Sampling and Analysis Plan and Quality Assurance Project Plan

Green River and Newaukum Creek Temperature and Dissolved Oxygen Study

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2004 303(d) Listings Addressed in this Study:

Green River (AB62OX, AJ33YB, FK76HV, YD05HE) – Temperature
Green River (YD05HE) – Dissolved Oxygen
Newaukum Creek (JX80LS) – Temperature, Dissolved Oxygen
Hill (Mill) Creek (BI99NR) – Temperature
Hill (Mill) Creek (BI99NR) – Dissolved Oxygen
Mullen Slough (BP27QP) – Dissolved Oxygen

Waterbody Numbers: WA-09-1020, WA-09-1030 (Green River), WA-09-1028 (Newaukum Creek), WA-09-1022 (Hill/Mill Creek), none (Mullen Slough)

Project Code: 05-065-02

Sampling and Analysis Plan
and Quality Assurance Project Plan

Green River and Newaukum Creek
Temperature and Dissolved Oxygen Study

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Abstract

Monitoring of temperature and/or dissolved oxygen by the Department of Ecology, King County Department of Natural Resources, and the Muckleshoot Indian Tribe indicates that there are segments of streams in the Green River/Newaukum Creek watershed that do not meet the water quality standards for temperature or dissolved oxygen for varying periods of time between June and October. These segments are listed under Section 303(d) of the federal Clean Water Act as impaired waters.

The present study is designed to organize and evaluate existing data and to supplement and integrate Department of Ecology and King County data collection to ensure that the density of the monitoring sites and the frequency and duration of data collection are adequate to develop a water quality model that provides well calibrated outputs. Water quality models will be used to develop pollutant load reduction amounts needed to bring the stream segments into compliance with the Washington State water quality standards.

Data collection and model development represent a cooperative approach between the Department of Ecology, King County, and the Muckleshoot Indian Tribe to develop Total Maximum Daily Load reduction targets for the Green/Newaukum system.

What is a Total Maximum Daily Load, or TMDL?

Federal Clean Water Act Requirements

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

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

TMDL Process Overview

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

Elements Required in a TMDL

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

If the pollutant comes from a discrete source (referred to as a point source) such as a municipal or industrial facility's discharge pipe, that facility's share of the loading capacity is called a wasteload allocation. If it comes from a set of diffuse sources (referred to as a nonpoint source) such as general urban, residential, or farm runoff, the cumulative share is called a load allocation.

The TMDL must also consider seasonal variations and include a margin of safety that takes into account any lack of knowledge about the causes of the water quality problem or its loading capacity. A reserve capacity for future loads from growth pressures is sometimes included as well. The sum of the wasteload and load allocations, the margin of safety, and any reserve capacity must be equal to or less than the loading capacity.

Water Quality Assessment/Categories 1-5

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

Category 1 – Meets tested standards for clean water

Category 2 – Waters of concern

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

Category 4 – Polluted waters that do not require a TMDL since the problems are being solved in one of three ways:

- 4a. – Has a TMDL approved and is being implemented
- 4b. – Has a pollution control plan in place that should solve the problem
- 4c. – Impaired by a non-pollutant such as low water flow, dams, culverts

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

Total Maximum Daily Load Analyses

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

Introduction

Data collected by the Department of Ecology, King County, and the Muckleshoot Indian Tribe demonstrate that segments of the Green River, Little Soos Creek, Hill (Mill) Creek, Mullen Slough, Smay Creek, and Ravensdale Creek do not meet Washington State water quality standards for temperature and/or dissolved oxygen. On the basis of those data, Ecology included these segments in the 2004 303(d) list of impaired waters.

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

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

The Green-Duwamish watershed is located in King County, within Water Resource Inventory Area (WRIA) 9. The watershed includes a drainage area of approximately 1,253 km^2 (484 square miles), consisting of the Puget Lowland and Cascades ecoregions (King County WLRD, 2002). The watershed extends from the crest of the Cascade Mountains at the headwaters of the Green River, west to the mouth of the Duwamish River where the river empties into Elliot Bay at the city of Seattle. The average areal precipitation is 59 inches per year within the watershed. The Green-Duwamish watershed is composed of the following subwatersheds (Figure 1):

1. Upper Green River subwatershed covering 569 km^2 (219.7 square miles) above river mile (RM) 64.5 at Howard Hanson Dam.

2. Middle Green River subwatershed covering 460 km^2 (177.5 square miles) from RM 64.5 to RM 32.0 at Auburn Narrows.

3. Lower Green River subwatershed covering 165 km^2 (63.8 square miles) from RM 32.0 to RM 11.0 at Tukwila.

4. Green-Duwamish Estuary subwatershed covering 57 km^2 (22.2 square miles) from RM 11.0 to RM 0.0 at Elliot Bay.

The Upper Green River sub-watershed (569 km^2, or 220 square miles) above Howard Hanson Dam is not included in this TMDL study, nor is the lower estuary reach which has a salt wedge influence. Major cities that are located within the study area include Seattle, Renton, Kent, Auburn, Tukwila, and Enumclaw. Major streams draining to the Green River within the study area are the Soos, Springbrook, Mill, and Newaukum creeks.

Newaukum Creek flows into the Middle Green River at RM 40.7 and is 14.35 miles long (WDFW, 1993). The basin is over 69 km^2 (27 square miles) in size (Kerwin and Nelson, 2000). The creek flows from the mountains east of the city of Enumclaw through the Enumclaw valley and then into the Green River. Basin land use consists of high-density development, agriculture/pasture, and forest/forestry practices.

