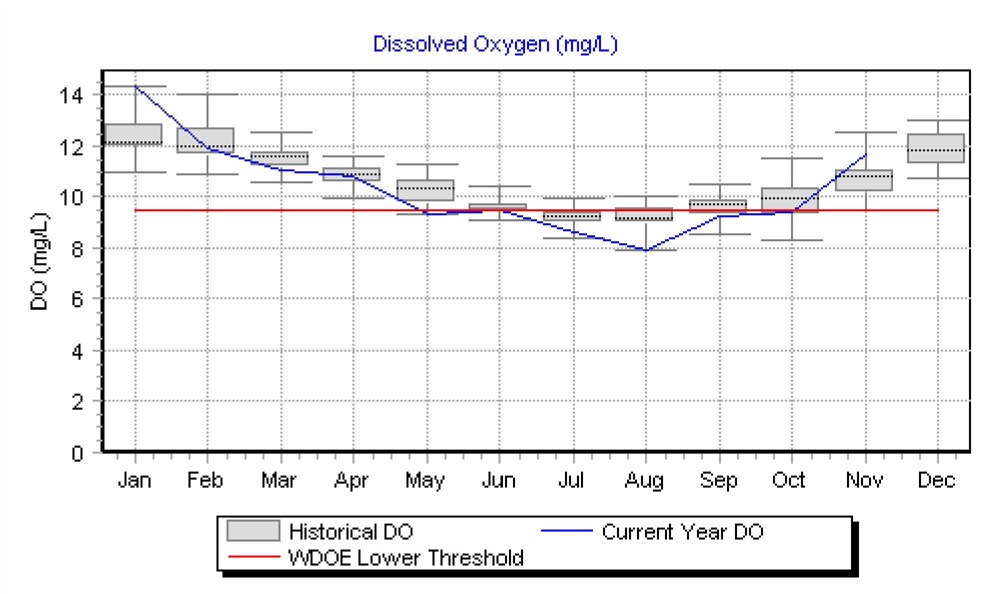


Figure A-4. Station J484, middle Bear Creek, dissolved oxygen record for 1974 to 2005.

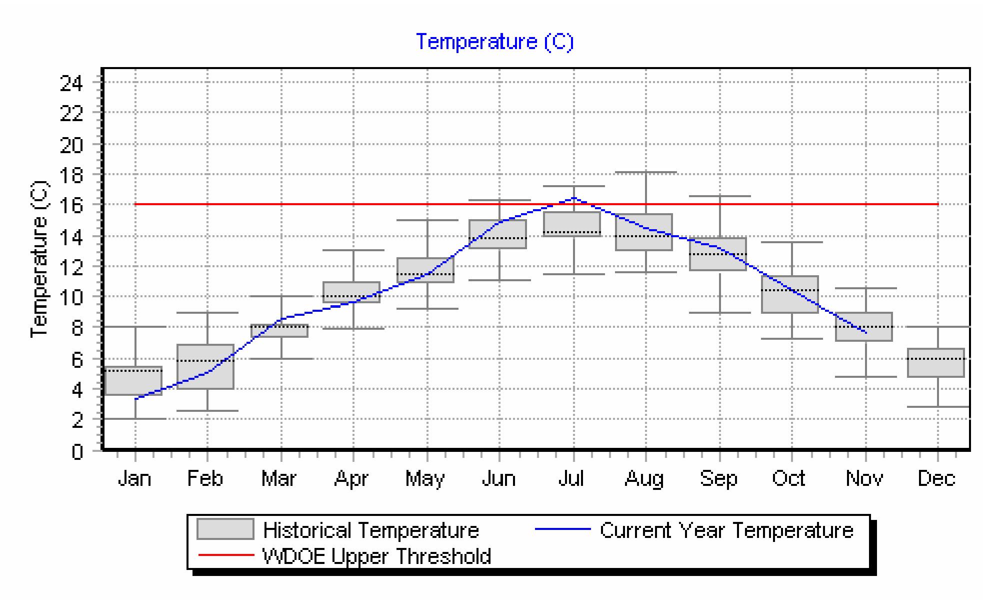


Figure A-5. Station N484, Cottage Lake Creek, temperature record for 1974 to 2005.

