Quality Assurance Project Plan

Upper Mainstem Stillaguamish River Dissolved Oxygen Study

DEPARTMENT OF ECOLOGY
State of Washington

March 2010

Publication No. 10-03-103

Publication Information

This plan is available on the Department of Ecology's website
at www.ecy.wa.gov/biblio/1003103.html

Data for this project will be available on Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search User Study IDs, MVP003, MVON001.

Ecology's Activity Tracker Code for this study is 09-182.

Federal Clean Water Act 2004 303(d) Listing Addressed in this Study:
Stillaguamish River (WA-05-1010)-Dissolved Oxygen

Author and Contact Information

Author: Markus Von Prause
Environmental Assessment Program
Washington State Department of Ecology
PO Box 47600
Olympia, Washington 98504-7710

For more information contact: Communication Consultant
Phone: 360-407-6764

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

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

Cover photo: North Fork Stillaguamish River at Whitehorse Mountain near Darrington.

Quality Assurance Project Plan

Upper Mainstem Stillaguamish River Dissolved Oxygen Study

Approved by:

Signature:	Date: March 2010
Ralph Svrjcek, Client, Water Quality Program, NWRO	
Signature:	Date: March 2010
Dave Garland, Client's Unit Supervisor, Water Quality Program, NWRO	
Signature:	Date: March 2010
Kevin Fitzpatrick, Client's Section Manager, Water Quality Program, NWRO	
Signature:	Date: March 2010
Markus Von Prause, QAPP Author, EAP	
Signature:	Date: March 2010
George Onwumere, Author's Unit Supervisor, EAP	
Signature:	Date: March 2010
Robert F. Cusimano, Author's Section Manager, EAP	
Signature:	Date: March 2010
Stuart Magoon, Director, Manchester Environmental Laboratory, EAP	
Signature:	Date: March 2010
Bill Kammin, Ecology Quality Assurance Officer	

Signatures are not available on the Internet version.
NWRO – Northwest Regional Office.
QAPP – Quality Assurance Project Plan.
EAP – Environmental Assessment Program.

Table of Contents

List of Figures

List of Tables

Abstract

During 2011, the Washington State Department of Ecology (Ecology) will be conducting a study of Stillaguamish River dissolved oxygen (DO) levels between river miles 11.36 and 6.92.

In 2004, Ecology completed a Total Maximum Daily Load (TMDL) study of DO in the Stillaguamish River. The study indicated low DO concentrations in a pool reach downstream of the City of Arlington's Wastewater Treatment Plant (WWTP). The QUAL2Kw water quality model results indicated that even with no contributions from anthropogenic sources, DO concentrations would likely drop below the water quality criterion of 8 mg/L to about 7.0 mg/L in some locations.

Ecology's 2004 study could not determine all the sources contributing to low DO conditions in the river. Ecology attributed the downstream DO depression to a combination of nonpoint source pollution inputs, discharge from the Arlington WWTP, and unknown factors. Clearly understanding the factors that affect DO levels is critical for meeting water quality standards and for treating and discharging municipal wastewater in a cost-effective manner. For that reason, in 2004 Ecology did not establish nutrient and oxygen-demand wasteload allocations for the Arlington WWTP.

This Quality Assurance Project Plan details a strategy to improve our understanding of low DO levels in the mainstem Stillaguamish below the WWTP discharge (Island Reach). This 2011 project will investigate currently un-quantified sources of DO deficits such as sediment oxygen demand, biological respiration, and groundwater DO levels. The data will be used to rerun the Stillaguamish River QUAL2Kw model for the Island Reach and to recommend load and wasteload allocations to various pollutant sources.

Each study conducted by Ecology must have an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives. After completion of the study, a final report describing the study results will be posted to the Internet.

Background

The Stillaguamish River basin includes portions of Snohomish and Skagit Counties in Washington State (Figure 1). Several rivers and streams in the Stillaguamish River basin were on the State's 1996, 1998, and 2004 Section 303(d) list because of violations of one or more water quality criteria. Ecology's Water Quality Program selected the basin for a Total Maximum Daily Load (TMDL) assessment in 2000. Ecology's Environmental Assessment Program designed and conducted the TMDL evaluation for the basin (Joy, 2004).

During 2011, Ecology will be conducting an additional study of Stillaguamish River dissolved oxygen (DO) levels between river miles 11.36 and 16.92. The TMDL monitoring data documented a DO sag in the river, approximately 12.84 river miles (21.7 river kilometers) from the mouth, during periods of prolonged dry weather in the summer (the critical period). The sag occurs in a pool reach approximately 4 miles (6.6 km) downstream of the confluence of the North and South Forks of the Stillaguamish River and the Arlington wastewater treatment plant (WWTP).

The QUAL2Kw water quality model used in Ecology's 2004 TMDL study indicated that even with no contributions from anthropogenic sources, DO concentrations would likely drop below the water quality criterion of 8 mg/L to about 7.0 mg/L in some locations. The model further predicted that even the target DO concentration of 7 mg/L could not be achieved at this river location during periods of low river flows, unless upstream nutrient levels and WWTP effluent nutrient discharges are kept at lower concentrations than reported in 2001 (Joy, 2004).

Ecology's 2004 study could not determine all the sources contributing to low DO conditions in the river. This prevented Ecology from establishing pollutant load and wasteload allocations for this portion of the Stillaguamish River.

This Quality Assurance (QA) Project Plan details the strategy for improving our understanding of low DO levels in the mainstem Stillaguamish below the WWTP discharge. This 2011 project will use a wide array of investigative tools that are typically unnecessary in most DO studies. Our revised approach will investigate currently un-quantified sources of DO deficits such as sediment oxygen demand, biological respiration, and groundwater DO levels. The data will be used to rerun the Stillaguamish River QUAL2Kw model for the Island Reach and recommend load and wasteload allocations to various pollutant sources.

Study Area

The Stillaguamish River is the fifth largest tributary to Puget Sound and is located within Water Resource Inventory Area (WRIA) 5. The watershed covers 1047 mi^2 ($1770 km^2$) and extends from sea level to 2,086 meters in elevation on Whitehorse Mountain in the Squire Creek drainage. The Stillaguamish River is formed from two major forks at river mile (RM) 17.8 (RKM 28.6); the North Fork drains 435.5 mi^2 (736 km^2) and the South Fork drains 390 mi^2 (660 km^2).

Average annual precipitation in the watershed ranges from about 30 inches/year (80 cm/year) at lower elevations to about 150 inches/year (380 cm/year) at higher elevations (Pess et al., 1999)

Soil types vary widely but follow the patterns of the underlying alluvial geology. The valley soils over alluvial deposits tend to have low permeability and a high seasonal water table. In other words, Hydrologic Group C and D soils predominate along the valley floors of the North Fork, lower South Fork, and along the mainstem and lower mainstem tributaries to Port Susan. More permeable Hydrologic Group A or B soils are found on the plateaus and hillsides.

The geology of the Stillaguamish basin in the vicinity of the study area has been briefly described in the Salmon Habitat Limiting Factors Analysis (Washington Conservation Commission, 1999):

"Glacial outwash from the Puget Lobe of the Cordilleran ice sheet forms the terraces in the forks and the topography of the lower watershed. Younger alluvial deposits are inset within the terraces in the wider portions of the valleys of the forks. The mainstem of the Stillaguamish flows through an alluvium-floored valley 1.5-3 km wide, inset within terraces of glacial outwash.
The clay, silt and sand deposits of glacial and lake origin are the main source of the significant sediment production in the watershed. In the steeper sloped areas, these deposits are particularly prone to landslides, which are a significant problem for fisheries in this drainage. "

This study will investigate DO processes in the mainstem Stillaguamish River from the confluence of the North and South Fork Stillaguamish Rivers (RM 16.92 /RKM 28.6) to Interstate 5 (RM 11.36 /RKM 19.2). This area, known as the Island Reach, includes the March Creek, Kackman Creek, Armstrong/Harvey, and Portage Creek tributaries (Figure 1).

The Arlington WWTP outfall is located near the top of the study area at RM 16.9. The average Stillaguamish mainstem channel widths within the study area range from 75 ft to over 150 ft. Stream banks are stable, composed of broad and gently sloping gravel and step cut banks. Levees and dikes were built along the Stillaguamish River by diking districts and private land owners for flood prevention.

The primary land use in the study area is agriculture and rural residential. Livestock grazing, dairies, and plant nurseries are prominent agricultural activities. The City of Arlington's current population is about 15,000 and is expected to double by 2025. Agriculture is still quite active in the study area, but conversions from agriculture to rural residential or non-commercial farm uses are becoming more common within the study area.

The Stillaguamish Tribe has cultural, economic, and natural resource interests in the Stillaguamish basin including in the study area. Their fishing and water quality areas of interest include Port Susan, as well as the Stillaguamish River and its tributaries.

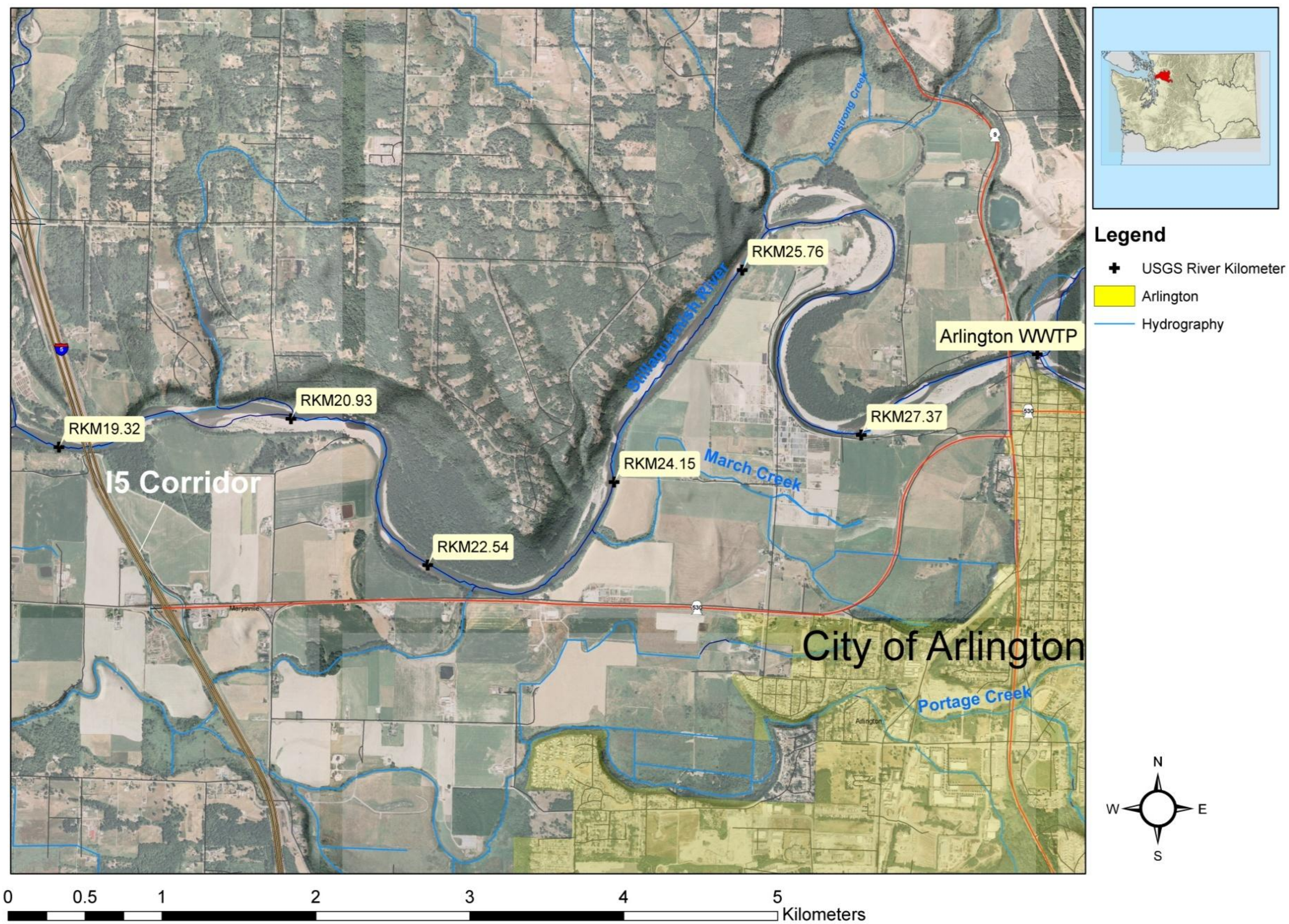

Figure 1. Study area for the 2011 dissolved oxygen study in the upper Stillaguamish River mainstem.

Channel alterations and land-use changes have affected the tributaries within the study area. Tributaries stretch across a predominately agricultural setting in the flood plain area and are impacted by increased sediment loading, high winter flows, low summer flows, and little riparian vegetation coverage.

Stormwater from Arlington discharges directly from the Marysville plateau to a steep 90 ft gradient near the headwaters of March Creek. March Creek does not meet (exceeds) state surface water quality standards for DO and fecal coliform bacteria.

Streamflows

Flows in the Stillaguamish River respond to rainfall and snowmelt. There are no large storage or diversion structures in the basin. Small glaciers and snowfields at the highest elevation, and groundwater in the lower valleys, supply water during the lowest flow periods.

The United States Geological Survey (USGS) currently gages flows in the North Fork Stillaguamish River near Arlington (station 1216700) and in the South Fork near Granite Falls (station 1216100 – stage height only). Historically, USGS has gaged flows at several other stations in the watershed on an intermittent basis. Only one historical gaging station, the Stillaguamish River near Silvana (USGS #12167700), was established in the mainstem Stillaguamish River below the confluence of the two forks. Ecology currently maintains a manual stage height station at this location for instantaneous flow measurements. There are statistically strong correlations between flows at the long-term gages in the upper basin and the intermittent data collected at the Silvana gage site (Joy, 2004).

Table 1. Mean daily discharge (in cfs) by month for two long-term USGS gage stations on the North and South Fork Stillaguamish River.

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
North Fork	2840	2420	2160	2200	2170	1660	865	463	668	1530	2780	3040
South Fork	1420	1210	1020	1200	1360	1140	599	299	484	985	1420	1660

Table 2. Summary of the annual 7-day, 10-year (7Q10), low-flow statistics for selected USGS gaging stations on the North and South Fork Stillaguamish River.

Station	Description	Period	Drainage area (km^2)	7Q10 low cfs (cms)
12167000	North Fork near Arlington	1928-2007	679	169 (4.78)
12161000	South Fork near Granite Falls	1928-1980	308	79 (2.23)

The Silvana gage site is operated and maintained by Ecology. The Silvana gage is located on the Interstate 5 bridge north of Arlington, exit 208. Silvana has been operational since 1959 and measures streamflow data at a 3-hour interval. Conventional water quality samples are also collected at Silvana on a monthly basis.

Snohomish County operates 2 real-time flood warning management stations located near Arlington by Highway 9 and at Interstate 5. River stage heights are recorded every 15 minutes.