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

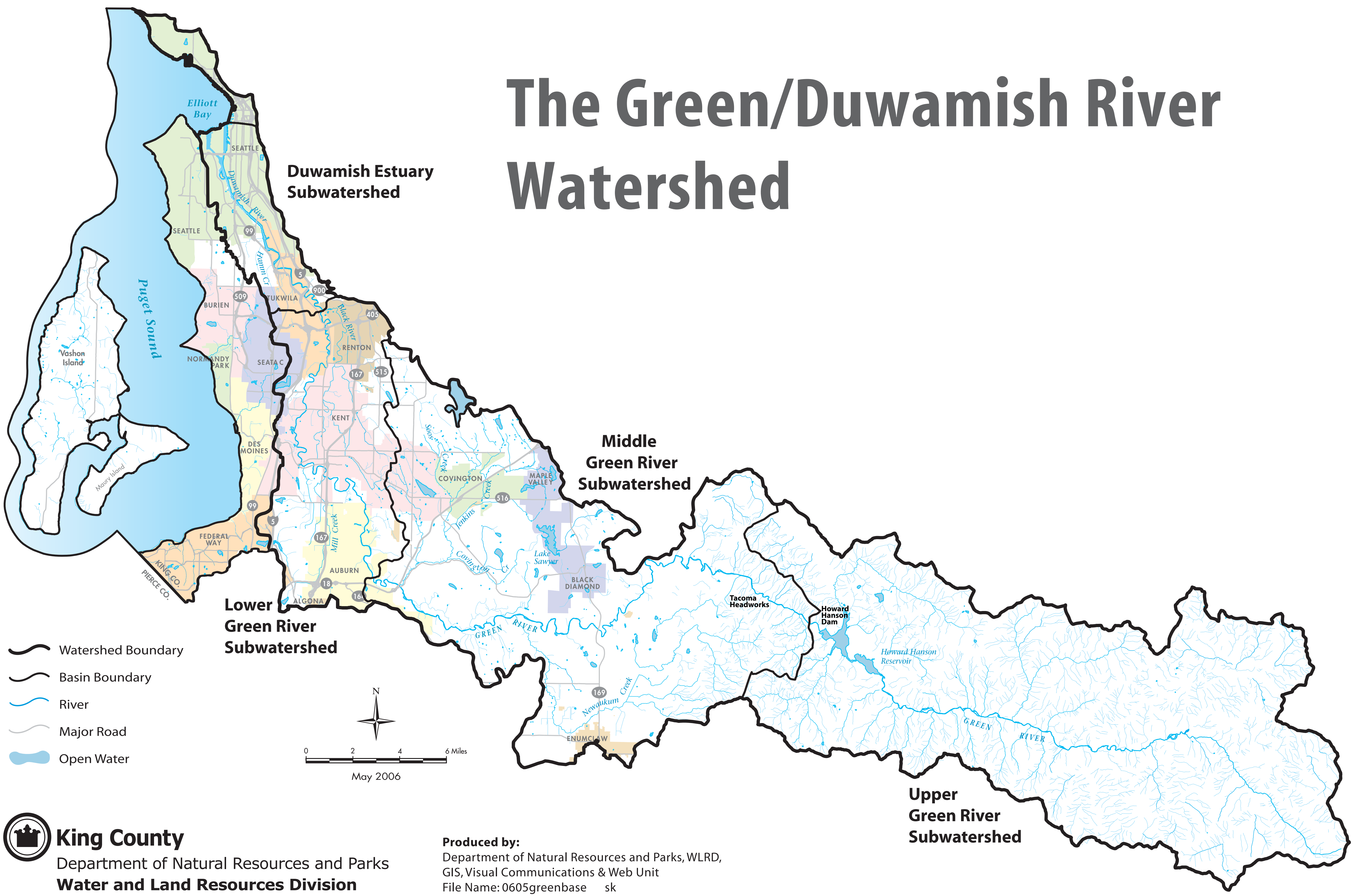


Figure 1. Green River watershed subbasins (source: King County).

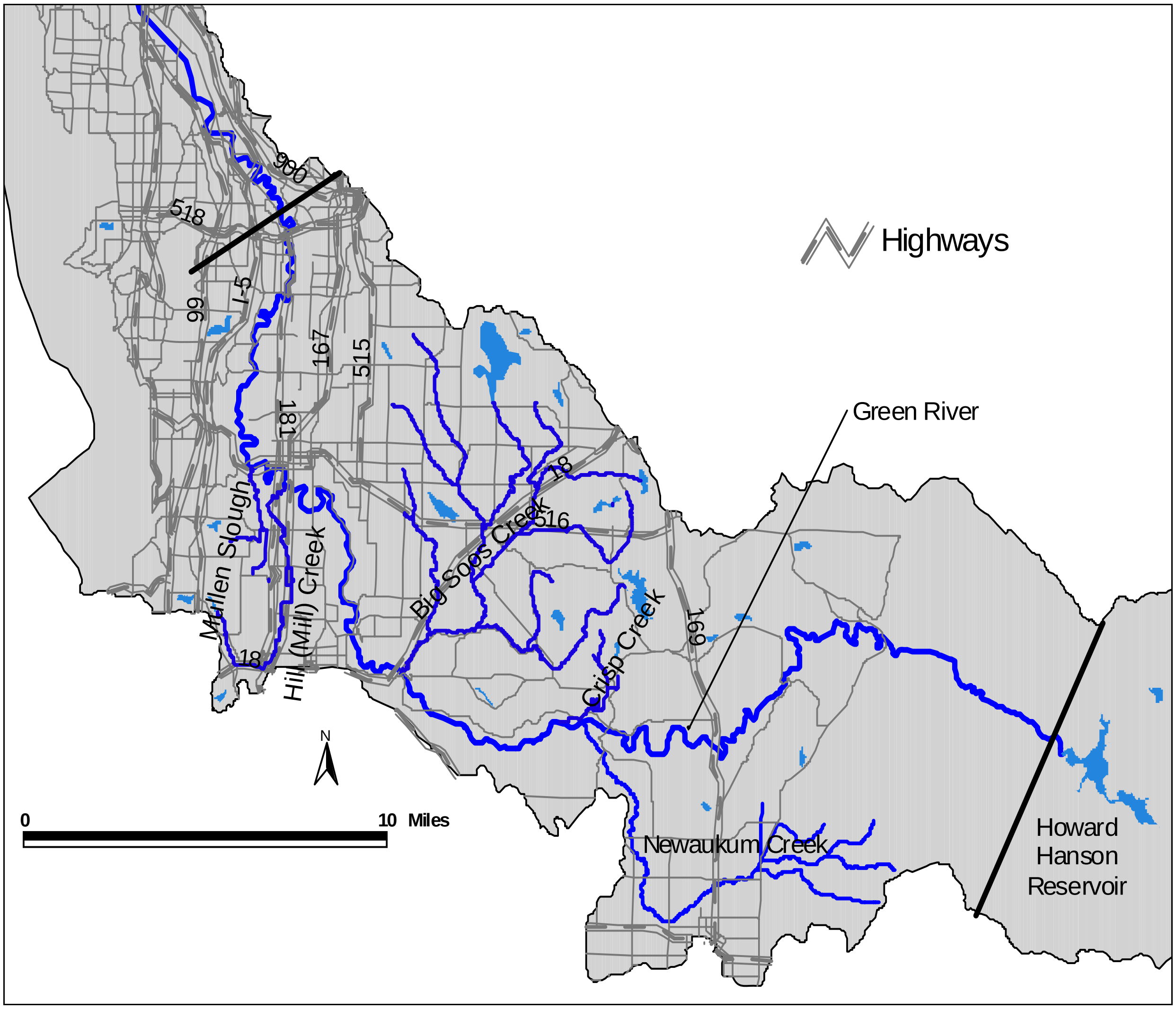


Figure 2. Green/Newaukum system.

Background

Project Objectives

The project objectives are to collect data and to develop temperature and dissolved oxygen models for the Green/Newaukum system during critical low-flow conditions. The data will supplement the ambient monitoring programs conducted by the Department of Ecology, King County, U.S. Army Corps of Engineer, City of Kent, and others. Following are specific tasks:

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

Study Area Description

The Green/Newaukum watershed, consisting of about 1253 km^2 (310,000 acres), includes portions of King County as well as the cities of Auburn, Covington, Maple Valley, Kent, Sea-Tac, Tukwila, Black Diamond, Enumclaw, and Renton. The headwaters of the Green River originate about 1,220 m (4,000 ft) above sea level and discharge to the Duwamish Waterway. The headwaters of Newaukum Creek originate about 920 m (3,000 ft) above sea level and discharge to the Green River near river mile 40.7 at an elevation of 55 m (180 ft). The Green River flows about 86 km (53.5 miles) from the outlet of Howard Hanson Dam to the confluence with Duwamish Waterway. Newaukum Creek runs about 23 km (14.4 miles) from its headwaters to the confluence with the Green River.

Land use in the Upper Green River watershed (not included in the TMDL study area) is dominated by forest and forestry practices and serves as the drinking water watershed for the City of Tacoma. Land use in the Middle and Lower Green River subwatersheds is dominated by agriculture and low- to high-density residential development with some forested areas. Below the TMDL study area, the Green-Duwamish Estuary subwatershed is an urban industrialized area serving the City of Seattle. In the Newaukum basin, land use consists of high-density development, agriculture/pasture, and forest/forestry practices. The majority of the agriculture land and urban development is in the middle portions of this subwatershed. The lower and upper reaches are more forested.

Coho, chinook, chum, sockeye, and pink salmon as well as coastal cutthroat, steelhead, bull trout/Dolly Varden char, and Atlantic salmon are found in the Green/Duwamish mainstem (King County and WSCC, 2000). Chinook, coho, sockeye, and chum salmon as well as winter steelhead have been observed spawning in Newaukum Creek (Kerwin and Nelson, 2000). This subbasin of the Green-Duwamish watershed is considered to be a major producer of winter steelhead, coho, and chinook salmon. The Middle Green River Baseline Habitat Survey Report (USACOE, 2002) provides more detailed information about habitat conditions in the Newaukum Creek area.