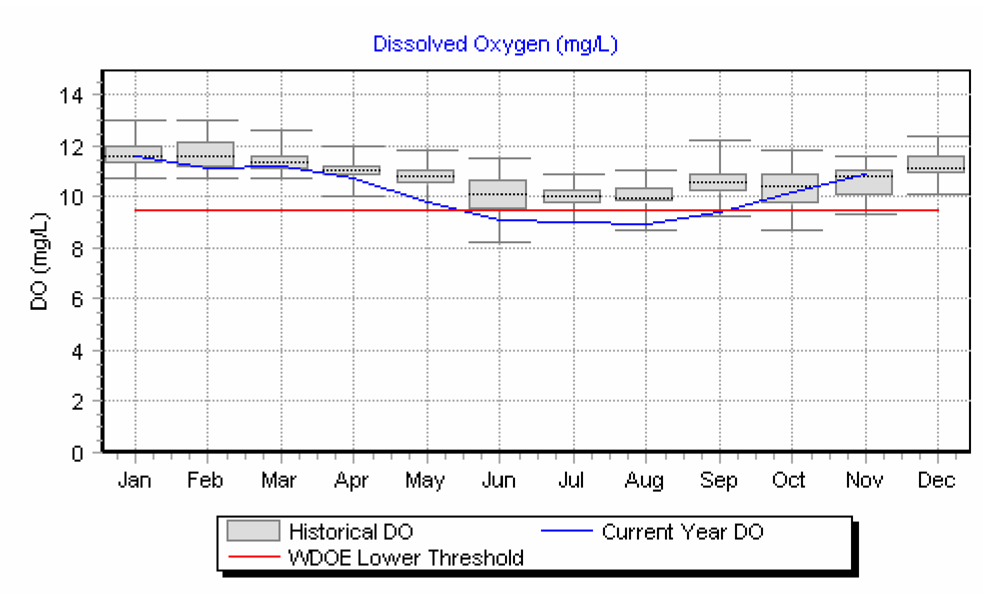


Figure A-6. Station N484, Cottage Lake Creek, dissolved oxygen record for 1974 to 2005.

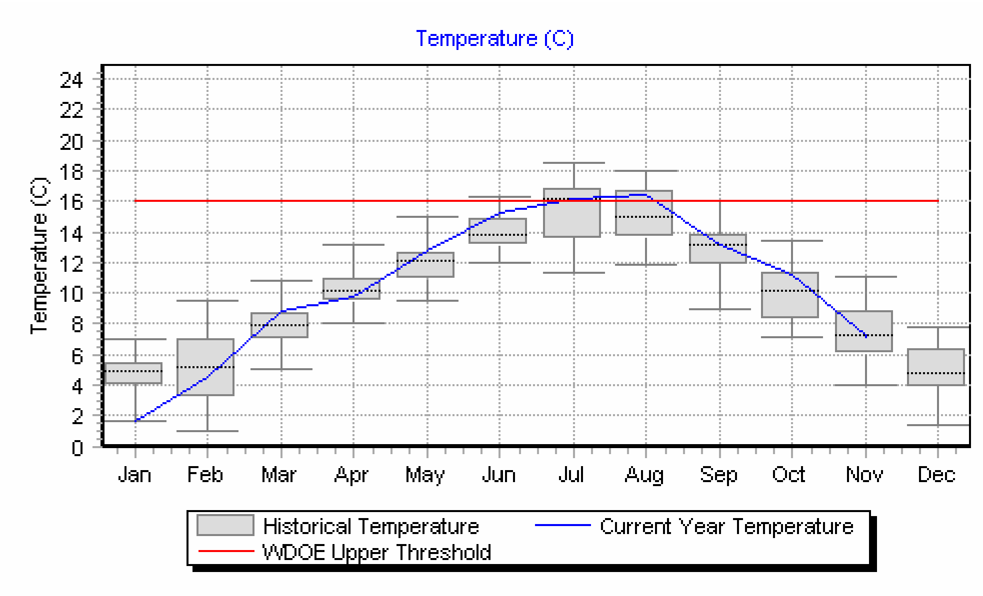


Figure A-7. Station B484, Evans Creek mouth, temperature record for 1971 to 2005.