Fisheries Resources

The Stillaguamish River basin is a migration corridor, and spawning and rearing area, for Puget Sound basin salmon runs. The most important uses identified by local groups are salmon spawning and rearing, recreation, and shellfish harvesting. Chinook salmon (*Oncorhynchus tshawytscha*) were listed as a threatened species under the federal Endangered Species Act in 1999. Substantial evidence has been accumulated to document the decline of Chinook salmon in the Stillaguamish River watershed (STAG, 2000). Habitat modeling indicates that current populations are at about 7% of historical levels (Mobrand Biometrics, 2004). Steelhead Trout (*Oncorhynchus mykiss*) are also present in the Stillaguamish River and were listed as a threatened species in 2007. Water quality impairments for DO, pH, and turbidity are the most likely to impair salmon health in the Stillaguamish watershed.

Fisheries specialists have recommended many habitat and channel improvements to assist salmon recovery in the Stillaguamish basin (Stillaguamish Technical Advisory Group, 2000). Channel sedimentation, increased peak flows and extreme low flows, increased temperatures, and reduced DO were identified problems in the basin. The Salmon Habitat Limiting Factors Report for the Stillaguamish River basin noted that nonpoint sources of pollution were the major cause of water quality problems. Many salmon habitats have been degraded by natural and anthropogenic activities. Just under one-third (1432 km) of the total stream network is available habitat for anadromous fish (WCC, 1999).

Potential Sources of Pollution

There are several potential point and nonpoint sources that could contribute to the low DO concentrations in the Stillaguamish River. WWTPs and dairies historically have been the focus of water quality actions in the lower basin to control oxygen-demanding inputs. However, housing densities near Arlington are increasing, resulting in larger contributions to the local sanitary and storm sewer systems.

Point Sources

The Arlington WWTP discharges municipal wastewater directly to the Stillaguamish River just below the confluence of the North and South Forks. Discharges from the WWTP are regulated by a National Pollutant Discharge Elimination System (NPDES) permit. It is self-monitored, and the WWTP operators report effluent data to Ecology monthly when the WWTP is in operation. Increased housing densities and expanding utilities within the City of Arlington have required the WWTP to increase their treatment capacities. The Arlington WWTP completed an upgrade of its facility in 1998 and is planning additional upgrades by December 2010 (Ecology, 2009).

Arlington, Snohomish County, and the Washington State Department of Transportation (WSDOT) operate municipal stormwater systems. These systems are considered point sources, although the discharges of contaminants to those systems are widely dispersed. During dry weather, stormwater systems do not generally discharge water. Because the critical period for this study (August – October) occurs following prolonged periods of warm and dry weather, stormwater is not expected to be a significant contributor of pollutants. However, illicit discharges of car wash water or other nutrient sources to these municipal storm sewer systems during the critical period would be a concern. Also, illicit discharges may be occurring and contributing pollution during the critical period.

Snohomish County and WSDOT are required to implement a stormwater management program under the Phase 1 Municipal General Stormwater Permit. Snohomish County has monitored and implemented improvements in several areas of the Stillaguamish basin with stormwater drainage and nonpoint runoff problems (Snohomish County, 2007). Arlington is required to manage its municipal stormwater under the Phase 2 Municipal General Stormwater Permit. Stormwater from the Arlington municipal area historically has been routed through several storm drains to the South Fork and mainstem Stillaguamish River, and to drainages in the Portage and March Creek subbasins.

Arlington has made some improvements in its stormwater collection system and has worked with WSDOT in using wetlands for stormwater treatment and flood control in some areas. Ecology recently provided a grant for the design and construction of a stormwater treatment wetland to provide additional treatment to much of Arlington's downtown area.

Nonpoint Sources

Nonpoint sources of pollution are not easily identified or monitored. Nonpoint sources are usually associated with land uses such as timber harvesting, construction, agricultural production, intensive recreational activities, and urban development. Many types of nonpoint sources are intermittent. Some occur only when it rains (e.g., stormwater running from the land into a stream). Other examples include livestock moving in and out of streams or poor manure management practices.

Properties converted from commercial, agricultural, and forestry uses to rural residential, non-commercial agriculture, or commercial/industrial uses do not necessarily result in reduced levels of pollution. These new uses can generate the same or greater loads of pollution from residential fertilizer use or poor animal-keeping practices on the many smaller lots. These sources along with poorly maintained and failing onsite septic systems, and inadequate stormwater treatment and control, can contribute to water quality problems.

There is a potential for phosphorus pollution of groundwater and surface water within the study area. Some farms are believed to be receiving poultry manure from a local egg producer. Staff from Ecology's from Northwest Regional Office are working with the egg producer and the Snohomish Conservation District to ensure that poultry manure, which has high levels of phosphorus, is properly applied to local farms. Groundwater pollution from excessive phosphorus applications is also a concern.

If the groundwater table is close to the surface, the application of waste at excessive rates or at nitrogen-based rates will most likely contaminate the groundwater beneath those soils.

Several dairies were located in the study area when the 2004 TMDL was prepared. However, there are currently no active dairies within the area. According to a 2006 aerial photo survey, manure lagoons are still present and in relatively close proximity to surface waters. It is anticipated that these lagoons are inactive, although some heifer production has been noted in the area. There are three major nursery operations within the area. One of the nurseries is located close to the mainstem Stillaguamish and has a large number of greenhouse facilities.

Natural Sources

In addition to anthropogenic sources of pollution, natural conditions may exist in the study area. These sources may complicate some aspects of the study. Riparian wetlands and groundwater seepage into small tributaries could be natural sources of lower DO concentration during baseflow conditions. Phytoplankton and periphyton life cycles potentially affect pH, DO, dissolved organic carbon (DOC), and nutrient uptake such as phosphorus and nitrogen. Factors that potentially influence phytoplankton and periphyton include light, temperature, water chemistry, current, substrate, scouring effects of floods, and grazing by macroinvertebrates.

Some of the channel and valley features of the Island Reach of the Stillaguamish River suggest that an interaction between surface water and water in the channel bed. The process under and along the sides of the channel bed, called the hyporheic process, has been identified in other parts of the Stillaguamish River (Vervier and Naiman, 1992) and in many rivers like it with channels of coarse alluvial materials (Naegeli and Uehlinger, 1997; Uehlinger, 2000). One hyporheic process involves heterotrophic bacteria communities capable of using oxygen that decompose organic materials and result in lower DO levels. As the bacteria breakdown the organic material, they release nitrogen and phosphorus in the dissolved inorganic form, which helps support periphyton growth.

Streams and rivers with a healthy biotic structure have a proper balance of these factors so that heterotrophic and photosynthetic organisms are neither over-productive nor under-productive (Allan, 1995). A more detailed description of the Stillaguamish Basin features is provided in the original TMDL study (Joy, 2004).

Washington State Water Quality Standards

The Washington State Water Quality Standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, waterbody classifications, and numeric and narrative water quality criteria for surface waters of the state. This section discusses the DO criteria found in those standards and their application to the Stillaguamish watershed.

In July 2003, Ecology made significant revisions to the state's surface water quality standards (Chapter 173-201A WAC). These changes included eliminating the classification system the state used for decades to designate uses for protection by water quality criteria (e.g., temperature, DO, bacteria). As shown in Table 3, these changes did not significantly affect numeric DO criterion for the study area during the August – October critical period.

Table 3. Washington State water quality criteria for dissolved oxygen, including historical and current standards.

Water Quality Parameter	1997 Standards Classification	1997[1] Criteria	2006 Use Revision	2006[1] Criteria
Dissolved Oxygen	Class A	8.0 mg/L	Salmonid Spawning, Rearing, and Migration	8.0 mg/L 1-DMin[2]

1. Criteria have been established in the existing water quality standards for specific waterbodies that differ from the general criteria shown in the above table. These special conditions can be found in WAC 173-201A-130 of the 1997 version, and WAC 173-201A-602 of the 2006 version of the standards.

2. 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the waterbody.

Dissolved Oxygen

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

Oxygen levels can fluctuate over the day and night in response to changes in climatic conditions as well as the respiration or photosynthesis of aquatic plants and algae. Since the health of aquatic species is tied predominantly to the pattern of daily minimum oxygen concentrations, the criteria are the lowest 1-day minimum oxygen concentrations that occur in a waterbody.

In the state water quality standards, freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition]. For the Stillaguamish River from the mouth to the junction of the North and South Forks (RM 17.8/RKM 30.0), the following designated aquatic life use(s) and criterion is to be protected: ―Salmonid Spawning, Rearing, and Migration" where the lowest 1-day minimum oxygen level must not fall below 8.0 mg/L more than once every ten years on average.

The above described criterion is used to ensure that where a waterbody is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. The combined effects of all human activities must not cause more than a 0.2 mg/L decrease below natural DO levels.

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

Key Findings from Previous TMDL Studies

The diel (24-hour) study conducted below the Arlington WWTP by Earth Tech (1997) consultants in August 2007 found that DO concentrations at RKM 21.7 (RM 13.5) upstream of the Interstate 5 bridge dropped to 7.2 mg/L in the early morning, and rose to 11 mg/L in the later afternoon. An effluent BOD model by consultants demonstrated that effluent BOD and nitrogenous oxygen demand had little effect on instream DO concentrations. They considered oxygen demand from periphyton biomass respiration the primary cause of low diel DO concentration during the survey.

The same stream reach, identified as having pre-dawn DO concentration less than 8 mg/L in the Earth Tech (1997) study, was investigated during the 2004 TMDL study. Ecology deployed continuous recording probes in September 2000 and October 2001 to record DO over 48-hour periods. The September 2000 DO conditions below Arlington were well within the DO criterion. However, the October 2001 survey confirmed that the pool reach at RKM 21.7 (RM 13.5) downstream of the Arlington WWTP outfall experienced a wide diel DO range, with minimum DO concentrations below 8 mg/L in the early morning hours. The minimum DO in 2001 was only 7.9 mg/L compared to 7.3 mg/L in 1997, but the diel DO range in 2001 was far greater than the upstream and DO downstream ranges (Joy, 2004).

Ecology constructed a QUAL2Kw model for the study area to examine the possible causes of the DO depression (Joy, 2004). Groundwater and hyporheic functions were included in the model, and simulations of the DO data collected in 1997 (Earth Tech, 1997) were run with and without the hyporheic function (Figure 2). When the hyporheic function was added to the QUAL2Kw model, the DO fit the field data much better. As a verification test, simulations of the October 2001 field data responded in a similar way.

The 2004 TMDL study (Joy, 2004) concluded that the largest diel ranges accompanied by DO minima below 8 mg/L seem to occur when the following situations coincide:

- Abundant nutrients are available in the water column.
- River flows decrease for a week or more below 1000 cfs (28.32 cms), causing an increase in pool retention time.
- High water clarity promotes increased periphyton growth.
- Periphyton biomass is not interrupted, or scoured away or disrupted, by large storm events.
- Groundwater inputs, or chemical and gas exchanges from hyporheic and heterotrophic bacteria respiration processes, may interact with water in pool reaches.

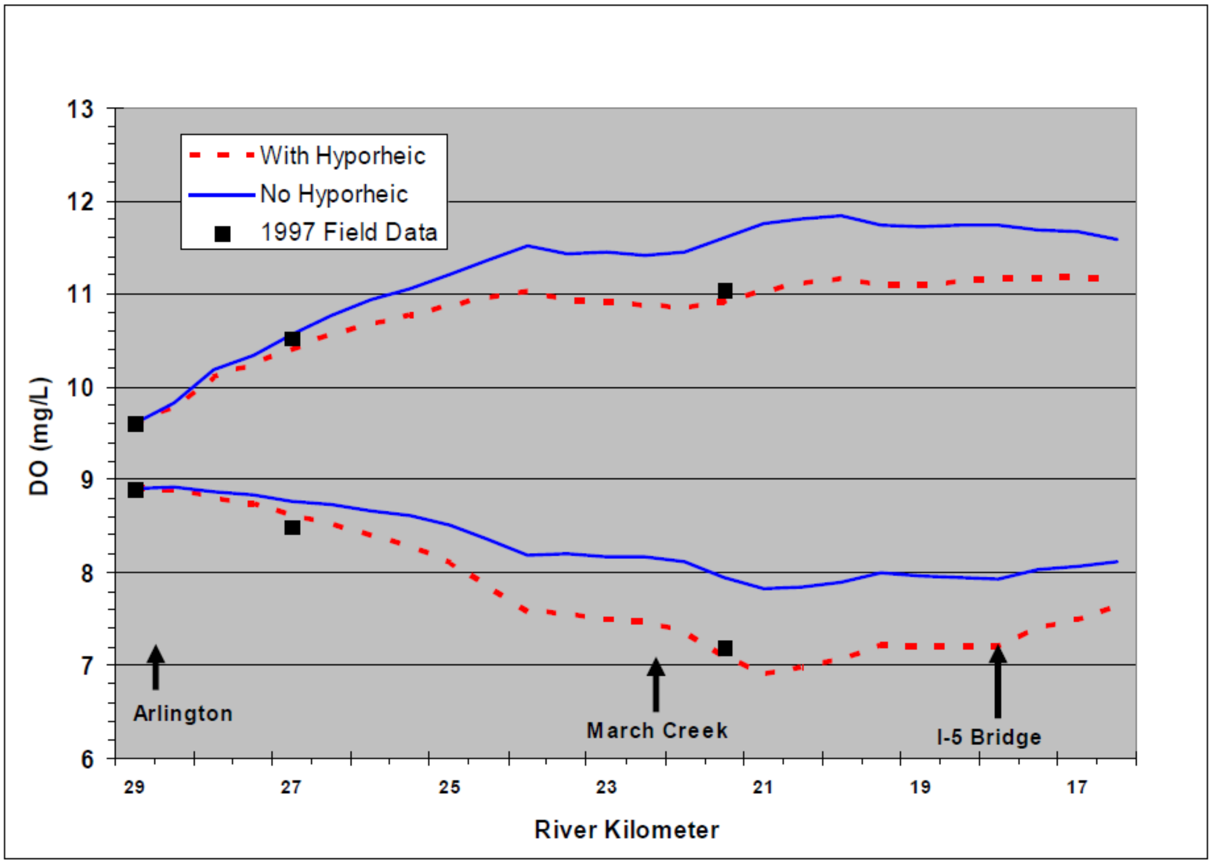

Figure 2. QUAL2Kw simulations of maximum and minimum dissolved oxygen profiles in the mainstem Stillaguamish River compared to diel dissolved oxygen data collected by Earth Tech in August 1997. *Simulated hyporheic respiration shown in dashed lines.*

The Arlington WWTP, several tributaries, and nonpoint sources discharge phosphorus to the river between the confluence of the North and South Forks and Interstate 5.

Arlington WWTP effluent is the major contributor of phosphorus into the RM 12.84 reach during the low-flow season. Based on the TMDL synoptic surveys during the summer and fall:

- 56% to 78% of the total phosphorus load comes from upstream.
- 15% to 33% comes from the Arlington WWTP.
- 1.5% to 2% comes from Armstrong Creek.
- 0.2% comes from March Creek.
- 1.6% to 14% comes from unidentified nonpoint sources or instream sources (Joe, 2004).