Water Quality Impairments

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

Table 1. Clean Water Act Section 303(d) Category 5 listings for temperature and dissolved oxygen (2004).

Name	Listing ID	Parameter	Township	Range	Section	New WBID	Old WBID
Green River	*7482*	Temperature	21N	08E	18	AB62OX	WA-09-1030
Green River	*7480*	Temperature	21N	05E	22	AJ33YB	WA-09-1020
Green River	*7478*	Temperature	22N	04E	15	FK76HV	WA-09-1020
Green River	*7479*	Temperature	22N	05E	30	YD05HE	WA-09-1020
Green River	*7037*	Temperature	23N	04E	24	YD05HE	WA-09-1020
Green River	*7043*	Temperature	21N	06E	28	YD05HE	WA-09-1020
Green River	*7481*	Temperature	21N	06E	29	YD05HE	WA-09-1020
Green River	*6574*	Temperature	21N	07E	10	YD05HE	WA-09-1020
Green River	*7483*	Temperature	21N	08E	28	YD05HE	WA-09-1020
Hill (Mill) Creek	*7041*	Temperature	22N	04E	25	BI99NR	WA-09-1022
Green River	*12708*	DO	21N	06E	28	YD05HE	WA-09-1020
Green River	*10812*	DO	23N	04E	24	YD05HE	WA-09-1020
Newaukum Creek	*12700*	DO	21N	06E	33	JX80LS	WA-09-1028
Mullen Slough	*15825*	DO	22N	04E	26	BP27QP	(None)
Mullen Slough	*15826*	DO	22N	04E	23	BP27QP	(None)
Hill (Mill) Creek	*7488*	DO	21N	04E	01	BI99NR	WA-09-1022
Hill (Mill) Creek	*12707*	DO	22N	04E	25	BI99NR	WA-09-1022
Hill (Mill) Creek	*15811*	DO	22N	04E	26	BI99NR	WA-09-1022
Hill (Mill) Creek	*15814*	DO	22N	04E	35	BI99NR	WA-09-1022

WBID – waterbody identification

Water Quality Standards and Parameters of Concern

This report and the subsequent TMDL are designed to address impairments of characteristic uses caused by high temperatures. The characteristic uses designated for protection in the Green/Newaukum system are described in Chapter 173-201A WAC.

Table 2 presents the waterbody classifications, which include both Class AA (extraordinary) and Class A (excellent) waters. All streams that are not specifically named in Table 2 that are tributaries to Class AA waters are classified Class AA. All other non-specified surface waters are classified Class A.

Table 2. Waterbody classification for the Green/Newaukum system.

Name	Classification
Green River	Class A from Black River (river mile 11.0) to Flaming Geyser State Park (river mile 42.3)
Green River	Class AA from Flaming Geyser State Park (river mile 42.3) to river mile 59.1
Newaukum Creek	Class A
Hill (Mill) Creek	Class A
Mullen Slough	Class A

The Washington State water quality standards establish beneficial uses of waters and incorporate specific numeric and narrative criteria for parameters such as water temperature. The criteria are intended to define the level of protection necessary to support the beneficial uses. The beneficial uses of the waters in this specific area include:

- *Recreation* - Primary contact recreation, sport fishing, boating, and aesthetic enjoyment.
- *Fish and Shellfish* - Salmonid migration, rearing, spawning, and harvesting.
- *Water Supply* (domestic, industrial, and agricultural) *and Stock Watering.*
- *Wildlife Habitat* - Riparian areas are used by a variety of wildlife species, which are dependent on the habitat.
- *Commerce and navigation*

Temperature is a water quality concern because most aquatic organisms, including salmonids, are cold-blooded and are strongly influenced by water temperature (Schuett-Hames et al., 1999). Temperature affects the physiology and behavior of fish and other aquatic life. Temperature is a major concern in the Green River and its tributaries because of the use of its waters by steelhead and bull trout, and their listing as threatened species under the Endangered Species Act. Elevated temperature and altered channel morphology resulting from various land-use activities – such as removal of riparian vegetation, flood control, and agriculture – limit available spawning and rearing habitat for salmonids.

1997 (Current) Temperature and Dissolved Oxygen Criteria

Numeric freshwater water quality criteria for Class AA and Class A state that temperature shall not exceed 16.0°C for Class AA (extraordinary) or 18.0°C for Class A (excellent). These numeric criteria are designed to ensure specific communities of aquatic life will be fully protected whenever and wherever the numeric criteria are met. The state standards recognize, however, that some waterbodies may not be able to meet the numeric criteria at all places and all times.

WAC 172-201A states that: *"Temperature shall not exceed [the numeric criteria] due to human activities. When natural conditions exceed [the numeric criteria], no temperature increases will be allowed which will raise the receiving water temperature by greater than 0.3°."*
(WAC 173-201A-030(1)(c)(iv), (2)(c)(iv), (3)(c)(iv), (4)(c)(iii))

Thus at times and locations where the assigned numeric criteria cannot be attained even under estimated natural conditions, the state standards hold human-caused warming to a cumulative allowance for additional warming of 0.3°C above the natural conditions estimated for those locations and times.

In addition to placing a limit on the amount of human-caused warming allowed when temperatures exceed the numeric criteria, the state standards restrict the amount of warming that point and nonpoint sources can cause when temperatures are cooler than the numeric criteria. If natural conditions are below the temperature standard, incremental temperature increases resulting from nonpoint source activities shall not exceed 2.8°C or bring the stream temperature above the specified standard of the class at any time (Chapter 173-201A-030 WAC). Where natural conditions are below the temperature standard, incremental temperature increases from point sources are restricted using equation 23/(T+5) in Class AA waters, where T is the upstream water temperature. The equation of 28/(T+7) is used for Class A waters.

Freshwater dissolved oxygen shall exceed 9.5 mg/L for Class AA waters and must exceed 8.0 mg/L for Class A waters. When natural conditions occur causing the dissolved oxygen to be depressed near or below the levels described above by class, natural dissolved oxygen levels may be degraded by no more than 0.2 mg/L by the combined effect of all human-caused activities.

2003 (Revised) Temperature and Dissolved Oxygen Criteria

In July 2003, the state Department of Ecology (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 had used for decades to designate uses to be protected by water quality criteria (e.g., temperature, dissolved oxygen, turbidity, bacteria). Ecology also revised the numeric temperature criteria that were to be assigned to waters to protect specific types of aquatic life uses (e.g., native char, trout, and salmon spawning and rearing, warm water fish habitat).

The revised water quality standards regulation was submitted to EPA for federal approval. EPA was not satisfied that Ecology's 2003 standards met the requirements of the federal Clean Water Act and the federal Endangered Species Act. Their main concerns were over the temperature criteria applied to waters that support endangered fish species (e.g., bull trout, salmon, steelhead). As a consequence, EPA has formally disapproved portions of the revised standards (EPA, 2006; Gearheard, 2006).

Ecology has agreed to initiate state rule revision proceedings that will consider making the changes EPA has highlighted as necessary. The result of the corrective state rulemaking will be that a number of streams and stream segments would receive more stringent temperature and dissolved oxygen criteria. The state expects to conclude its corrective rulemaking proceedings in fall 2006. Until that time, TMDLs must be based on the 1997 version of the state water quality standards, rather than the 2003 version that has been disapproved by EPA.

Table 3 provides a general structure for understanding how the 1997 standards were translated into the 2003 and draft 2006 standards for both temperature and dissolved oxygen. EPA's findings on designated uses are presented in Figure 3.

Table 3. Water quality standards for temperature and dissolved oxygen.