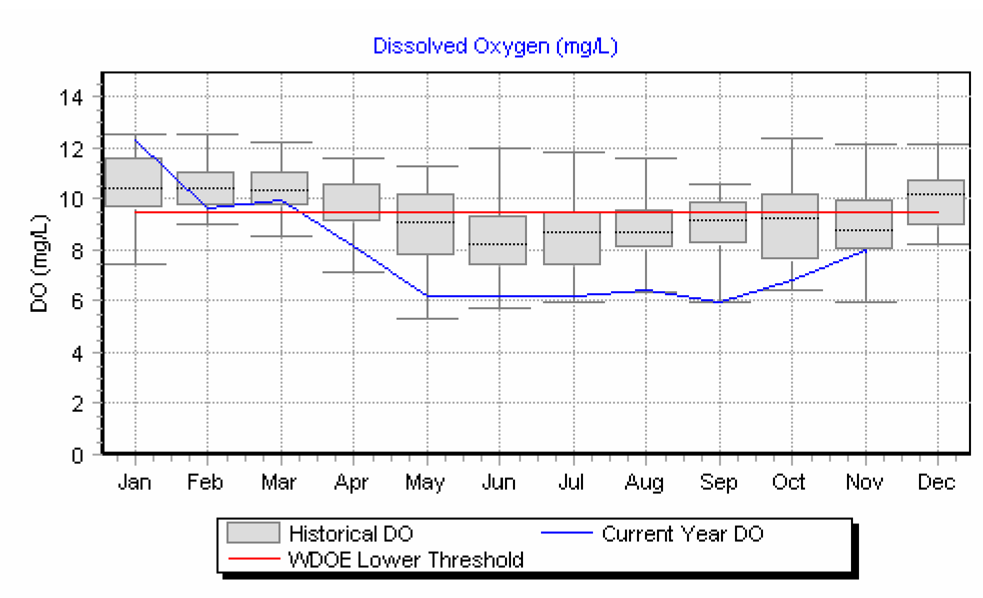


Figure A-8. Station B484, Evans Creek mouth, dissolved oxygen record for 1971 to 2005.

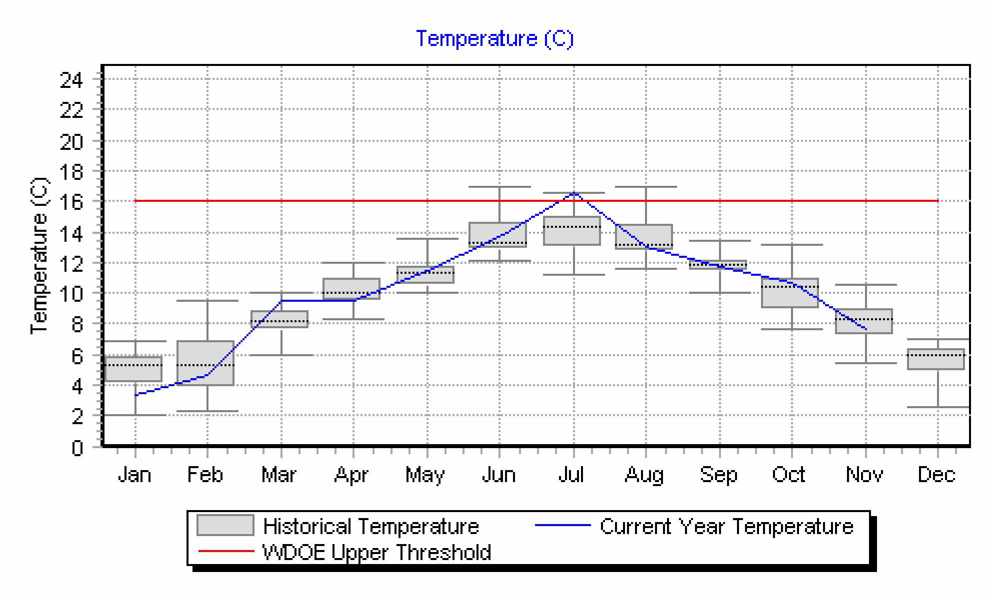


Figure A-9. Station S484, Evans Creek, temperature record for 1981 to 2005.