Ecology determined in the 2004 TMDL study that all the sources that may contribute to low DO conditions in the river were not fully identified (Joy, 2004). The QUAL2Kw model results indicated the data were not sufficient to clearly set load and wasteload allocations for all contributing sources to achieve compliance with the DO water quality criterion.

Project Goal and Objectives

Goal

The overall goal of the project is to characterize processes causing low DO in the Stillaguamish River Island Reach between RM 16.86 (RKM 28.5) near Arlington to RM 11.35 (RKM 19.19) near Interstate 5 during the critical low-flow period.

Objectives

The objective of this study is to collect adequate data on the processes controlling DO levels so that the QUAL2Kw model can better simulate the critical condition. The objective of this study will be achieved as follows:

- Characterize surface water physical and chemical processes governing low DO levels in the Stillaguamish River Island Reach, including the influence of tributaries.
- Characterize groundwater physical and chemical processes impacting low DO in the Island Reach.
- Characterize sediment oxygen demand processes within the Island Reach during critical conditions.
- Complete a QUAL2Kw model simulation of collected field data and recommended load allocations for background sources and wasteload allocations for point sources, to meet the DO water quality criterion and protect beneficial uses along the Island Reach during the critical period.

Study Design

Overview

A key component of the study design is to perform two to three synoptic surveys. A synoptic survey is a complete characterization of all major stream processes and local environmental conditions over a one-to-two day period. This allows Ecology to develop and test the QUAL2Kw model's ability to simulate DO levels under critical conditions.

Table 4 details the wide variety of field studies to be used to characterize physical and chemical processes influencing DO conditions in the river during critical conditions (August-October).

Table 4. Field study methods to be used for characterizing dissolved oxygen levels during the critical period.

<table>
<tr><th>Target Area</th><th>Study Mechanisms</th><th>Frequency</th></tr>
<tr><td rowspan="2">Point Source Effluent</td><td>Arlington WWTP effluent chemistry</td><td>Monthly</td></tr>
<tr><td>Arlington WWTP flow</td><td>Daily</td></tr>
<tr><td rowspan="5">Surface Water</td><td>Longitudinal temperature/DO profiling</td><td>Single event</td></tr>
<tr><td>Fixed network water quality sampling at 13 sites</td><td rowspan="6">Monthly</td></tr>
<tr><td>1-2 day continuous monitoring at several locations</td></tr>
<tr><td>Benthic oxygen demand measurements at 4 locations</td></tr>
<tr><td>Periphyton sampling</td></tr>
<tr><td rowspan="5">Groundwater</td><td>Groundwater chemistry and temperature at 9 sites</td></tr>
<tr><td>Groundwater direction at 9 sites</td></tr>
<tr><td>Hydraulic conductivity</td><td>Single event</td></tr>
<tr><td>Porewater sampling</td><td rowspan="4">Monthly</td></tr>
<tr><td>Off-stream groundwater sampling at 2 sites</td></tr>
<tr><td rowspan="2">Flow</td><td>Tributary streamflow monitoring at 5 locations</td></tr>
<tr><td>Mainstem flow monitoring at multiple locations</td></tr>
</table>

Modeling tasks will be completed by Ecology's Environmental Assessment Program staff by the spring of 2013.

Each of the study mechanisms to be used is discussed in detail below.

Longitudinal Temperature and Dissolved Oxygen Profile

A longitudinal temperature and DO profile will be developed using methods outlined in Gregory and Covert (2006) when the river flow approaches 1,000 cfs. The purpose of the profiling is to identity locations where piezometers will be placed and groundwater inputs /losses and groundwater quality can be measured as part of the 9 fixed-network groundwater sampling stations.

Ecology field staff will float down the river in a motorized raft equipped with a Hydrolab field meter which records temperature, DO, pH, and conductivity. A global positioning system (GPS) will simultaneously record location coordinates. Measurements will be made in a single longitudinal pass from RM 16.86 (RKM 28.5) to RM 11.35 (RKM 19.19).

Fixed-Network Sampling

Fixed-network surface water and groundwater stations will be established. Figures 3 and 4 and Table 5 show and describe the 13 fixed network of surface water sampling locations. Four stations are located at the mouths of tributaries: March Creek, Harvey/Armstrong Creek, and two unnamed tributaries (Figure 4). Effluent from the Arlington WWTP will also be sampled.

Fixed-network surface water stations were selected based on historical site locations, spatial resolution, and the location of tributaries. Sites may be added or removed from the sampling plan depending on access and new information provided during the field observation and preliminary data analysis from the longitudinal temperature and DO profile survey.

In addition, nine groundwater stations are proposed. Groundwater station placement will be determined based on results from the longitudinal temperature and DO profile survey tentatively scheduled for July 2010.

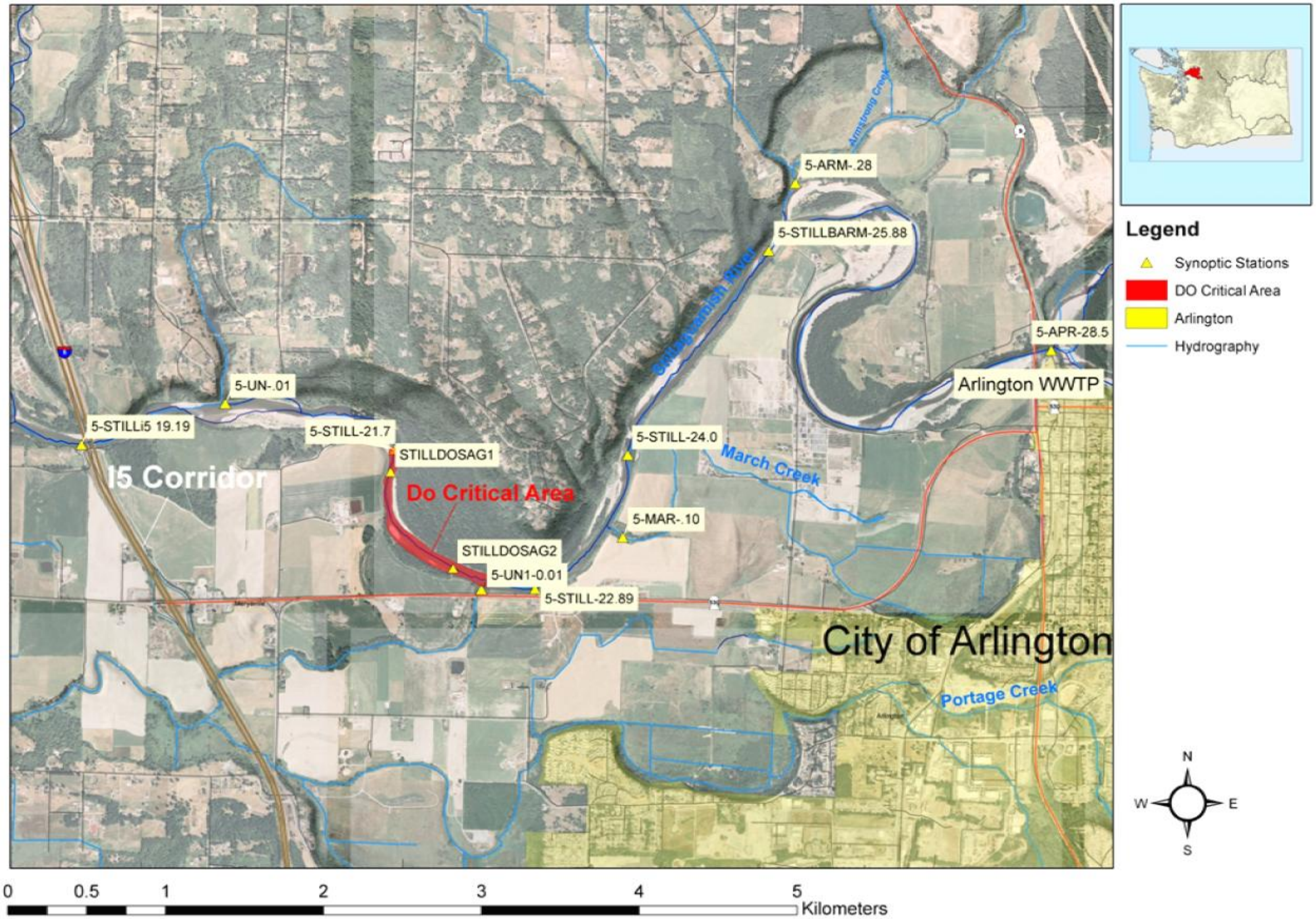

Figure 3. Sampling stations for the 2011 study.

Figure 4. Critical area of extent for low dissolved oxygen levels indicated by the 2004 TMDL Study (Joy, 2004).

Table 5. Fixed network surface water sites for the 2011 study.

Station ID	Latitude*	Longitude*	Description
5-APR-28.5	48.20356	-122.12836	Stillaguamish at Arlington above the Arlington WWTP outfall.
ARLINGTON WWTP	48.20276	-122.12833	Treated effluent collected by 24-hr compositor.
5-STILLBARM-25.8	48.20898	-122.15259	Below mouth of Armstrong Creek.
5-ARM-.28	48.21292	-122.15045	Armstrong Creek.
5-STILL-24.0	48.19698	-122.16421	Mainstem of Stillaguamish before March Creek.
5-MAR-.10	48.19222	-122.16447	Mouth of March Creek.
5-STILL-22.89	48.18911	-122.17185	Mainstem Stillaguamish after mouth of March Creek.
5-UN1-0.01	48.18990	-122.17641	Unnamed tributary.
STILLDOSAG2	48.1957	-122.18437	Critical area station by unnamed tributary.
STILLDOSAG1	48.1902	-122.17887	Critical area station before 5-STILL-21.7.
5-STILL-21.7	48.19702	-122.18407	Mainstem of Stillaguamish before 27th Avenue.
5-UN2-.01	48.19947	-122.19857	Unnamed tributary before Interstate 5.
5-STILLi5-19.19	48.19693	-122.21072	Mainstem of Stillaguamish at Interstate 5.

*Geographic Coordinate System and Projections: 83NAD 1983 HARN State Plane Washington South FIPS, Lambert Conformal Conic. USGS river miles were converted to kilometer units by using x miles * 1.69 km.

Surface water synoptic surveys

DO and associated conventional parameters will be measured at the fixed-network of stations (Table 4 and Figure 3) during the low-flow months (August to October). Conventional parameters sampled will include chloride, total suspended solids, total non-volatile suspended solids, turbidity, ammonia-N, nitrite+nitrate-N, orthophosphate, total phosphorous, total persulfate N, dissolved and total organic carbon, alkalinity, iron, and chlorophyll-*a*. Field teams will record in-situ parameters (temperature, DO, pH, and conductivity) and collect representative grab samples for laboratory analysis early in the morning and late in the afternoon.

One discharge measurement will be made for the river, tributaries, and WWTP during each synoptic survey event. Synoptic surveys will be conducted at least 2 times throughout the course of the project to provide calibration and corroboration of data sets.

Continuous diel monitoring for pH, DO, conductivity, and temperature will be conducted within a 24-48-hour period at several fixed-network sites with the Hydrolab DataSondes® units. The monitoring units will be pre-programmed to retrieve water quality measurements from the water column during the synoptic survey events. Benthic oxygen demand will be characterized by installing benthic flux chambers in 4 representative reaches along the river during the surveys or within a 24-hour period following the monthly surveys (Roberts, 2007). The benthic chambers will remain in place for at least 24 hours. Grab samples will be taken from the chambers for Winkler titration of DO at dawn and dusk. Respiration and eventual die-off of plants and bacteria is an oxygen-demanding process measured by the benthic flux chambers.

Periphyton sampling will be conducted during each synoptic survey at all fixed network sampling sites to analyze chlorophyll-*a* concentrations and to determine biomass using ash free dry mass analysis (Porter et al., 1993; Hauer and Lamberti, 2006). Phytoplankton and other plant periphyton are photosynthetic primary producers in aquatic systems and emit oxygen during daylight hours. Periphyton sampling from the stream bottom helps us quantify the oxygen inputs from photosynthesis and assess nutrient enrichment in the stream. Ecology's periphyton field sampling protocols will be adapted from the revised USGS protocols (Moulton et al., 2002). Ecology will evaluate channel substrates and channel morphology at each individual site to determine appropriate areas to collect periphyton. Sampling schedule may change if flow conditions increase over 1,000 cfs.

Surface water temperatures

Continuous temperature dataloggers (thermistors) will be deployed at each fixed-network site except the Arlington WWTP (Table 4 and Figure 3). Each site will have at least 2 thermistors deployed for approximately 90 days, one to measure water temperature and another to measure air temperature. The thermistors will measure temperature at 30-minute intervals. Instream thermistors are deployed in the thalweg of a stream such that they are suspended off the stream bottom following EAP protocols (Bilhimer and Stohr, 2007). Some sites may also have a datalogger measuring relative humidity. Thermistors will be placed in the instream piezometers and will be checked and downloaded monthly.

Groundwater synoptic surveys

Groundwater/surface water interactions will be evaluated monthly via a combination of field techniques. Nine instream piezometers will be installed in August 2010 at the majority of the fixed-network sites (Sinclair and Pitz, 2009). The piezometers will be used to monitor surface water/groundwater head relationships, streambed temperatures, groundwater quality, and streambed hydraulic conductivity. Three of the 9 piezometers will be installed in areas influenced by groundwater/surface water interactions delineated during the temperature/DO longitudinal profile survey.

Piezometers will be fitted with 3 thermistors for continuous monitoring of streambed temperatures (Figure 5). One thermistor will be located near the bottom of the piezometer, one 0.5 feet below the streambed, and one roughly equidistant between the upper and lower thermistors. Thermistors will be downloaded monthly. Manual temperature measurements will be made at the time of downloading for comparison with thermistors using a calibrated electronic field meter. An additional thermistor will be placed in flowing stream waters to measure surface water temperatures.

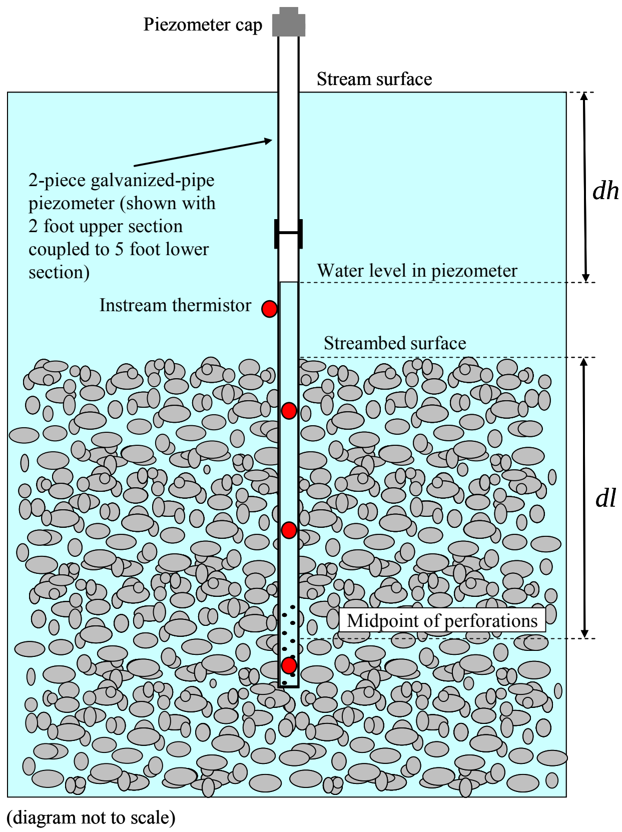

Figure 5. Instream piezometer conceptual diagram (diagram not to scale).