1997 Standards Classification	Water Quality Parameter	1997 Criteria[3]	2003 Use Revision	2003/2007 Criteria[3]
Class AA [1]	Temperature	16°C 1-Dmax[5]	Native Char	12°C 7-DADMax[4, 6]
			"Core" Salmon/Trout	16°C 7-DADMax[4, 6]
	Diss. Oxygen	9.5 mg/L 1-DMin[7]	*Either of above*	9.5 mg/L 1-DMin[7]
Class A[2]	Temperature	18°C 1-Dmax[5]	Native Char	12°C 7-DADMax[4, 6]
			"Non-core" Salmon/Trout	17.5°C 7-DADMax[4, 6]
	Diss. Oxygen	8.0 mg/L 1-DMin[7]	Native Char	9.5 mg/L 1-DMin[7]
			"Non-core" Salmon/Trout	8.0 mg/L 1-DMin[7]

1. Class AA waters were subcategorized into "native char" and "salmon/trout core rearing" designated use types during the 2003 revision to the water quality standards regulation.
2. Class A waters were subcategorized into "native char" and "salmon/trout non-core rearing" designated use types during the 2003 revision to the water quality standards regulation.
3. 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 2003 version of the standards.
4. The 2007 corrected water quality standards rule will contain supplemental spawning and incubation temperature criteria (13°C for salmon and trout, and 9°C for native char) that will be applied to specific portions of many of these waters.
5. 1-DMax means the highest annual daily maximum temperature occurring in the waterbody.
6. 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
7. 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the waterbody.

As described in the disapproval, portions of the Green/Newaukum system also must not exceed 13°C between September 15 and July 1 to protect spawning and incubation. Figure 4 presents the spatial extent of the designation. This project is designed to evaluate summer peak temperatures, and other conditions are not evaluated explicitly.

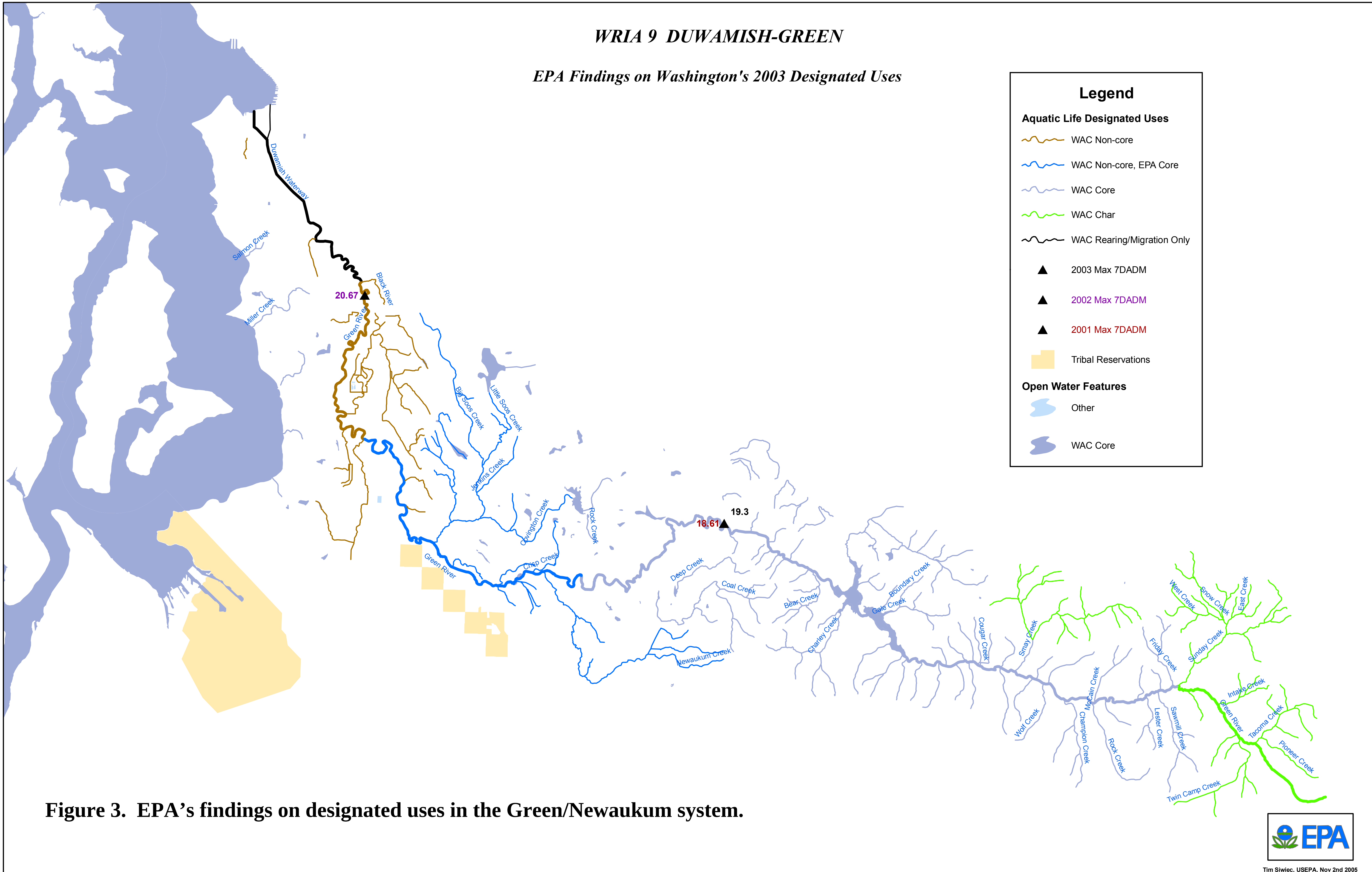


Figure 3. EPA's findings on designated uses in the Green/Newaukum system.