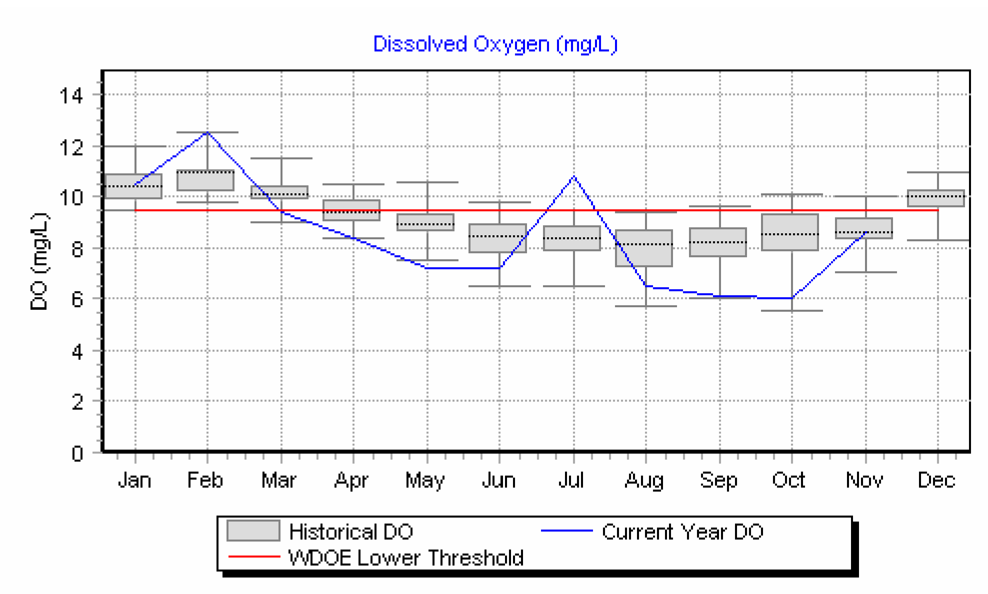


Figure A-10. Station S484, Evans Creek, dissolved oxygen record for 1981 to 2005.