During the monthly site visits, surface water stage and piezometer water levels will be measured according to EAP methods (Sinclair and Pitz, 2009) to determine whether groundwater levels in the local stream reach are reflective of a gaining, losing, or static condition. The water level (head) difference between the piezometer and the river indicates the vertical hydraulic gradient and the direction of flow between the river and groundwater. When the piezometer head exceeds the river stage, groundwater is discharging to the river. Similarly, when the river stage exceeds the head in the piezometer, water is flowing from the river to groundwater.

The measurements of surface water and groundwater interactions will be necessary to determine the volume of water exchange between the groundwater and surface water interface. Hydraulic conductivity (K) is a measure of the permeability of the streambed sediments. K values will be estimated using the constant head injection test (CHIT) (Pitz, 2006).

Porewater sampling

Biogeochemical processes are predominately active within a few inches to several feet of the groundwater/surface-water interface. These processes can cause significant changes in the water quality of groundwater discharging to a surface water system (Constanz, 2007; Winter et al., 1998; Ford, 2005; Bridge, 2005). Biogeochemical processes within the transition zone include oxidation-reduction (redox), acid-base reactions, precipitation and dissolution, sorption and ion exchange, and biodegradation reactions. These processes can create strong vertical solute concentration gradients over short distances and significantly influence the chemical character of the groundwater discharging to surface water (USEPA, 2000a; Ford, 2005; Laskov et al., 2007).

High-resolution porewater sampling can provide data representing the concentration of solutes within a few centimeters of the groundwater/surface water interface. If substrate conditions are suitable, porewater samples will be collected once using the push-point sampling method described by Pitz (2006) (Figure 6). Sediment characteristics and hydraulic conductivity results from CHIT tests will determine site suitability for porewater extraction. Porewater samples will be field-filtered (0.45 um pore size) and analyzed for ammonia-N, nitrate+nitrite-N, orthophosphate, total phosphorus, and DOC (Table 8).

Porewater will be drawn into a 60-ml syringe using a low-flow pump (≤ 2.5 ml/min). Porewater samples will be field-filtered (0.45 um pore size), transferred to sample containers, and cooled to ≤4°C before transporting to MEL for analysis. Porewater results will be used in the QUAL2Kw model’s hyporheic function.

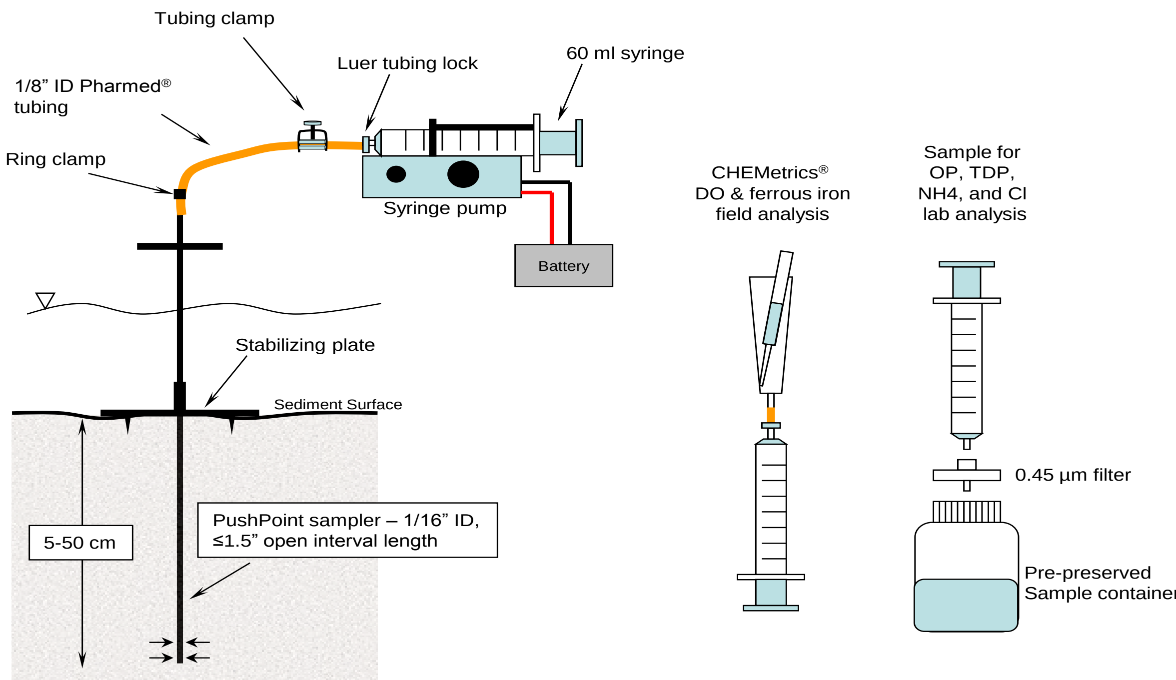

Figure 6. Diagram of push-point porewater sampling apparatus (Pitz, 2008).

Off-stream well sampling

Ecology will sample 2 off-stream domestic wells to observe "regional" groundwater levels, temperatures, and groundwater quality. Ecology will use approved Environmental Assessment Program methods. Wells close to areas of concern that have drilling logs will be selected. Water levels in wells will be measured (Marti, 2009) and samples collected monthly from August to October for temperature, pH, conductivity, DO, DOC, ammonia-N, nitrate+nitrite-N, orthophosphate, and total phosphorus.

Surface flow monitoring

Surface flow measurement (seepage run) will be conducted in conjunction with the monthly surface water surveys to determine the flow mass balance of the Island Reach. Ecology’s Freshwater Monitoring Unit (FMU) will conduct seepage runs along the mainstem Stillaguamish from RM 16.8 (RKM 28.5) to RM 11.3 (RKM 19.1). Discharge information will be collected approximately every kilometer during a 24-48-hour period during monthly surface water (Shedd et al., 2008; Shedd, 2009) Results will be compared to groundwater vertical hydraulic gradient measurements to determine losing and gaining areas. Seepage runs will be used to verify that accumulative discharge for all stations meets the conditions of less than 1,000 cfs.

Real-time staff gages provided by Snohomish County will be used to measure background stream stage heights during the surveys at Arlington RM 16.8 RM (RKM 28.5) and at Interstate 5. Tributary discharges will be measured using a Marsh-McBirney flow meter according the standard operating procedures for estimating streamflow outlined in (Sullivan, 2007). WWTP flows recorded by City staff will be reported on field data sheets.

WWTP effluent sampling

Composite effluent samples will be collected from the Arlington WWTP during each synoptic survey. The compositor will sample finished effluent. Aliquots of milliliters will be collected every 1½ hour for 24 hours to accumulate a total volume of 2 liters. Samples of effluent will be collected at the beginning and end of the compositor deployment. MEL will analyze composite effluent samples for Ultimate Biological Oxygen Demand (UBOD), chloride, total suspended solids, total non-volatile suspended solids, turbidity, ammonia-N, nitrite+nitrate, orthophosphate, total phosphorous, total persulfate N, dissolved and total organic carbon, and alkalinity.

Modeling and Analysis Framework

Water quality modeling will be conducted using QUAL2Kw (Chapra and Pelletier, 2003). QUAL2Kw model components are defined in Appendix B. The model will use kinetic formulations for simulating DO in the water column based on data collected from the survey components defined in Figure 7.

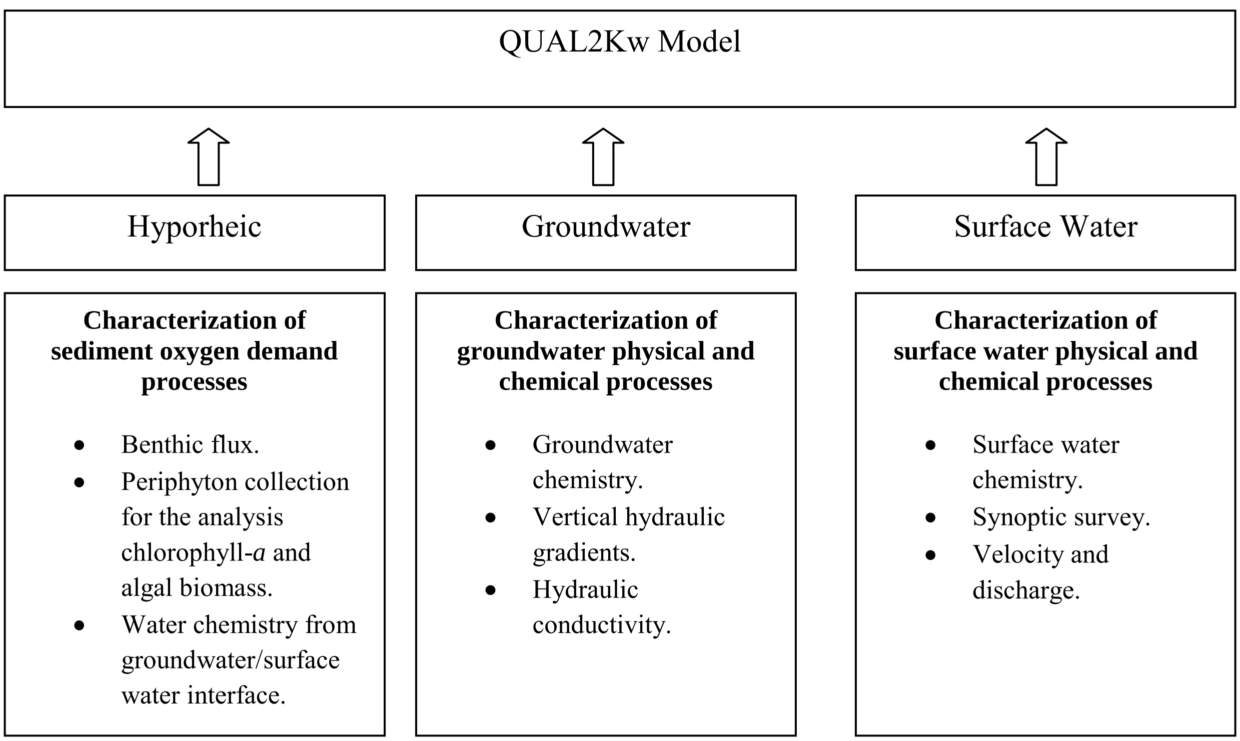

Figure 7. Physical survey components required for QUAL2Kw model re-simulation of dissolved oxygen.

The QUAL2Kw model requires data for calibrations of longitudinal changes and diurnal ranges during the summer-fall critical season. These data must be accurate to definitively assess compliance with the DO water quality criterion. The model requires reach-specific data for physical channel and riparian structure, biomass, and chemistry. Calibration and verification data for critical conditions are needed to determine model sensitivity and the degree of robustness.

Preliminary Survey and Fixed Network Sampling Timeline

Table 6 represents the proposed survey schedule for the study. Reconnaissance visits to locate wells and gain permission for site access will begin in spring of 2010. Thermistors and Relative Humanity (RH) units will be installed after fixed network sites are confirmed. Synoptic surveys will be completed during the critical period (under 1,000 cfs). A completed overview of survey components, sampling methods, timeline, and logistics is presented in Appendix C.

Table 6. Proposed field/survey schedule, 2010.

Survey Parameter	Pre-survey	July	August	September	October
Temperature/DO longitudinal profile survey.	--	X[1]	--	--	--
DO and synoptic survey periphyton collection.	X	--	X[2]	X[2]	X[2]
Groundwater, synoptic surveys, and upland well sampling.	--	X[3]	X	X	X
Seepage surveys.	--	X	X	X	X

X[1] Temperature/DO profiling will occur by towed Hydrolab if the river is approaching flows less than 1,000 cfs at the Interstate 5 Station. If not, then this will occur in August if flows are less than 1,000 cfs.

X[2] Winkler DO samples will be included for lab check of field measurements.

X[3] Installation of groundwater stations if longitudinal survey will be completed in July; if not, then this will occur in August.

Following groundwater piezometer installation, the piezometer network will be checked for subsurface flow variability due to sediment clogging and flushing rates prior to fixed network sampling.

Practical Constraints

The sampling window is very limited, and the conditions necessary to evaluate the problem may not occur in 2011. The 2004 TMDL study indicated that DO critical conditions occurred during the summer and fall low-flow season (August – October). Low DO concentrations occur during a stable low-flow, when both biomass growth and benthic demand occur (Joy, 2004).

Critical conditions for the Stillaguamish River Island Reach also are characterized as having these features:

- Abundant nutrients are available in the water column.
- Discharge decreases for an extended period below 28.32 cms (1,000 cfs) so retention time through pools increases.
- Water clarity increases allowing increased periphyton growth.
- Periphyton biomass is not interrupted or scoured away by large summer storm events.
- Groundwater inputs, or chemical and gas exchanges from hyporheic or heterotrophic bacteria respiration processes, may interact with water in pool reaches (Joy, 2004).

In some years, the combination of these features may not occur long enough to create a critical condition that can be adequately investigated. In this case, the field surveys will be postponed until critical conditions are established.

The October 2001 diel monitoring results indicate the DO criterion violation may be limited to the pool at RM 12.84 (RKM 21.7), since DO concentrations in the next pool downstream at RM 10.4 (RKM 17.7) were significantly above 8 mg/L (Joy, 2004). However, a more extensive area may be affected under critical conditions such as experienced during a 7-day, 10-year low-flow event. For the purpose of this 2011 study, it will be necessary to focus monitoring above and below RM 12.84 (RKM 21.7) (Figures 3 and 4).

Access to sampling sites will be achieved on foot. Property access will be determined based on the landowner's permission. Ecology will work with the City of Arlington to contact landowners prior to field surveys. Specific tasks and fixed network sites inaccessible by foot will be accessed by watercraft launched from Haller Park in Arlington.

Sampling Procedures

Field sampling and measurement protocols will follow those listed by Ecology's Environmental Assessment Program quality assurance guidance and methodology procedures www.ecy.wa.gov/programs/eap/quality.html.

Sampling will follow the Environmental Assessment Program's SOPs for minimizing the spread of aquatic organisms in areas of moderate concern.

Grab samples will be collected directly into pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL) and described in the MEL Users Manual (2008). DO grab samples will be collected and field processed according to the SOP for the Collection and Processing of Stream Samples (Ward, 2007). Sample parameters, containers, volumes, preservation requirements, and holding times are listed in Table 7. All samples for laboratory analysis will be stored in the dark, on ice, and delivered to MEL within 24 hours of collection via Greyhound and Ecology courier.

A minimum of 10% of the samples will be field duplicates used to assess total (field and lab) variability. Where it can be done safely, grab samples will be collected in the thalweg and just under the water's surface. Some bank-side sampling may be necessary in pool areas approached without the use of a watercraft.

Compositors will be pre-cleaned prior to deployment. After collection, the compositor jug will be thoroughly mixed before filling pre-cleaned containers for MEL analyses.