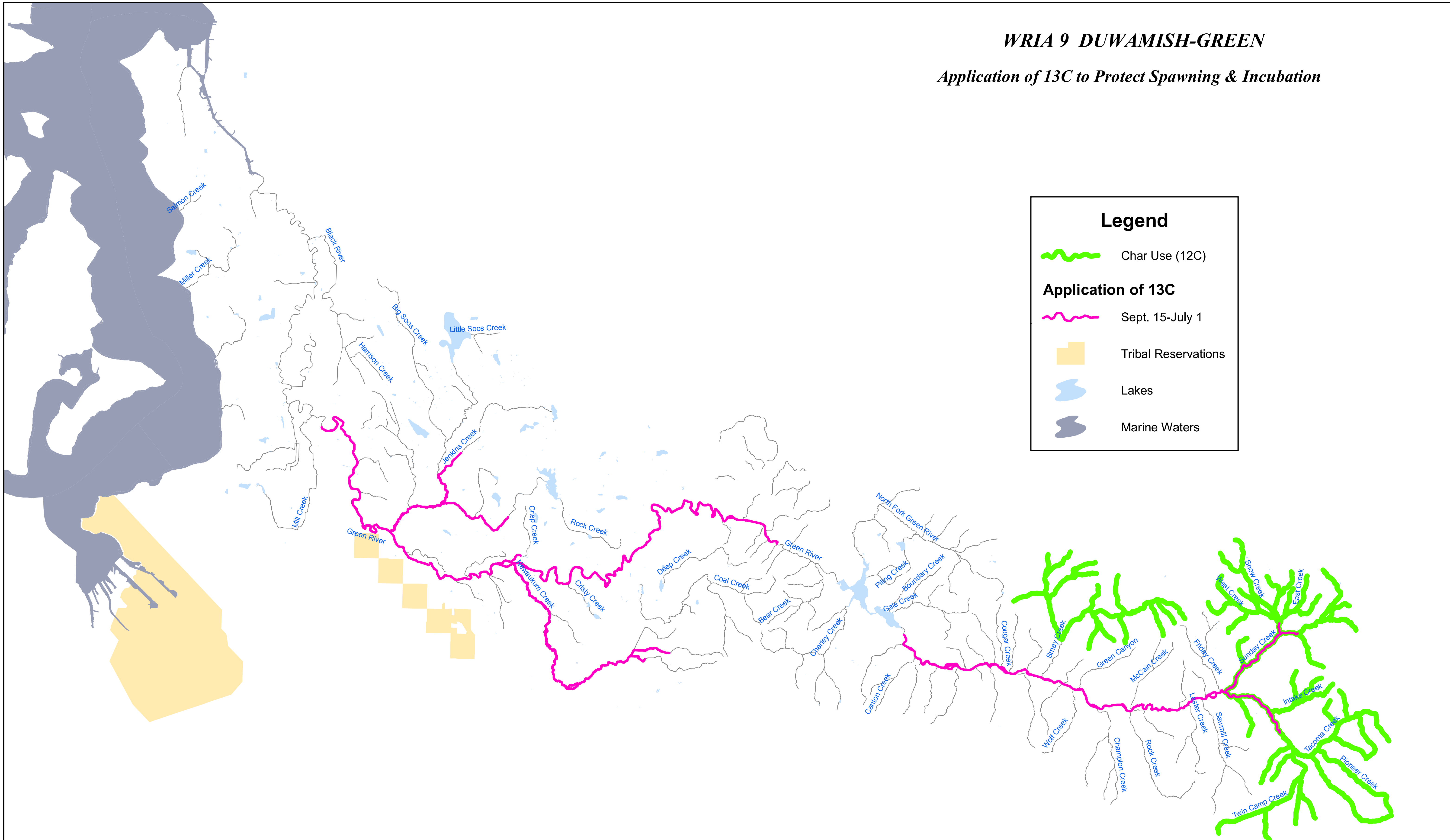


Figure 4. Extent of the 13.0°C criteria in the Green River and Newaukum Creek.

Tim Siwiec, USEPA, Oct 20th 2005

During this uncertain transition period, TMDLs will be designed with formal allocations that meet the existing 1997 EPA approved standards. In all TMDL technical studies completed during this transition period, the analysis must include a scenario evaluating what would be needed to meet the EPA required standards in the corrective rule.

Sources of further information include the following:

- Proposed revisions to the existing standards can be found online at Ecology's water quality standards website: www.ecy.wa.gov/programs/wq/swqs.
- Information on EPA's findings on the fisheries uses of the Green/Newaukum system can be found in map form on EPA's website: http://yosemite.epa.gov/R10/WATER.NSF/Water+Quality+Standards/WA+WQS+EPA+Disapproval
- The most current information about how the state's 2003 temperature criteria were developed can be found in a draft discussion paper by Hicks (2002).

Potential Sources and Permit Holders

Temperature

The temperature TMDL will be developed for heat (i.e., incoming solar radiation). Heat is considered a pollutant under Section 502(6) of the Clean Water Act. The transport and fate of heat in natural waters has been the subject of extensive study. Edinger et al. (1974) provide an excellent and comprehensive report of this research. Thomann and Mueller (1987) and Chapra (1997) have summarized the fundamental approach to the analysis of heat budgets and temperature in natural waters that will be used in this TMDL. Figure 5 shows the major heat energy processes or fluxes across the water surface or streambed, described further in Pelletier et al. (2005).

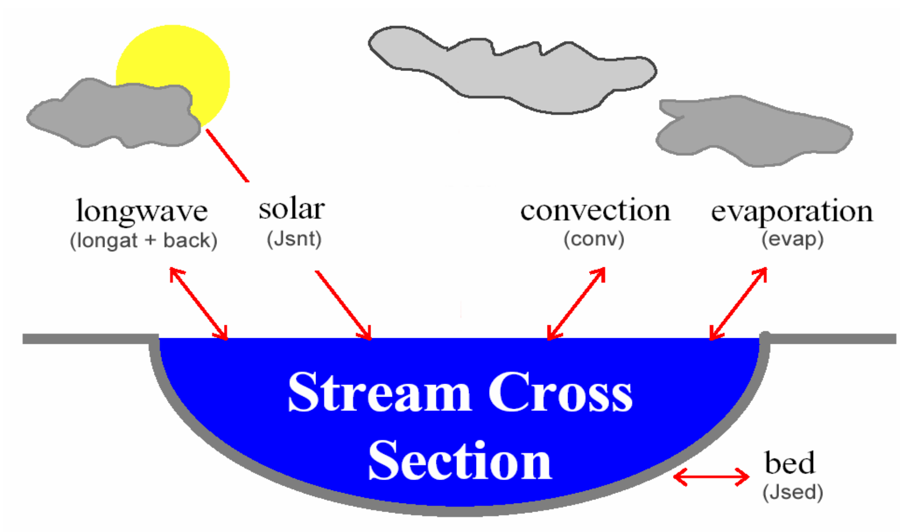


Figure 5. Surface heat transfer processes that affect water temperature.

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

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

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

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

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

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

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

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

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

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

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

- Near-stream vegetation height, width, and density combine to produce shadows that can reduce solar heat flux to the surface of the water.
- Riparian vegetation creates a thermal microclimate that generally maintains cooler air temperatures, higher relative humidity, lower wind speeds, and cooler ground temperatures along stream corridors.
- Bank stability is largely a function of near-stream vegetation. Specifically, channel morphology is often highly influenced by land cover type and condition by affecting floodplain and instream roughness, contributing coarse woody debris, and influencing sedimentation, stream substrate composition, and streambank stability.

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

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

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

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

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

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

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

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

Dissolved Oxygen, Nutrients, and pH

Nonpoint Sources

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

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

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

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

The diel (24-hour) cycle of algal growth adds DO during the daylight hours as the plants photosynthesize, but reduces DO levels to a natural minimum around daybreak as respiration occurs. Enhanced growth increases the daily variation resulting in lower levels of DO than would have resulted under natural conditions. These same processes affect pH.

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

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

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

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

Point Sources

No point sources discharge to the Green/Newaukum system under individual NPDES permits, except those covered by stormwater. Several general permits for sand and gravel and industrial stormwater/construction have been issued for the Green/Newaukum watershed, and these are listed in Table 4. The watershed is also covered by both the municipal stormwater Phase I (Seattle and King County) and municipal stormwater Phase II (Algona, Auburn, Black Diamond, Burien, Des Moines, Enumclaw, Federal Way, Kent, Maple Valley, Normandy Park, Renton, SeaTac, and Tukwila) permits, as shown in Figure 6. Highways within the Phase I area are covered by Washington State Department of Transportation's stormwater permit.

Table 4. Facilities covered under permits within the Green/Newaukum system.

	Type	Permittee
Stormwater Permits		
	Phase I stormwater	King County
	Phase I stormwater	Department of Transportation
	Phase II stormwater*	City of Algona
	Phase II stormwater*	City of Auburn
	Phase II stormwater*	City of Black Diamond
	Phase II stormwater*	City of Burien
	Phase II stormwater*	City of Covington
	Phase II stormwater*	City of Des Moines
	Phase II stormwater*	City of Enumclaw
	Phase II stormwater*	City of Federal Way
	Phase II stormwater*	City of Kent
	Phase II stormwater*	City of Maple Valley
	Phase II stormwater*	City of Normandy Park
	Phase II stormwater*	City of Renton
	Phase II stormwater*	City of SeaTac
	Phase II stormwater*	City of Tukwila
Other General Permits		
	Sand and Gravel	(varies with time)
	Construction Stormwater	(varies with time)

* expected to be issued during study.