# Appendix C
# Descriptions of Monitoring Locations

| Site Name | Location/access | Tidbit/Hobo Owner | Site Type |
|---|---|---|---|
| **Bear (roughly south to north)** | | | |
| Bear/Evans near mouth | Off Redmond Way behind Blockbuster Near RR crossing and smolt trip | ECY | Temp |
| Bear/Evans just downstream of confluence | Off Union Hill Road behind Millennium Property by concrete bridge | RH2 | Temp/YSI/Nutrients |
| Bear Creek upstream of Evans confluence | Off Union Hill Road behind Millennium Property by concrete bridge | ECY/RH2 | Temp/YSI/Nutrients |
| Ashford Park tributary | Ditch off Avondale Road and 180th NE | Redmond | Temp |
| Tributary at trail crossing, off NE 95th Street | Small access trail at SE corner of Bear Creek @ 95th bridge; follow trail until you reach a small tributary with log bridge | ECY/Redmond | Temp/Nutrients |
| Bear Creek at NE 95th Street | Road crossing at NE 95th Street | Redmond? | Temp |
| Bear Creek at NE 106th Street | Road crossing at NE 106th Street | Redmond? | Temp |
| Mackey Creek near mouth | At 18669 NE 106th St - Simpatico Stables; don't park near stable entrance | ECY/Redmond | Temp/Nutrients |
| Tributary near Avondale & NE 116th Street | Crossing with Avondale just north of NE 116th Street | Redmond | Temp |
| Cottage Lake Creek upstream of confluence with Bear | Site moved to 132nd crossing | ECY | Temp/YSI/Nutrients |
| Bear just upstream (east) of crossing with Avondale | Off main road at 12430 Avondale | ECY | Temp/YSI/Nutrients |
| Cottage Lake Creek at NE 132nd Street | Park at Verizon equipment shed at intersection of 132nd and Avondale | ECY | |
| Seidel Creek at 198th Avenue NE | 13312 198th Avenue NE (off NE 133rd Street) | ECY | Temp |
| Bear Creek at crossing with NE 133rd Street | Off 133rd | ECY-medium | Temp |
| Collins Creek near mouth | Accessed off Tolt pipeline trail several hundred yards down from trail head behind 20100 148th St near new construction house | ECY | Temp/YSI/Nutrients |
| Bear near confluence with Collins Creek | Access from north side of Tolt pipeline trail | ECY | Temp/YSI/Nutrients |
| Cottage Lake Creek at Tolt pipeline trail | Park off Avondale or Bear Creek road and walk down trail crossing | ECY | Temp |
| East fork of Bear Creek | At crossing with 212th Avenue NE near cedar stump | ECY-medium | Temp |
| Bear at Woodinville Duvall Road | Road crossing near Bear Creek road | ECY-medium | Temp |
| Bear at footbridge in Bear Creek Conservation Area | Off 204th Avenue; parking. Walk out of site line probably upstream, maybe downstream | ECY | Temp/YSI/Nutrients |

| Site Name | Location/access | Tidbit/Hobo Owner | Site Type |
|---|---|---|---|
| Daniels Creek at NE 195th Street | SE corner of 195th and 176th Avenue, take 176th Avenue from Woodinville-Duvall Road low flow, may be dry during synoptic | ECY?? | Temp |
| Cottage Lake Creek downstream of Cold Creek | 500 ft north of NE 165th Street; moved to crossing with NE 165th | ECY | Temp/YSI/Nutrients |
| **Evans (down to upstream)** | | | |
| Evans Creek upstream of confluence | Off Union Hill Road behind Millennium Property by concrete bridge | ECY/RH2 | Temp/YSI/Nutrients |
| Evans Creek at old wooden bridge | Private access; contact Jon Lowry at RH2 | RH2 | Temp |
| Evans Creek at Union Hill Road | Crossing with Union Hill, location of King Co. stream gage | RH2 | Temp |
| Evans Creek at 196th (north) | Park property off 196th Avenue NE (brick rd) | ECY/RH2 | Temp/YSI/Nutrients |
| Tributary near Evans @196th (north) | Crossing with 196th just north of Evans Creek (north) crossing | ECY-medium | Temp |
| Evans Creek at 196th (south) | Crossing with 196th Avenue NE south of Redmond-Fall City Rd; park south of entrance to construction staging area on 196th | ECY/RH2 | Temp |
| Rutherford Creek near mouth | Crossing with Redmond Fall City Road just east of milepost 11 | ECY | Temp/YSI/Nutrients |
| Rutherford Creek at mouth | Private access; contact Jon Lowry at RH2 | RH2 | Temp |
| Evans up and downstream of Rutherford confluence | Private access; contact Jon Lowry at RH2 | RH2 | Temp |
| Evans at NE 44th Street | Crossing with NE 44th St (off 220th Avenue NE) | ECY | Temp/YSI/Nutrients |
| Evans near fish ladder | Crossing with Redmond Fall City Road by fish ladder | ECY/RH2 | Temp/YSI/Nutrients |
| Wetland 22 Outlet @224th Street | Crossing with NE 224th St. | RH2 | Temp |
| Tributary off logging road | Crossing with logging road at end of NE 31st WY | ECY | Temp |
| Evans at 238th Avenue | Crossing with 238th Avenue NE (below Peterson Pond); don't go from upstream side | ECY/RH2 | Temp/Nutrients |