Ecology's periphyton field sampling protocols will be adapted from the revised USGS protocols (Moulton et al., 2002). Three samples plus duplicates will be collected at each site where periphyton is present. Depth, velocity, substrate, and shade will be considered in site selection to find similar conditions between sites. Sampling will consist of randomly grabbing representative substrates from the left bank, thalweg, and right bank. Periphyton biomass samples will be collected by scraping material from a measured surface area on representative substrates into a pretreated sample bottle for lab analysis.

The scraped surface area will be measured by placement of tin foil over the surface area. The measured foil will be placed in ziplock bags and marked with a sample ID tag. Sample surface areas will be measured by scanning the foil on a flat bed scanning device. The photo-replicated sample area will be estimated by image analysis software (Image J software/ Photoshop). Periphyton biomass samples will be analyzed for chlorophyll-*a* and ash-free dry weight. Net production will be estimated by gain in ash-free weight per substrate unit area from each collection period for MEL analysis.

In predominantly sand and silt locations, periphyton sampling will be performed by inserting a petri dish lid into the top layer of sand/silt at a depth of 5–7 mm. A spatula will isolate the sediment within the petri dish. The contents will then be transferred to a tray/container while rinsing the residue from the petri dish, and then filtered into a 1,000 mL amber poly bottle.

Samples will not be collected for species verification. Site benthic area coverage by periphyton will be documented by digital photography.

Temperature monitoring stations and piezometers will be checked monthly for accumulated debris. Documentation of the temperature monitoring stations will include:

- GPS coordinates and a sketch of the site (during installation only).
- Depth of the instream temperature instrument (TI) under the water surface and height off the stream bottom.
- Stream temperature.
- Serial number of each instrument and the action taken with the instrument (i.e., downloaded data, replaced TI, or note any movement of the TI location to keep it submerged in the stream).
- The date and time before the dataloggers are installed or downloaded, and the date and time after they have been returned to their location, will be noted. All timepieces and computer clocks should be synchronized to the atomic clock using Pacific Daylight Savings Time. Pacific Standard Time will be reported if instruments are still in place during the time change.

Samples collected from piezometers for laboratory analysis will be analyzed according to the methods listed in Table 8. MEL staff will consult the project manager if any changes in procedures over the course of the project are recommended or if matrix difficulties are encountered. MEL will analyze all samples in accordance with standard protocols (MEL, 2008).

Filtered/unfiltered samples, Winkler DO samples, and Hydrolab Sonde DO measurements from benthic chambers will be collected and field processed according to the SOP for benthic flux chambers (Roberts, 2007). Benthic chamber deployment will be conducted 24 hours after the monthly survey events.

Table 7. Containers, preservation requirements, and holding times for samples collected (MEL, 2008).

Parameter	Bottle	Preservative	Holding Times
Dissolved Oxygen	300 mL BOD bottle and stopper	2 mL manganous sulfate reagent + 2 mL alkaline-azide reagent	4 days
Alkalinity	500 mL polypropylene	Cool to 4°C	14 days
Ammonia Nitrogen	125 mL clear	H2SO4 to pH <2 Cool to 4°C	28 days
Dissolved Organic Carbon	60 mL ploy	HCL to pH <2 Cool to 4°C	28 days
Nitrate-Nitrite	125 mL clear poly	H2SO4 to pH <2 Cool to 4°C	28 days
Orthophosphate	125 amber mL poly	Cool to 4°C	48 hours
Total Persulfate Nitrogen	125 mL clear poly	H2SO4 to pH <2 Cool to 4°C	28 days
Total Phosphorus	125 mL clear poly	HCL to pH <2 Cool to 4°C	28 days
Chlorophyll-*a*[4]	1000 mL	Cool to 4°C	28 days after filtering
Chloride	500 mL poly	Cool to 4°C	28 days
Total Suspended Solids, TVNSS[1]	1000 mL wide-mouth poly	Cool to ≤6°C	7 days
Turbidity	500 mL poly	Cool to ≤6°C	48 hours
Total Organic Carbon	60 mL bottles	HCL to pH <2 Cool to 0 to 6°C	28 days
Biological Oxygen Demand	4 liter cubitainer	Cool to ≤6°C	48 hours
Total Iron (filtered)	500 mL HDPE[2] bottle	Filter within 15 minutes of collection; then add HNO3 to pH<2 [3] Cool to ≤6°C	6 months

TNVSS[1] = Total nonvolatile suspended solids.
HDPE[2] = high-density polyethylene.
pH<2[3] = Preserved in lab within 24 hours of arrival. Samples for dissolved mercury must be filtered within 24 hours of collection and preserved within 48 hours.
[4]Periphyton tissue matrix: Chlorophyll a and ash-free dry weight.

Field Measurement Procedures

Field measurements of surface water will include conductivity, temperature, pH, and DO using a calibrated Hydrolab DataSonde® or MiniSonde®. DO will also be collected and analyzed using the Winkler titration method (www.ecy.wa.gov/programs/eap/quality.html).

Piezometer and groundwater temperature, water level, conductivity, pH, and DO will be measured. A WTW 340i multi-meter will be used to measure water conductivity and temperature of groundwater in piezometers. Measurement of relative head conditions between the piezometer and the river will be accomplished by direct comparison measurements directed by (Sinclair and Pitz, 2009). Temperature dataloggers will also be downloaded monthly or bi-monthly using protocols established in (Bilhimer and Stohr, 2007).

River flow velocity and cross-section channel characteristics will be made by a Teledyne Rd Instruments Acoustic Doppler Current Profiler (ADCP). ADCP sampling will be conducted by watercraft at sites unwadeable. Real-time stream gage height stations provided by Snohomish County will be used to measure stream height at Arlington RKM 28.5, Highway 9, and at Interstate 5. Ecology will obtain additional streamflow gage information at the Stillaguamish River station near Silvana.

All continuous recording dataloggers, such as Hydrolabs and Tidbits thermistors, will be synchronized to official U.S. time.

Temperature and water depth data for the longitudinal temperature/DO survey will be gathered using a Solinst® Levelogger® Model 3001 towed in a protective plastic housing behind a single-seat inflatable pontoon craft. Location data will be gathered and logged for time using a Trimble® GeoXM™ using TerraSync™ and Geoexplorer® CE software. Generally, the craft will be kept in the thalweg of the stream. The GPS unit will be carried aboard the pontoon craft. The housing assembly will be attached to a rope approximately 8 feet long, gathering temperature and depth measurements every 6 seconds. The GPS unit will record position every 30 seconds. GPS track-log raw data will be evaluated and reduced.

DO measurements will be conducted within the critical area of interest (Figure 4) using Hydrolabs by watercraft. Measurements will be made at .20 km intervals between stations 5-STILL-21.7 and STILLDOSAG2. Areas indicating significant reduction in DO levels will be recorded. Station placements within the critical area of interest may be delineated depending on the DO survey results.

Data Quality Objectives

Field sampling procedures and laboratory analysis inherently have associated error. Measurement quality objectives state the allowable error for a project. Precision and bias are data quality criteria used to indicate conformance with measurement quality objectives.

Precision is defined as the measure of variability in the results of replicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for replicates will be expressed as percent relative standard deviation (%RSD).

Bias is defined as the difference between the population mean and true value of the parameter being measured. Bias affecting measurement procedures can be inferred from the results of quality control procedures involving the use of blanks, check standards, spiked samples, and calibration errors. Bias in field measurements will be minimized by strictly following sampling and handling protocols, and will be assessed by submitting field blanks.

Temperature and Streamflow Surveys

The summary of measurement quality objectives and manufacturer measurement limits of field equipment used in the study are defined in Table 8.

Table 8. Summary of measurement quality objectives and manufacturer measurement limits of field equipment.

Measurement/ Instrument Type	Bias (% deviation from true value)	Required Resolution
Continuous temperature/ Hobo Water Temp Pro	±0.2°C at 0 to 50°C (± 0.36°F at 32° to 122°F)	0.2°C for water temperature
Continuous temperature/ Stow Away Tidbits -5°C to +37°C model	±0.4°F (±0.2°C) at +70°F	0.2°C for water temperature
Stream velocity/ Teledyne RDI's StreamPro ADCP (Acoustic Doppler Current Profiler)	(cell = 1/2 max.) ±1.0%±0.2cm/s	0.1 cm/sec
Stream velocity/ Marsh McBirney Flo-Mate model 2000	±2% of reading; 0.1 ft/s 5%-8% measurement error	0.05 ft/sec
Continuous water levels/ Hobo Water Level Logger U-20-001-01	±2.1 cm (0.07 ft) and ±0.37°C at 20°C (0.67°F at 68°F);	0.01 ft
Instantaneous conductivity and temp./ TetraCon 325C probe and WTW 340i multi-meter	±1% of value (conductivity) 0.2°C (temperature)	0.2°C for water temperature
Water temperature and specific conductivity/ Hydrolab MiniSonde®	+/- 0.1°C (temperature) +/- 0.5% (conductivity)	0.1°C (temp) 0.1 µmhos/cm (conductivity)
Continuous temperature / StowAway Tidbits -20°C to +50°C	±0.8°F (±0.4°C) at +70°F	0.4°C for air temperature
Relative humidity/ Hobo Pro	±3% RH	N/A

Groundwater Monitoring

Groundwater sampling events will be conducted to assess the quality of groundwater discharging to the Stillaguamish river along gaining river reaches. The samples will be evaluated for the parameters shown in Table 9.

Table 9. Groundwater sampling parameters, test methods, and detection limits.

Parameter	Equipment Type and Test Method	Reporting Limit
Field Measurements		
Water Level	Calibrated E-tape	0.01 foot
Temperature	Sentix® 41-3 probe[2]	0.1ºC
Specific Conductance	Tetracon® probe[2]	1 µmhos/cm
pH	Sentix® 41-3 probe[2]	0.1 SU
Dissolved Oxygen	Cellox® 325 probe[2]	0.1 mg/L
Laboratory Analyses		
Alkalinity	SM 2320B	5 mg/L
Ammonia N[1]	SM 45000-NH_3^-H	0.01 mg/L
Dissolved Organic Carbon[1]	SM 5310B	1.0 mg/L
Nitrate-Nitrite-N[1]	SM 4500 NO_3^-I	0.1 mg/L
Orthophosphate[1]	SM 4500-P G	0.003 mg/L
Filtered Total Persulfate Nitrogen-N[1]	SM 4500NO_3^- B	0.25 mg/L
Filtered Total Phosphorus[1]	SM 4500-P FI	0.01 mg/L
Chloride	EPA 300.0	0.1 mg/L
Dissolved Iron (Filtered) [3]	EPA 200.7	0.05 mg/L

[1] Dissolved fraction.
[2] Probe used with a WTW multiline P4 meter.
[3] Samples are filtered through a 0.45 micron membrane filter.
SM = Standard Method.

Dissolved Oxygen and Nutrient Surveys

Analytical methods, expected precision of sample replicates, and method reporting limits and resolution are given in Table 10. The targets for analytical precision of laboratory analyses are based on historical performance by MEL for environmental samples taken during TMDL studies around the state by the Environmental Assessment Program (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives. The laboratory's measurement quality objectives and quality control procedures are documented in their Lab Users Manual (MEL, 2008).

Quality Objectives for Modeling or Other Analysis

Model resolution and performance will be measured using the root-mean-square-error (RMSE) or Nash-Sutcliffe coefficient. The RMSE is a commonly used measure of model variability (Reckhow, 1986). The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values. Nash-Sutcliffe coefficient of efficiency (Nash and Sutcliffe, 1970) measures model errors in estimating the mean or variance of the observed data sets. It is more sensitive to outliers in continuous simulation output than the RMSE.

Table 10. Target for precision and reporting limits for measurement systems.

Analysis	Equipment Type and Method	Duplicate Samples Relative Standard Deviation (RSD)	Method Reporting Limits and/or Resolution
Field Measurements			
Water Temperature[1]	Hydrolab MiniSonde®	0.025°C	0.01°C
Specific Conductivity[2]	Hydrolab MiniSonde®	±0.05%	0.1 umhos/cm
pH[1]	Hydrolab MiniSonde®	0.05 SU	1 to 14 SU
Dissolved Oxygen[1]	Hydrolab MiniSonde®	<10% RSD	0.1 mg/L
Dissolved Oxygen[1]	Winkler Titration	<10% RSD	0.1 mg/L
Laboratory Analyses			
Alkalinity	SM 2320B	<10% RSD[3]	5 mg/L
Ammonia Nitrogen	4500-NH_3H	<10% RSD[3]	0.01 mg/L
Dissolved Organic Carbon	EPA 415.1	<10% RSD[3]	1.0 mg/L
Nitrate-Nitrite	SM 4500-NO_3 I	<10% RSD[3]	0.1 mg/L
Filtered Nitrate-Nitrite (benthic)	SOP EAP025	<10% RSD[3]	0.1 mg/L
Orthophosphate	SM 4500-PG	<10% RSD[3]	.003 mg/L
Total Persulfate Nitrogen	SM 4500	<10% RSD[3]	0.025 mg/L
Total Phosphorus	SM 4500-P I	<10% RSD[3]	0.01 mg/L
Filtered Total Phosphorus (benthic)	SM EAP025	<10% RSD[3]	0.1 mg/L
Chlorophyll- *a* (water column)	SM 10200H(3)	<10% RSD[3]	0.01 ug/L
Chloride	EPA 300.0	<10% RSD[3]	0.1 mg/L
Total Non-Volatile Suspended Solids	SM 2540D	<10% RSD[3]	1 mg/L
Total Suspended Solids	SM 2540A	<10% RSD[3]	1 mg/L
Turbidity	SM 2130	<10% RSD[3]	1 NTU
Total Organic Carbon	EPA 415.1	<10% RSD[3]	1 mg/L
Biological Oxygen Demand	SM 5210C	<10% RSD[3]	2 mg/L
Ash-free dry weight	10300C	<10% RSD	1 mg/L
Periphyton chlorophyll a	SM 10200H(3)	<10% RSD	1 mg/Kg

[1] as units of measurement, not percentages.
[2] as percentage of reading, not RSD.
[3] replicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately.
SM = Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, AWWA and WEF, 1998).
EPA = EPA Method Code.
EAP = Ecology's Environmental Assessment Program.

Quality Control

Total variability for field sampling and laboratory analysis will be assessed by collecting replicate samples. Replicate samples are used for quality assurance/quality control (QA/QC) purposes. Total sample precision will be assessed by collecting replicates for 10-20% of samples for each parameter of interest in each survey. MEL routinely duplicates sample analyses in the laboratory to determine laboratory precision. The difference between field variability and laboratory variability is an estimate of the sample field variability.

Laboratory

All samples will be analyzed MEL following standard QC procedures outlined in the laboratory QA plan and the lab Users Manual (MEL, 2008). The laboratory's data quality objectives are documented in MEL (2008). QC procedures used during field sampling and laboratory analysis will provide estimates toward understanding accuracy of the monitoring data. Field sampling and measurements will follow QC protocols described in Ecology (1993). The project manager and MEL staff will check data for QC, if any of these QC procedures are not met, the associated results may be qualified by MEL or the project manager and used with caution or not used at all.