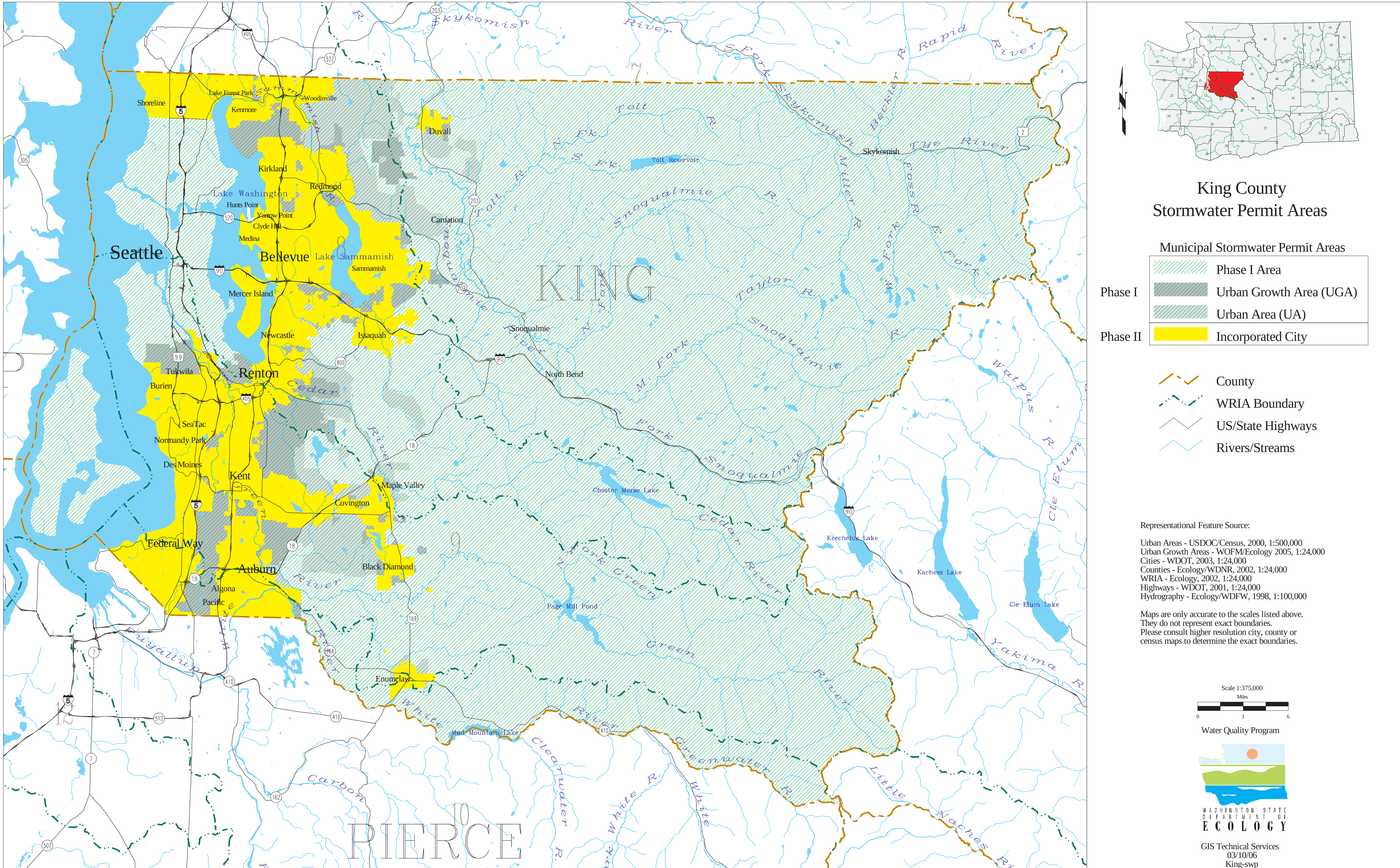


Figure 6. Stormwater permit coverage for the greater Seattle area, including the Green/Newaukum system.

Historical Data Review

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

King County

King County has been conducting monthly baseline water quality monitoring at several sites along the Green-Duwamish River beginning in the early 1970s. Appendix B summarizes historical monitoring data at the stations shown in Figure 7.

- *Duwamish River* - Station 0309 is located in the Duwamish River at the bridge on East Marginal Way in Allentown. The county samples two additional stations (0305 and 0307) further downstream on the Duwamish River. These downstream sites are strongly influenced by tidal water and therefore are not included with the other streams in freshwater assessments.

- *Lower Green River* - Two stations are located in the Lower Green River. Station 3106 is located at the bridge at Fort Dent Park downstream of the former Renton Wastewater Treatment Plant outfall. Station 0311 is located a few hundred yards upstream from the former outfall at the Renton Junction Bridge on West Valley Road at Highway 1.

- *Middle Green River* - There are two stations located in the Middle Green River. Station A319 is located upstream of the confluence of Soos Creek at the bridge on Black Diamond Road. Station B319 is located upstream of the confluence of Newaukum Creek at the bridge on Southeast Green Valley Road. King County does not monitor the Green River upstream from Howard Hanson Dam.

Monitoring data indicate a decline in overall water quality in terms of both temperature and dissolved oxygen. Water quality in the Duwamish River has been characterized as “fair”, the Lower Green as “fair to good”, and the Middle Green as “good to very good” (Metro, 1990; Herrera, 2005).

To determine what changes in Green River water quality have occurred since 1979, a 25-year trend analysis (1979 – 2004) was conducted using the data from the three upstream sampling locations (0311, A319, and B319). Results from this analysis show that there has been a significant decrease in dissolved oxygen, pH, and orthophosphorus at all three stations. Total suspended solids decreased significantly at stations A319 and B319, and turbidity decreased significantly at station B319. Fecal coliform bacteria decreased significantly at stations 0311 and A319. Temperature increased significantly at station 0311 over this time period. Total phosphorus increased significantly at B319.

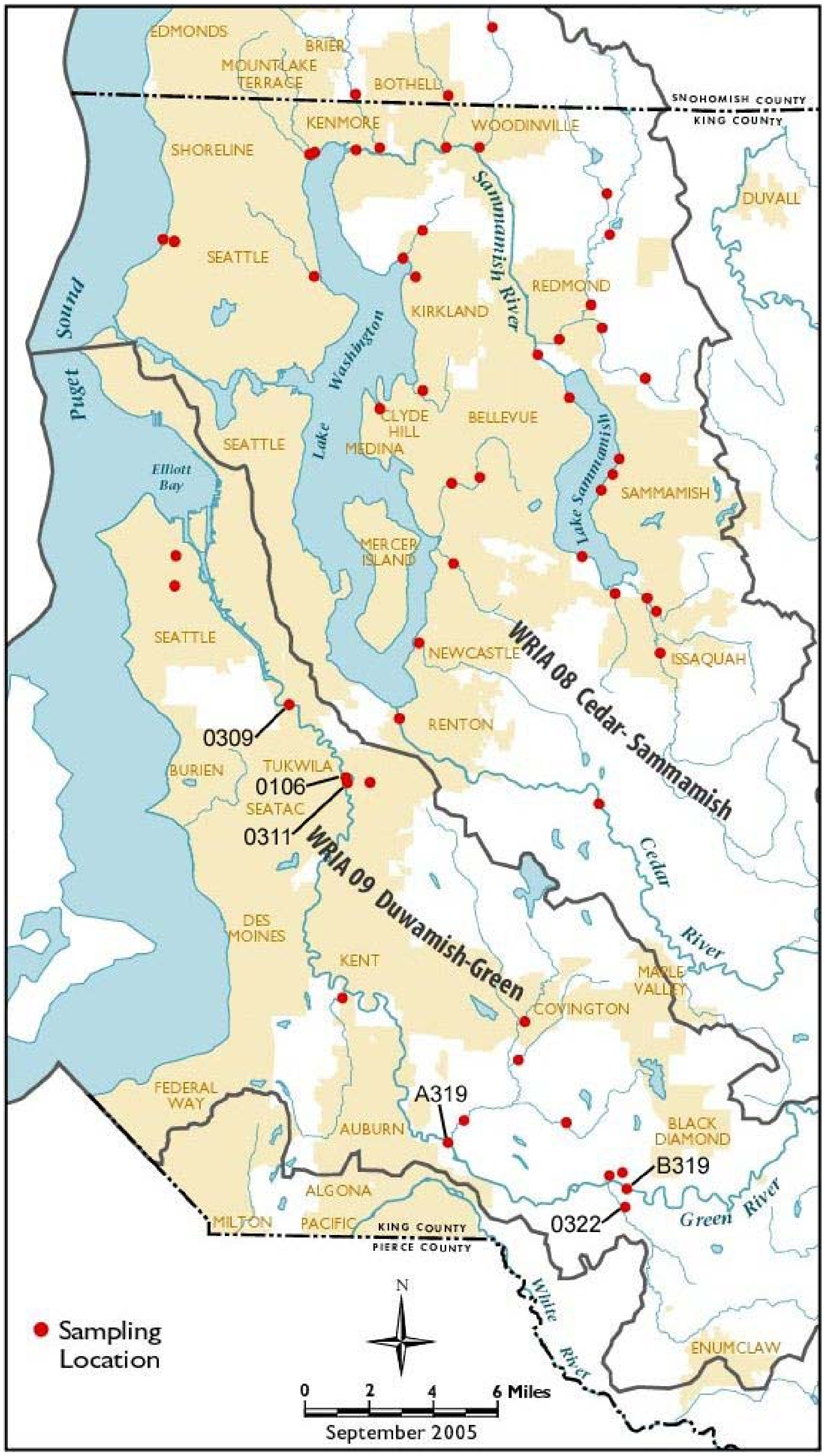


Figure 7. King County monitoring locations.

Water quality conditions in Newaukum Creek have historically been characterized as fair (Metro, 1990) due to high nutrient concentrations and high fecal coliform bacteria counts related to agricultural practices. As for the Green River, a 25-year (1979 – 2004) trend analysis was conducted with baseflow water quality data collected from the mouth of Newaukum Creek. This analysis shows that there have been some improvements in water quality since 1979. Total suspended solids, ammonia, total nitrogen, and fecal coliform bacteria have all shown a significant decrease in this 25-year time period. The pH values have shown a significant decreasing trend. However, conductivity and phosphorus concentrations (both orthophosphorus and total phosphorus) have increased significantly during this same time period and pH levels have lowered.

In spite of improvements noted since 1979, a water quality data assessment conducted for the Green-Duwamish River in 2003 found that Newaukum Creek continues to have low dissolved oxygen and high nitrate-nitrogen, total nitrogen, orthophosphorus, and total phosphorus concentrations in both base and storm flow, particularly at sites representing agricultural land use, relative to the rest of the Green-Duwamish watershed (Herrera, 2005). Turbidity and total suspended solids were elevated in the creek during storm events. Total aluminum concentrations exceeded EPA chronic criterion during baseflow sampling, and acute criterion during storm flow sampling.

Summary graphics of the Green/Duwamish and Newaukum temperature and dissolved oxygen data are presented in Appendix B.

Department of Ecology

Ecology has monitored two stations on the Green River as part of its long-term monitoring program. The Green River at Tukwila (09A080) has been monitored since 1991 and the Green River at Kanaskat (09A190) has been monitored continuously since 1978. Monthly parameters include total persulfate nitrogen, nitrate + nitrite, ammonium, total phosphorus, orthophosphate, suspended solids, temperature, dissolved oxygen, and pH. The lowest instantaneous dissolved oxygen level (9.4 mg/L) occurred on August 16, 2004 at 08:14.

In addition, continuous water and air temperature data during the summer season are available for station 09A190 since 2001 and for station 09A080 in 2002. Figure 8 summarizes 2005 temperature results for station 09A190. The highest 7-day average of the daily maximum temperature was 17.9°C for August 6, 2005.

Ecology also has monitored sites within the study area periodically, as summarized in Table 5. In 2005, the peak 7-day average of the daily maximum temperature was 17.1°C in Newaukum Creek (Figure 9) and 18.2°C in Big Soos Creek on July 29.

Muckleshoot Indian Tribe

Caldwell (1994) collected water temperature data in the Green River basin at five sites between river miles 12.5 and 41.5 in the mainstem. Hourly temperature data were collected at these sites during summer months in 1992.

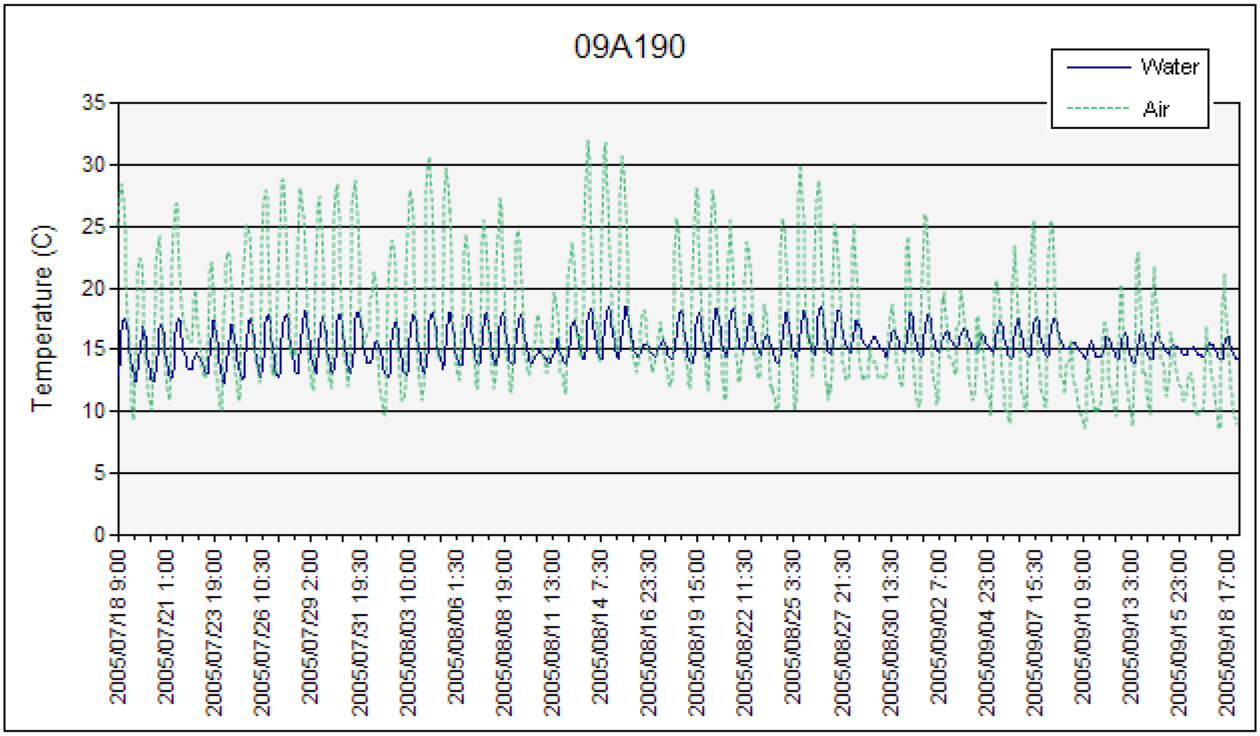


Figure 8. Temperature monitoring for the Green River at Kanaskat by Ecology.

Table 5. Water quality monitoring at rotating stations within the Green/Newaukum system.