Data reduction, review, and reporting will follow the procedures outlined in MEL's Lab Users Manual (MEL, 2008). In addition, lab results will be checked for missing and/or improbable data. Data variability of field replicates and lab duplicates will be quantified using the methods described above. Should concentrations vary over an order of magnitude during the study at any given station, standard deviation and other parameters may be analyzed using the logarithms of concentration. If lab blanks show levels of an analyte above reporting limits, the resulting data will be disqualified, as appropriate.

Field

Groundwater field staff will conduct a QA/QC calibration check for temperature dataloggers. The Onset StowAway Tidbits©, Hobo Water Temp Pro©, and Hobo Water Level Logger© instruments will have a calibration check both pre- and post-study in accordance with Ecology Temperature Monitoring Protocols (Ward, 2003). This check will be to document instrument bias or performance at representative temperatures. An NIST-certified reference thermometer will be used for the calibration check. The calibration check may show that the temperature datalogger differs from the NIST-certified thermometer by more than the manufacturer-stated accuracy of the instrument (range greater than ±0.2°C or ±0.4°C).

A datalogger that fails the pre-study calibration check will not be used. If the temperature datalogger fails the post-study calibration check, then the actual measured value will be reported along with its degree of accuracy based on the calibration check results. As a result, these data may be qualified or rejected.

Variation for field sampling of instream temperatures and potential thermal stratification will be addressed with a field check of stream temperature at all monitoring sites upon deployment, during regular site visits, and during instrument retrieval at the end of the 2010 study period. The Onset Hobo Water Level Logger© pressure transducers will be checked for accuracy both before and after deployment using a graduated vertical water column that is capable of simulating the range of water depths the instruments will likely encounter during deployment.

Water levels both in the piezometer and at the stream-stage reference point will be measured in the field with an e-tape and steel engineer's tape. Barometric pressure will be recorded at representative stations to compensate for atmospheric pressure effects on the water level loggers.

The WTW 340i multi-meter will be calibrated at the beginning of each sampling day using commercially prepared conductivity standards and reference solutions in accordance with the manufacturer's calibration procedures. The calibration will be rechecked at the end of each sampling day.

Table 11 summarizes the accuracy and reporting limits of the equipment used. Certain instruments are used exclusively for water temperature and others for air, as noted in the table.

Table 11. Summary of measurement quality objectives and manufacturer measurement limits of field equipment.

Measurement/ Instrument Type	Accuracy (% Deviation from True Value)	Required Resolution
Continuous temperature/ Hobo Water Temp Pro	±0.2°C at 0 to 50°C (± 0.36°F at 32° to 122°F)	0.2°C for water temperature
Continuous temperature / Stow Away Tidbits -5°C to +37°C model	±0.4°F (±0.2°C) at +70°F	0.2°C for water temperature
Stream velocity/ Teledyne RDI's StreamPro ADCP (Acoustic Doppler Current Profiler)	(cell = 1/2 max.) ±1.0%±0.2 cm/s	0.1 cm/sec
Stream velocity/ Marsh McBirney Flo-Mate model 2000	±2% of reading; 0.1 ft/s 5%-8% measurement error	0.05 ft/s
Continuous water levels/ Hobo Water Level Logger U-20-001-01	±2.1 cm (0.07 ft) and ±0.37°C at 20°C (0.67°F at 68°F);	0.01 ft
Instantaneous conductivity and temp./ TetraCon 325C probe and WTW 340i multi-meter	±1% of value (conductivity) 0.2°C (temperature)	0.2°C for water temperature
Water Temperature and Specific Conductivity/Hydrolab MiniSonde®	+/- 0.1°C (temp) +/- 0.5% (conductivity)	0.1°C (temp) 0.1 µmhos/cm (conductivity)
Hobo Pro Relative Humidity	±3% RH	n/a
Continuous temperature / StowAway Tidbits -20°C to +50°C	±0.8°F (±0.4°C) at +70°F	0.4°C for air temperature

Data Management Procedures

Field measurement data will be entered into a field book with waterproof paper in the field and then entered into EXCEL® spreadsheets (Microsoft, 2001) as soon as practical after returning from the field. Field measurement data will be kept with the project manager. The data will be located on Ecology's shared network storage system. This database will be used for preliminary analysis and to create a table to upload data into Ecology's Environmental Information Management (EIM) System.

MEL will enter project data Ecology's Laboratory Information Management System (LIMS). These data will be exported prior to entry into EIM and added to a cumulative spreadsheet for laboratory results. Project data will be kept with the project manager. The data will be located on Ecology's network storage system.

This spreadsheet will be used to informally review and analyze data during the course of the project. The project database will include station location information and data QA information. This database will facilitate summarization and graphical analysis of the temperature data and also create a data table to upload temperature data to the EIM geospatial database. All of the continuous data will be summarized for EIM and used for future data reference.

An EIM user study ID (MVP003) has been created for this study. All monitoring data will be available via the internet once the project data have been verified and validated. The URL address for this geospatial database is: apps.ecy.wa.gov/eimreporting. Project data will be uploaded to EIM by the EIM data engineer after all data have been reviewed for QA and finalized.

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

Audits and Reports

MEL will submit laboratory reports, QA worksheets, and chain-of-custody records to Environmental Assessment Program staff. The laboratory will report any problems and associated corrective actions to the project manager.

All project data will be made available to the assigned project QUAL2Kw modeler who will conduct modeling simulation and additional data analysis. Results from the QUAL2Kw modeling simulations will be summarized and published in a final technical report.

Data Verification

Data verification involves examining the data for errors, omissions, and compliance with QC acceptance criteria. MEL is responsible for performing the following functions:

- Reviewing and reporting QC checks on instrument performance such as initial and continuing calibrations.
- Reviewing and reporting case narratives. This includes comparison of QC results with method acceptance criteria such as precision data, surrogate and spike recoveries, laboratory control sample analysis, and procedural blanks.
- Explaining flags or qualifiers assigned to sample results.
- Reviewing and assessing MEL's performance in meeting the conditions and requirements set forth in this QA Project Plan.
- Reporting the above information to the project manager or lead.

After field measurements and MEL results have been recorded, MEL will verify the results to ensure that:

- Data are consistent, correct, and complete, with no errors or omissions.
- Results of QC samples accompany the sample results.
- Established criteria for QC results were met.
- Data qualifiers are properly assigned where necessary.
- Data specified in the Sampling Process Design were obtained.
- Methods and protocols specified in the QA Project Plan were followed.

MEL is responsible for verifying all analytical results. Reports of results and case summaries provide adequate documentation of the verification process. MEL analytical data will be reviewed and verified by comparison with acceptance criteria according to the data review procedures outlined in the Lab Users Manual (MEL, 2008).

Appropriate qualifiers will be used to label results that do not meet QA requirements. MEL will provide an explanation for data qualifiers.

Surface water field personal will record field data during the field survey events. Assigned hydrogeologists will collect all groundwater data. All field data will be turned over to the project manager after each survey event. Field personnel will be responsible for notifying the project manager of any potential data discrepancies or errors prior to submitting field data results.

Data for instream temperature monitoring stations will be verified against the corresponding air temperature station to ensure the stream temperature record represents water temperatures. Measurement accuracy of individual TIs is verified using a NIST-certified reference thermometer and field measurements of stream temperature at each TI location several times during the 2010 study period.

The project manager will examine the complete data package to determine compliance with procedures outlined in the QA Project Plan and the SOPs.

After data verification and data entry tasks are completed, all field, laboratory, and flow data will be entered into a file labeled FINAL and then uploaded into EIM by the EIM data engineer. Ten percent of the project data in EIM will be independently reviewed by another Environmental Assessment Program field assistant for errors. If significant entry errors are discovered, a more intensive review will be undertaken. At the end of the field study, the data will be compiled in a formal data summary report.

Data Quality (Usability Assessment)

The surface water field lead will verify that all measurement and other data quality objectives have been met for each monitoring station. Assigned hydrogeologists will verify that all measurement and other data quality objectives have been met for each piezometer station. The field lead will make this determination by examining the data and all of the associated QC information. Data that does not meet the project data quality criteria will be qualified or rejected as appropriate. The field lead will produce a station QA report that will include site descriptions, data QA notes, and graphs of all continuous data.

Project Organization and Schedule

Table 12. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Dave Garland WQP, NWRO (425) 649-7031	Unit Supervisor of Project Manager	Provides internal review of the QAPP, and approves the final QAPP.
Ralph Svrjcek WQP, NWRO (425) 649-7165	EAP Client	Clarifies scope of the project, provides internal review of the QAPP, and approves the final QAPP
To be determined (WQP)	Project Manager	Implements the QAPP. Coordinates field surveys and oversees field sampling. Conducts QA review of data, and analyzes and interprets data. Writes the quarterly reports, draft report, and final report.
To be determined (WQP)	Principal Investigator	Organizes synoptic surface water field crews. Collects field samples and records field information under the supervision of the project manager. Analyzes and interprets data. Writes data summary. Helps write the draft report and final report.
To be determined (WQP)	Licensed Hydrogeologist	Provides hydrogeologic assistance with study design including interpretation of historical geology and groundwater data in the basin. Selects shallow upland wells for sampling. Selects piezometer sites. Oversees equipment installation and groundwater data collection. Performs data analysis. Writes report. Provides project manager with relevant data and analyses.
To be determined	Freshwater Monitoring Unit (FMU) lead	Leads seepage runs and surface water discharge data collection. Supplies project manager with QA'd data and analyses.
To be determined	QUAL2Kw Modeler	Conducts QUAL2Kw modeling re-simulation and analysis of survey data. Provides project manager with relevant data and analyses.
Markus Von Prause Western DSU/EAP 360-407-7406	QAPP Author and EIM Data Engineer	Writes the draft and final QAPP. Approves the final QAPP. Enters and manages data for entry into EIM.
Robert F. Cusimano WOS/EAP (360) 407-6596	Section Manager of the QAPP Author	Approves the QAPP and the final report.
George Onwumere Western DSU/EAP (360) 407-6730	Unit Supervisor of the QAPP Author	Reviews and approves the QAPP, staffing plan, technical study budget, and the final report.
Stuart Magoon Manchester Environmental Laboratory, EAP, (360) 871-8801	Director	Provides laboratory staff and resources, sample processing, analytical results, and QA/QC data. Approves the QAPP.
William R. Kammin EAP (360) 407-6964	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

WQP – Water Quality Program, NWRO – Northwest Regional Office, EAP – Environmental Assessment Program, DSU – Directed Studies Unit, EIM – Environmental Information Management system, WOS – Western Operations Section, QAPP – Quality Assurance Project Plan.

The project is proposed to run from August of 2011 to December 2012, depending on staff and resource availability (Table 13). Field work is tentatively scheduled during critical conditions from August 2011 to October 2011.

Table 13. Proposed schedule for completing field and laboratory work, data entry into EIM, and FMU and groundwater reports.

Field and laboratory work	
Team selection	March 2011 – May 2011
Pre-survey preparation	May 2011 – August 2011
Field work	August 2011 – October 2011
Laboratory analyses completed	November 2011
Environmental Information System (EIM) system	
EIM data engineer	Markus Von Prause
EIM user study ID	MVP003
EIM study name	Additional Study of Low DO Levels In The Upper Stillaguamish River Main Stem
Surface water, groundwater, and streamflow data due in EIM	December 2011
Freshwater Monitoring Unit (FMU) Data Summary	
Author lead	To be determined
Schedule	
Analysis and data provided to modeler	April 2012
Draft due to supervisor	February 2012
Draft due to client/peer reviewer	March 2012
Final report due on web	May 2012
Groundwater report	
Activity Tracker code	09-182
Author lead	To be determined
Schedule	
Analysis and data provided to modeler	February 2012
Draft due to supervisor	November 2012
Draft due to client/peer reviewer	December 2012
Draft due to external reviewer	January 2013
Final report due on web	February 2013

Table 14. Proposed schedule for completing annual and final reports.

Annual reports	
Author lead	To be determined
Schedule	
1st annual report	January 2012
2nd annual report	January 2013
Surface and groundwater data summary	February 2012
Final report	
Author lead schedule	To be determined
QUAL2Kw modeling development starts	March 2012
QUAL2Kw modeling completed	April 2013
Draft due to supervisor	March 2013
Draft due to client/peer reviewer	May 2013
Draft due to external reviewer	June 2013
Final report due on web	July 2013

Laboratory Budget

Table 15 presents the surface water laboratory budget for this study. The budgets for surface water, groundwater, upland well, benthic flux, and porewater sampling, as well as the total laboratory budget for all components, are represented in Tables 15-19. The estimated budget and lab sample load is based on (1) one longitudinal temperature/DO profile survey, (2) two synoptic surface water surveys (including QA/QC replicates), (3) two groundwater quality surveys (including QA/QC replicates), and (4) one periphyton assessment. All sites have not yet been selected; this is an estimate only.

Table 15. Surface water sampling laboratory budget.

Parameter	Cost/ Sample	Number of Sites	Number of Samples (Including field QA)	Number of Surveys	Total Cost
Turbidity	$11.42	12	39	3	$445.52
Total Suspended (TSS) + TNVSS	$36.35	12	39	3	$1,417.55
Alkalinity	$17.65	12	39	3	$688.53
Chloride	$13.50	12	39	3	$526.52
Chlorophyll-a (lab filtered)	$57.12	12	39	3	$6,340.04
Periphyton Chlorophyll *a*	$44.66	36	111	3	$4,956.76
Periphyton AFDW	$23.89	36	111	3	$1,417.55
Ammonia (NH3)	$13.50	12	39	3	$688.53
Nitrite-Nitrate (NO2/NO3)	$13.50	12	39	3	$526.52
Total Persulfate Nitrogen (TPN)	$17.65	12	39	3	$2,227.58
Orthophosphate (OP)	$15.58	12	39	3	$1741.56
Total Phosphorus (TP)	$18.69	12	39	3	$931.53
Periphyton (biovolume, ID)	$79.96	36	111	3	$8,876.06
Dissolved Organic Carbon	$36.35	12	39	3	$1,417.55
Total Organic Carbon	$34.27	12	39	3	$1,336.55
Iron	$39.46	12	39	3	$1,539.06
Biological Oxygen Demand 5	$57.12	1	3	3	$171.35
Ultimate Biological Oxygen Demand	$1,038.50	1	1	1	$1,038.50
				Total:	$36,287.27

Table 16. Groundwater sampling laboratory budget.

Parameter	Cost/ Sample	Number of Sites (9 piezo-meters)	Number of Samples (including field QA)	Number of Surveys	Total Cost
Alkalinity	$17.65	9	33	3	$582.45
Chloride	$13.50	9	33	3	$445.50
Ammonia-N (NH3-N)	$13.50	9	33	3	$445.50
Nitrite-Nitrate-N (NO2+NO3-N)	$13.50	9	33	3	$445.50
Total Persulfate Nitrogen (TPN)	$17.65	9	33	3	$582.45
Orthophosphate (OP)	$15.58	9	33	3	$514.14
Total Phosphorus (TP)	$18.69	9	33	3	$616.77
Iron	$39.46	9	33	3	$1,302.18
				Total:	$4,934.49

Table 17. Upland well sampling laboratory budget.

Parameter	Cost of Sample	Number of Off Shore Wells	Number of Samples (including QA)	Number of Surveys	Total Cost
Alkalinity	$17.65	2	6	3	$105.93
Chloride	$13.50	2	6	3	$81.00
Ammonia-N (NH3-N)	$13.50	2	6	3	$81.00
Nitrite-Nitrate-N (NO2+NO3-N)	$13.50	2	6	3	$81.00
Total Persulfate Nitrogen (TPN)	$17.65	2	6	3	$105.93
Orthophosphate (OP)	$15.58	2	6	3	$93.47
Total Phosphorus (TP)	$18.69	2	6	3	$112.16
Iron	$39.46	2	6	3	$236.78
				Total:	$897.26

Table 18. Benthic flux sampling laboratory budget.

Parameter	Cost of Sample	Number of Benthic Flux Chambers	Number of Samples (Including QA)	Number of Surveys	Total Cost
Nitrite-Nitrate-N (NO2+NO3-N)	$13.50	4	15	3	$202.51
Filtered Nitrate-Nitrite (benthic)	$13.50	4	15	3	$202.51
Total Phosphorus (TP)	$18.69	4	15	3	$280.40
Filtered Total Phosphorus (TP)	$18.69	4	15	3	$280.40
				Total:	$965.81

Table 19. Porewater sampling laboratory budget.

Parameter	Cost of Sample	Number of Porewater Samples	Number of Samples (Including QA)	Number of Surveys	Total Cost
Nitrite-Nitrate-N (NO2+NO3-N)	$13.50	9	33	3	$445.50
Ammonia-N (NH3-N)	$13.50	9	33	3	$445.50
Total Phosphorus (TP)	$18.69	9	33	3	$616.77
Dissolved Organic Carbon	$36.35	9	33	3	$1,199.55
Orthophosphate (OP)	$15.58	9	33	3	$514.14
				Total:	$3,221.46

Table 20. Total laboratory budget for the Stillaguamish Island Reach low dissolved oxygen study.

Budget Component	Total Cost
Surface water Sampling	$36,287.27
Groundwater Sampling	$4,934.49
Upland Well Sampling	$897.26
Benthic Flux Sampling	$965.81
Porewater Sampling	$3,221.46
Total:	$46,306.29

References

Allan, J.D., 1995. Stream Ecology: structure and function of running waters. Kluwer Academic Publishers. Dordrecht, Netherlands.

APHA, AWWA, and WEF, 1998. Standard Methods for the Examination of Water and Wastewater. 20th Edition. American Public Health Association, Washington, D.C.

Bridge, J.W., 2005. High resolution in-situ monitoring of hyporheic zone biogeochemistry, United Kingdom Environment Agency Science Report SC030155/SR3. 51 p. http://publications.environment-agency.gov.uk/pdf/SCHO0605BJCO-e-e.pdf.

Bilhimer, D. and A. Stohr, 2007. Standard Operating Procedures for continuous temperature monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature, Version 2.2. Washington State Department of Ecology, Olympia, WA. SOP No. EAP044. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_044Cont_Temp_Monit_TMDL.pdf.

Chapra, S.C. and G.J. Pelletier, 2003. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality: Documentation and Users Manual. Civil and Environmental Engineering Department, Tufts University, Medford, MA.

Constanz, J., 2007. The Streambed as a Dynamic Membrane in the Watershed, Abstract. Eos Transactions. American Geophysical Union, 88(52). Fall Meeting Supplement.

Earth Tech, 1997. City of Arlington Stillaguamish River Water Quality Monitoring Report. Prepared for the City of Arlington by Earth Tech Consultants. Bellevue, WA. December 1997. 24 pgs. + appendices.

Ecology, 1993. Field Sampling and Measurement Protocols for the Watershed Assessments Section. Washington State Department of Ecology, Olympia, WA. Publication No. 93-e04. www.ecy.wa.gov/biblio/93e04.html.

Ecology, 2009. National Pollutant Discharge Elimination System Waste Discharge Permit No. WA-002256-0. Water Quality Program, Washington State Department of Ecology. Northwest Regional Office. Bellevue, WA. www.ecy.wa.gov/programs/wq/permits/permit_pdfs/arlington_wwtp/ArlingtonWWTPpermit.pdf

Ford, R.G., 2005. The Impact of Ground-water/Surface-water Interactions on Contaminant Transport with Application to an Arsenic Contaminated Site. U.S. EPA Environmental Research Brief. National Risk Management Research Laboratory, Ada, OK. EPA 600-S-05-002. 22 p. www.epa.gov/ada/download/briefs/epa_600_s05_002.pdf

Gregory, Guy J. and John J. Covert, 2006. Spokane River Temperature Profile, Barker Road to Plantes Ferry Park, September, 2005. Washington State Department of Ecology. Publication No. 06-11-005. www.ecy.wa.gov/biblio/0611005.html.

Hauer, R.F. and G. Lamberti, 2006. Methods in Stream Ecology. Elsevier Academic Press.

Joy, J., 2004. Stillaguamish River Watershed Fecal Coliform, Dissolved Oxygen, pH, Mercury, and Arsenic Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-017. www.ecy.wa.gov/biblio/0403017.html.

Laskov, C., Herzog, C., Lewandowski, J., and Hupfer, M., 2007. Miniaturized photometrical methods for the rapid analysis of phosphate, ammonium, ferrous iron, and sulfate in pore water of fresh sediments. Limnology and Oceanography: Methods 4, p. 63-71.

Marti, P., 2009. Standard Operating Procedure for Manual Well-Depth and Depth-to-Water Measurements. Washington State Department of Ecology , Olympia, WA. SOP Number EAP052.
www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_052ManualWellDepth&DepthtoWaterMeasures_v_1_0.pdf

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

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

Microsoft, 2001. Microsoft Office XP Professional, Version 10.0. Microsoft Corporation.

Mobrand Biometrics, 2004. Future Scenario Population Performance. Ecosystem diagnosis and treatment model report to Snohomish County Surface Water Management.

Moulton II, S.R., J.G. Kennen, R.M. Goldstein, and J.A. Hambrook, 2002. Revised Protocols for Sampling Algal, Invertebrate, and Fish Communities as Part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open-File Report 02-150, Reston, Virginia.

Naegeli, M.W. and U. Uehlinger, 1997. Contribution of the hyporheic zone to ecosystem metabolism in a prealpine gravel-bed river. Journal of North American Benthological Society 16 (4): 794-804.

Nash, J.E. and J.V. Sutcliffe, 1970. River flow forecasting through conceptual models part I — A discussion of principles. Journal of Hydrology, 10 (3), 282–290.

Pess, G.R., B.D. Collins, M. Pollock, T. J. Beechie, A. Haas, and S. Grigsby, 1999. Historic and current factors that limit Coho salmon (*Oncorhynchus kisutch*) production in the Stillaguamish River basin, Washington state: Implications for salmonid habitat protection and restoration. Prepared for Snohomish County Department of Public Works, Everett, WA, and the Stillaguamish Tribe of Indians, Arlington, WA.

Pitz, C., 2006. An Evaluation of a Piezometer-Based Constant Head Injection Test (CHIT) for Use in Groundwater/Surface Water Interaction Studies. Washington State Department of Ecology, Olympia WA. Publication No. 06-03-042, 18 p. + appendices. www.ecy.wa.gov/biblio/0603042.html.

Pitz , C., 2008. Quality Assurance Project Plan High-resolution, Pore-water Sampling Near the Groundwater/Surface Water Interface. Washington State Department of Ecology, Olympia WA, Publication Number 08-03-115.

Porter, S.D., T.F. Cuffney, M.E. Gurtz, and M.R. Meador, 1993. Methods for Collecting Algal Samples as Part of the National Water-Quality Assessment Program. U.S. Geological Survey, Open-File Report 93-409, Denver, CO.

Reckhow, K.H., 1986. Statistical Goodness-of-Fit Measures for Waste Load Allocation Models. Work Assignment No. 33, EPA Contract No. 68-01-6904.

Roberts, M., 2007. Standard Operating Procedure for Benthic Flux Chambers, version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP036. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_036BenthicFluxChambers.pdf.

Shedd, J., C. Springer, C. Clishe, 2008. Standard Operating Procedure for Operation of the Teledyne RD Instruments Stream-Pro Acoustic Doppler Current Profiler. Washington State Department of Ecology Olympia, WA. SOP Number EAP055. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_055UseofStreamProADCP_v1_0.pdf

Shedd, J., 2009. Standard Operating Procedure for Measuring and Calculating Stream Discharge. Washington State Department of Ecology, Olympia, WA. SOP Number EAP056. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_056Measuring_and_CalculatingStreamDischarge_v1_0.pdf

Sinclair, K. and C. Pitz, 2009. Standard Operating Procedure for installing, measuring, and decommissioning hand-driven in-water piezometers. Washington State Department of Ecology, Olympia, WA. SOP Number EAP061. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_061Piezometers_v1_0.pdf

Snohomish County Public Works: Surface Water Management, 2007. Snohomish County NPDES Municipal Stormwater Permit Annual Report for 2007.

STAG (Stillaguamish Technical Advisory Group), 2000. Technical Assessment and Recommendations for Chinook Salmon Recovery in the Stillaguamish Watershed. Everett, WA.

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

Uehlinger, U., 2000. Resistance and resilience of ecosystem metabolism in a flood-prone river system. Freshwater Biology 45: 319-332.

U.S. EPA, 2000a. Proceedings of the Ground-Water/Surface-Water Interactions Workshop. EPA/542/R-00/007, Parts 1-3. U.S. Environmental Protection Agency.
www.epa.gov/tio/download/remed/gwsw/gwsw_part1.pdf.
www.epa.gov/tio/tsp/download/gwsw/gwsw_part2.pdf.
www.epa.gov/tio/tsp/download/gwsw/gwsw_part3.pdf.

Vervier, P. and R.J. Naiman, 1992. Spatial and temporal fluctuations of dissolved organic carbon in subsurface flow of the Stillaguamish River (Washington, USA). Archives Hydrobiologia 123(4): 401-412.

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

Ward, W., 2003. Continuous Temperature Monitoring Protocols for the Environmental Monitoring and Trends Section. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-052. www.ecy.wa.gov/biblio/0303052.html.

Ward, W., 2007. Standard Operating Procedure for the Collection, Processing, and Analysis of Stream Samples Version 1.3. Washington State Department of Ecology, Olympia, WA. SOP No. EAP034. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_034CollectionandProcessingofStreamSamples.pdf.

WCC, 1999. Salmon and Steelhead Habitat Limiting Factors Water Resource Inventory Area 5, Stillaguamish Watershed. Washington State Conservation Commission, Olympia, WA.

Winter, T.C., Harvey, J.W., Franke, O.L., and Alley, W.M., 1998. Ground Water and Surface Water – A Single Resource. U.S. Geological Survey Circular 1139. 79 p. http://pubs.usgs.gov/circ/circ1139/.

Appendices

Appendix A. Glossary, Acronyms, and Abbreviations

Glossary

Anadromous: Types of fish, such as salmon, that go from the sea to freshwater to spawn.

Anthropogenic: Human-caused.

Benthic: Bottom-dwelling organisms.

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

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

Critical period: In this study, the critical season is the low streamflow period, August through October.

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

Dissolved oxygen sag: A lowering or depression of dissolved oxygen in water.

Groundwater: Water in the subsurface that saturates the rocks and sediment in which it occurs. The upper surface of groundwater saturation is commonly termed the water table.

Heterotrophic: Pertaining to the utilization of organic compounds as source of carbon. For instance, a *heterotrophic* organism is one utilizing organic compound to obtain carbon that is essential for growth and development. Examples of such organisms are animals, which are not capable of manufacturing food by inorganic sources, hence, must consume organic substrates for sustenance.

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

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

Morphology: Shape (e.g., channel morphology).

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

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

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

Parameter: Water quality constituent being measured (analyte). A physical, chemical, or biological property whose values determine environmental characteristics or behavior.

Periphyton: Algae that grow on submerged rocks, plants, and debris.

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

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

Piezometer: A small-diameter, non-pumping well used to collect groundwater quality samples and hydraulic head measurements.

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

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

Porewater: Water occupying the spaces between sediment grains located between the land surface and the water table.

Reach: A specific portion or segment of a stream.

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

Salmonid: Any fish that belong to the family *Salmonidae*. Basically, any species of salmon, trout, or char. www.fws.gov/le/ImpExp/FactSheetSalmonids.htm

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

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

Synoptic survey: Comprehensive water quality survey designed to provide a water quality snapshot in a specific watershed. The survey typically collects surface water grab samples under a variety of environmental conditions at a number of sites in the watershed.

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

Total Maximum Daily Load (TMDL): A distribution of a substance in a waterbody designed to protect it from exceeding water quality standards. A TMDL is equal to the sum of all of the following: (1) individual wasteload allocations for point sources, (2) the load allocations for nonpoint sources, (3) the contribution of natural sources, and (4) a Margin of Safety to allow for uncertainty in the wasteload determination. A reserve for future growth is also generally provided.

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

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

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

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

7Q2 flow: A typical low-flow condition. The 7Q2 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every other year on average. The 7Q2 flow is commonly used to represent the average low-flow condition in a waterbody and is typically calculated from long-term flow data collected in each basin. For temperature TMDL work, the 7Q2 is usually calculated for the months of July and August as these typically represent the critical months for temperature in our state.

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

Acronyms and Abbreviations

BOD	Biological oxygen demand
DO	(See Glossary above)
DOC	Dissolved organic carbon
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System software
GPS	Global Positioning System
I5	Interstate 5
MEL	Manchester Environmental Laboratory
MQO	Measurement quality objective
NIST	National Institute of Standards and Technology
NPDES	(See Glossary above)
QA	Quality assurance
RM	River mile
RKM	River kilometer
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedures
SRM	Standard reference materials
TI	Temperature instrument
TMDL	(See Glossary above)
TNVSS	Total nonvolatile suspended solids
USGS	U.S. Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resources Inventory Area
WWTP	Wastewater treatment plant

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cms	cubic meters per second, a unit of flow.
dw	dry weight
ft	feet
g	gram, a unit of mass
km	kilometer, a unit of length equal to 1,000 meters.
m	meter
mg/L	milligrams per liter (parts per million)
mL	milliliters
SU	standard units
µg/L	micrograms per liter (parts per billion)
ww	wet weight

Appendix B. Data Analysis and Modeling Procedures

Modeling procedures will be conducted once field work and laboratory analysis have been completed. Means, maximums, minimums, and 90th percentiles of chemical analyses will be determined from the raw data collected at each monitoring location. For temperature and DO, the maximum, minimum, and daily average will be determined. Hourly data will be necessary for headwater and tributary or source inputs.

Physical channel and streamflow attributes will be supplied from data collected during the longitudinal temperature and DO survey and the streamflow synoptic surveys. Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data and piezometer data collected during the synoptic studies.

A model will be developed for DO critical conditions. Critical conditions for DO are characterized by a period of low flow. The QUAL2Kw model will be used to simulate primary production and respiration, and heterotrophic metabolism in the hyporheic zone, in active channel reaches in the study area based on field survey data.

Sensitivity analysis will be run to assess the variability of the model results. Model resolution and performance will be measured using the root-mean-square-error (RMSE), a commonly used measure of model variability (Reckhow, 1986), and the Nash-Sutcliffe coefficient. The RMSE is defined as the square root of the mean of the squared difference between the observed and simulated values.

QUAL2KW

QUAL2Kw (Q2K) is a river and stream water quality model that represents a modernized version of QUAL2E (Brown and Barnwell, 1987). Q2Kw 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 Q2K 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. For this study, Q2K will be used to simulate both forms of oxidizing carbon based on results of hyporheic porewater sampling for DOC.

- **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 DO 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.

- **Hyporheic Exchange and Sediment Porewater Quality**. Q2K also has the ability to simulate the metabolism of heterotrophic bacteria in the hyporheic zone.

Constituents and General Mass Balance

The model constituents are listed in Table B-1. The constituents in the water column are indicated by either the subscript ―1" or no subscript, and in the hyporheic porewater zone are indicated by the subscript ―2", except for attached bottom algae in the water column (a_b IN_b, IP_b) and heterotrophic bacteria in the hyporheic sediment zone (a_h).

Table B-1. Model State Variables.

Variable	Symbol	Units*
Conductivity	s_1, s_2	µmhos
Inorganic suspended solids	$m_{i,1}$, $m_{i,2}$	mgD/L
Dissolved oxygen	o_1, o_2	mgO_2/L
Slow-reacting CBOD	$c_{s,1}$, $c_{s,2}$	mg O_2/L
Fast-reacting CBOD	$c_{f,1}$, $c_{f,2}$	mg O_2/L
Organic nitrogen	$n_{o,1}$, $n_{o,2}$	µgN/L
Ammonia nitrogen	$n_{a,1}$, $n_{a,2}$	µgN/L
Nitrate nitrogen	$n_{n,1}$, $n_{n,2}$	µgN/L
Organic phosphorus	$p_{o,1}$, $p_{o,2}$	µgP/L
Inorganic phosphorus	$p_{i,1}$, $p_{i,2}$	µgP/L
Phytoplankton	$a_{p,1}$, $a_{p,2}$	µgA/L
Detritus	$m_{o,1}$, $m_{o,2}$	mgD/L
Pathogen	x_1, x_2	cfu/100 mL
Generic constituent	gen_1, gen_2	user defined
Alkalinity	Alk_1, Alk_2	$mgCaCO_3/L$
Total inorganic carbon	$c_{T,1}$, $c_{T,2}$	mole/L
Bottom algae (a_b in the surface water layer), biofilm of attached heterotrophic bacteria (a_h in the hyporheic sediment zone for the Level 2 option)	a_b,a_h	gD/m^2
Bottom algae nitrogen	IN_b	mgN/m^2
Bottom algae phosphorus	IP_b	mgP/m^2

* $mg/L=g/m^3$

Simulation of water quality constituents in the hyporheic sediment porewater is optional in Q2K. Three options are provided:

- **No hyporheic simulation**: Mass transfer between the water column and hyporheic porewater, and water quality kinetics in the hyporheic porewater will not be simulated.
- **Level 1**: Simulation of zero-order or first-order oxidation of fast-reacting CBOD with attenuation from CBOD and DO in the hyporheic sediment zone.
- **Level 2**: Simulation of heterotrophic bacteria biofilm growth (zero-order or first-order), respiration, and death with attenuation of growth from CBOD, DO, ammonia, nitrate, and inorganic phosphorus in the hyporheic porewater zone.

For all but the bottom algae variables, a general mass balance for a constituent in the water column of a reach is written as equation 1:

$$\frac{dc_i}{dt} = \frac{Q_{i-1}}{V_i} c_{i-1} - \frac{Q_i}{V_i} c_i - \frac{Q_{ab,i}}{V_i} c_i + \frac{E'_{i-1}}{V_i} (c_{i-1} - c_i) + \frac{E'_i}{V_i} (c_{i+1} - c_i) + \frac{W_i}{V_i} + S_i + \frac{E'_{hyp,i}}{V_i} (c_{2,i} - c_i) \quad (1)$$

where W_i = the external loading of the constituent to reach *i* [g/d or mg/d], and S_i = sources and sinks of the constituent due to reactions and mass transfer mechanisms [g/m^3/d or mg/m^3/d]. Exchange of mass between the surface water and the hyporheic sediment zone is represented by the bulk hyporheic exchange flow in reach i [$E'_{hyp,i}$ in m^3/day] and the difference in concentration in the surface water (c_i) and in the hyporheic sediment zone ($c_{2,i}$).

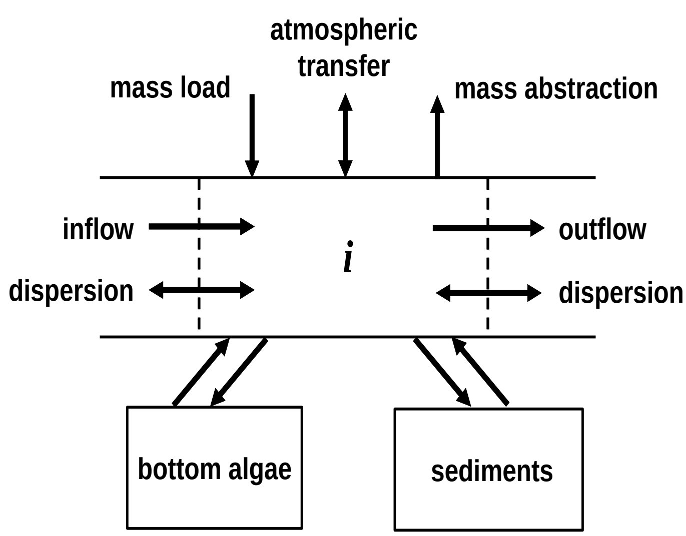

Figure B-1. Mass Balance.

For all but the heterotrophic bacteria biofilm, the general mass balance for a constituent concentration in the hyporheic sediment zone of a reach ($c_{2,i}$) is written as:

$$\frac{dc_{2,i}}{dt} = S_{2,i} + \frac{E'_{hyp,i}}{V_{2,i}}(c_i - c_{2,i}) \tag{2}$$

where $S_{2,i}$ = sources and sinks of the constituent in the hyporheic zone due to reactions, $V_{2,i}$ = $\phi_{s,i} A_{st,i} H_{2,i} / 100$ = volume of porewater in the hyporheic sediment zone [m^3], $\phi_{s,i}$ is the porosity of the hyporheic sediment zone [dimension less number between 0 and 1], $A_{st,i}$ = the surface area of the reach [m^2], and $H_{2,i}$ = the thickness of the hyporheic zone [cm]. Porosity is defined as the fraction of the total volume of sediment that is in the liquid phase and is interconnected (Chapra, 1997).

The external load is computed as:

$$W_i = \sum_{j=1}^{psi} Q_{ps,i,j} c_{psi,j} + \sum_{j=1}^{npsi} Q_{nps,i,j} c_{npsi,j} \tag{3}$$

where $c_{ps,i,j}$ is the jth point source concentration for reach i [mg/L or µg/L], and $c_{nps,i,j}$ is the jth nonpoint source concentration for reach i [mg/L or µg/L].

For bottom algae, the transport and loading terms are omitted:

$$\frac{da_{b,i}}{dt} = S_{b,i}$$

$$\frac{dIN_b}{dt} = S_{bN,i}$$

$$\frac{dIP_b}{dt} = S_{bP,i}$$

where $S_{b,i}$ = sources and sinks of bottom algae biomass due to reactions [gD/m^2/d], $S_{bN,i}$ = sources and sinks of bottom algae nitrogen due to reactions [mgN/m^2/d], and $S_{bP,i}$ = sources and sinks of bottom algae phosphorus due to reactions [mgP/m^2/d].

For heterotrophic bacteria in the hyporheic sediment zone (Level 2 option), the transport and loading terms are omitted:

$$\frac{da_{h,i}}{dt} = S_{ah,i}$$

where $S_{ah,i}$ = sources and sinks of heterotrophic bacteria in the hyporheic sediment zone due to reactions [gD/m^2/d].

Settled inorganic suspended solids, phytoplankton, and detritus are assumed to be deposited from the water column layer to the sediment diagenesis zone and do not enter the hyporheic porewater.

The rationale for this assumption is that hyporheic exchange typically does not occur in depositional areas of fine sediment. The sediment diagenesis sub-model accounts for anaerobic metabolism of settled material in the sediment. The hyporheic sub-model accounts for aerobic metabolism of heterotrophic bacteria in the hyporheic zone. Suspended materials are transported to the hyporheic porewater for the Level 1 and Level 2 simulation options of hyporheic metabolism.

The sources and sinks for the stated variables are depicted in Figure B-1 (note that the internal levels of nitrogen and phosphorus in the bottom algae are not depicted). The mathematical representations of these processes are presented in the following sections.

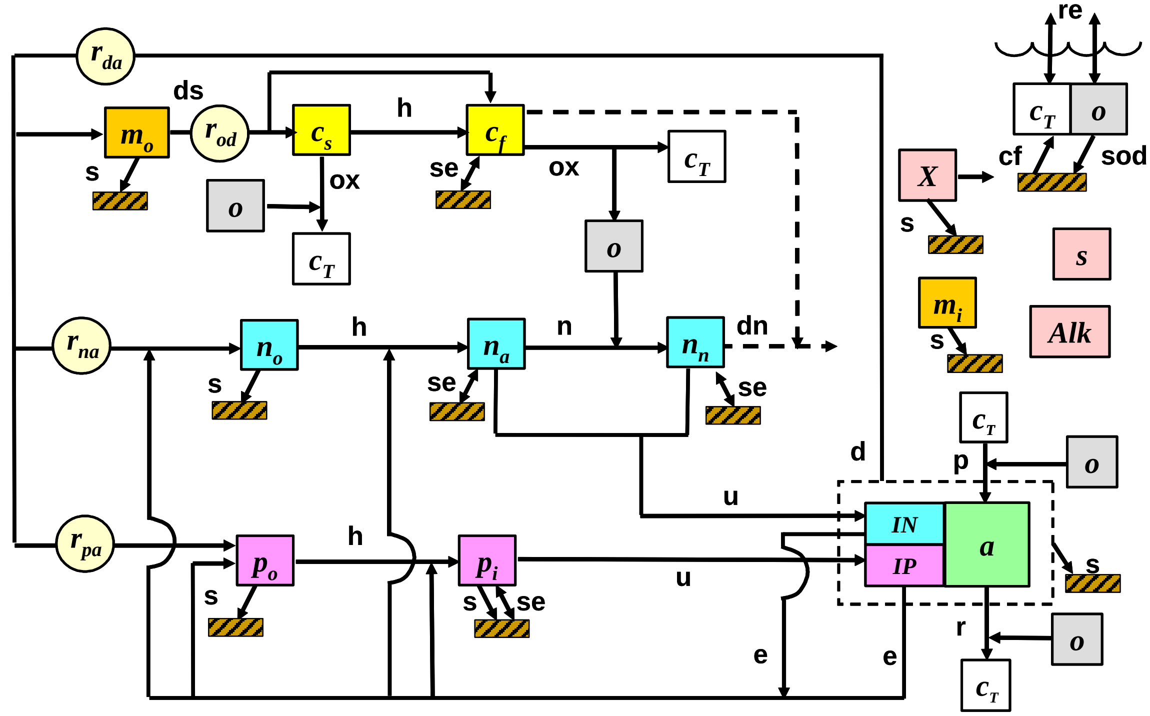

Figure B-2. Model Kinetics and Mass Transfer Processes.

Kinetic processes are dissolution (ds), hydrolysis (h), oxidation (ox), nitrification (n), denitrification (dn), photosynthesis (p), respiration (r), excretion (e), death (d), and respiration/excretion (rx). Mass transfer processes are reaeration (re), settling (s), sediment oxygen demand (SOD), sediment exchange (se), and sediment inorganic carbon flux (cf).

Appendix C. Island Reach Survey Logistics Table

Table C-1. Island Reach Survey Logistics.

Survey Component	Survey Component Objectives	Data Parameters	Methods	Sampling Time Line	Staff and Personal
Pre-survey 1	Study area verification.	Station verification. Upland well verification. Site access.	Physical inspection and GPS verification.	Spring 2011.	Project Manager. Principal Investigator. Directed Studies Unit. Groundwater Unit
Pre-survey 2	Temperature profiles to determine groundwater station delineation. DO concentration within critical area. Piezometer installation.	Temperature profile measurements. DO measurements.	Temperature/DO profiling by towed Hydrolab along Stillaguamish mainstem. X[1]	July 2011.	Project Manager. Principal Investigator. Directed Studies Unit. Groundwater Unit.
Surface Water	Characterization of surface water physical and chemical processes impacting low DO.	Surface water chemistry. Synoptic survey. Tributary discharges.	Standard Operating Procedures for the Collection, Processing, and Analysis of Stream Samples. (SOP EAP034). Standard Operating Procedures for the Collection and Analysis of DO. (Winkler Method) (SOP EAP023) Continuous diel monitoring for pH, DO, conductivity, and temperature by HydroSonde. Streamflow velocity by Mash McBirney. (SOP EAP024)	August 2011. September 2011. October 2011.	Project Manager. Principal. Investigator. Directed Studies Unit. Surface Water Field Personnel.

Table C-1. Island Reach Survey Logistics (continued).

Survey Component	Survey Component Objectives	Data Parameters	Methods	Time Line	Staff and Personal
Groundwater	Characterization of groundwater physical and chemical processes.	Piezometer installation. Measurements for: • Groundwater chemistry. • Vertical hydraulic gradient • Hydraulic conductivity.	Installing, measuring, and decommissioning hand-driven instream piezometers. (SOP EAP061) Groundwater samples collected by peristaltic pump method. Temperature dataloggers. (SOP EAP044) Water level measurements. (SOP EAP061) Constant Head Injection Test. (CHIT) Well-depth and depth-to-water measurements. (SOP EAP052)	August 2011. September 2011. October 2011.	Groundwater Unit.
Seepage Run	QUAL2Kw hydrological data requirements for fixed network stations and surface water stations during sampling events.	Velocity and discharge measurements of Stillaguamish stream corridor.	Measurements conducted by watercraft. Acoustic Doppler Current Profiler. (ADCP) (SOP EAP055)	August 2011. September 2011. October 2011.	Freshwater Monitoring Unit.
Hyporheic	Characterization of benthic oxygen demand and primary production processes within the Island Reach during critical conditions.	Benthic flux. Periphyton for the analysis of chlorophyll-a concentration and biomass by the ash free dry mass analysis (AFDM). Porewater sampling near groundwater/Surface water interface.	Deployment of benthic flux chambers. (SOP EAP036) Collection of 3 representative natural substrata (cobble, gravel or sediment) from each fixed network station where periphyton is present. Porewater sampling by push point method.	August 2011. September 2011. October 2011.	Directed studies Unit. Surface Water Field Personnel. Groundwater Unit.
Modeling	Re-simulation of the QUAL2Kw model.		Desktop data preparation. QUAL2Kw Re-simulation.	March 2012. April 2012-July 2013.	Modeling Staff.