Name	Station ID	Years	Parameters
Newaukum Creek near Enumclaw	Station 09F150	1999	Nutrients, instantaneous DO, and temperature
		2005	Continuous air and water temperature
Hill (Mill) Creek at Kent on West Valley Highway	Station 09E090	1984 through 1990	Nutrients, instantaneous DO, and temperature
Big Soos Creek near Auburn	Station 09B090	1994 and 1999	Nutrients, instantaneous DO, and temperature
		2005	Continuous air and water temperature

DO – dissolved oxygen

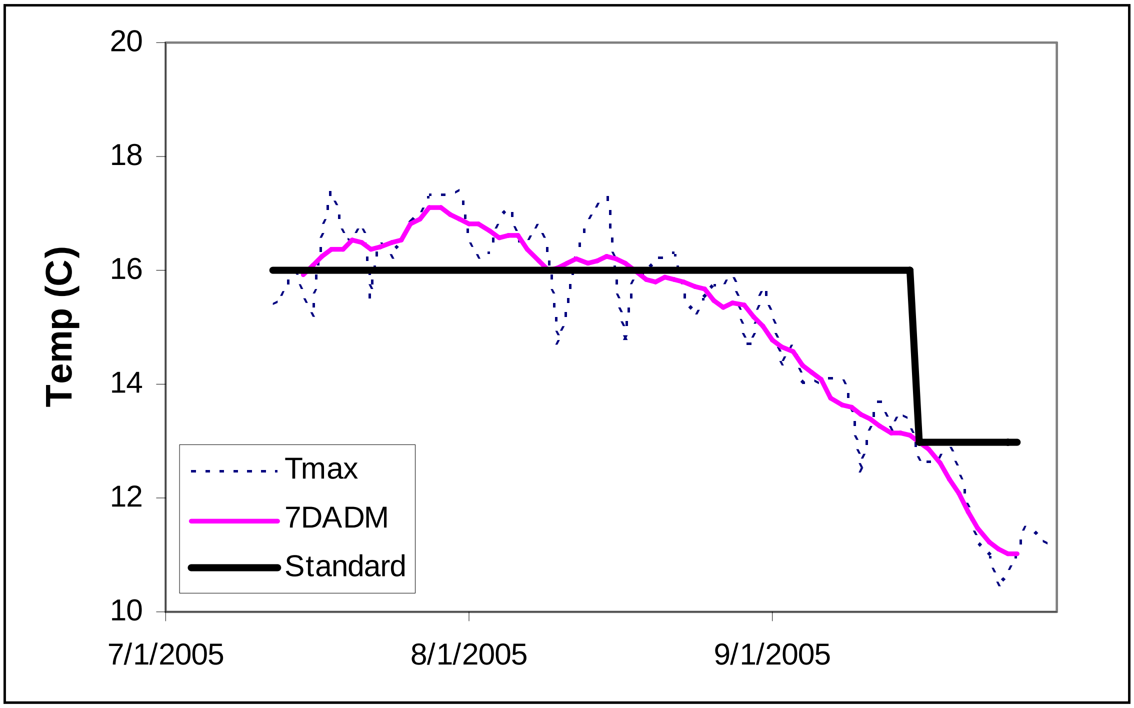


Figure 9. Continuous water temperature monitoring for Newaukum Creek.

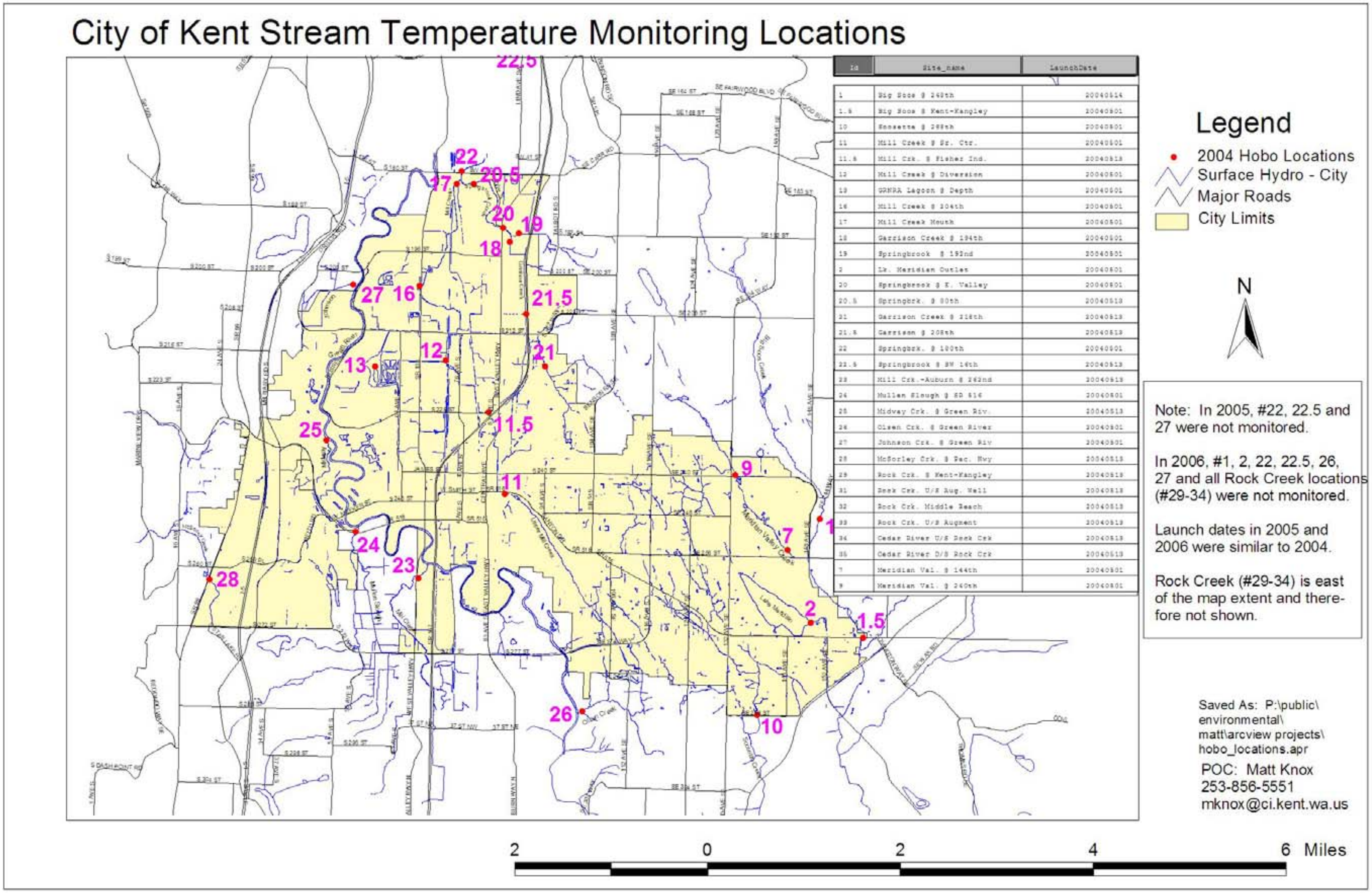
U.S. Army Corps of Engineers

The Seattle District of the Corps of Engineers monitors continuous water temperature at the Howard Hanson Dam tailwater as well as discharge in the Green River immediately downstream (U.S. Army Corps of Engineers, 2005). They have collected grab samples for nutrient analysis between April and October within the reservoir and have recorded field parameters (instantaneous dissolved oxygen, temperature, conductivity, and pH) since 2002 and will continue the program in 2006. Reservoir parameters include total phosphorus, soluble reactive phosphorus, total nitrogen, and nitrate + nitrite.

The Seattle District developed model-based estimates of travel time in the Green River from Howard Hanson Dam to Auburn and from Auburn to Tukwila for a variety of discharges. At 400 cfs, the lowest discharge evaluated with the HEC2 model, travel time from Howard Hanson Dam to Auburn is 12 hours and from Auburn to Tukwila is 24 hours (Brownell, 1996).

City of Kent

The City of Kent has installed continuous temperature probes in tributaries to the Green River since 2004. As shown in Figure 10, Mill Creek and Mullen Slough are included in the program.



Id	Site_name	LaunchDate
1	Big Soos @ 248th	20040514
1.5	Big Soos @ Kent-Kangley	20040501
10	Soosette @ 288th	20040501
11	Mill Creek @ Sr. Ctr.	20040501
11.5	Mill Crk. @ Fisher Ind.	20040513
12	Mill Creek @ Diversion	20040501
13	GRNRA Lagoon @ Depth	20040501
16	Mill Creek @ 204th	20040501
17	Mill Creek Mouth	20040501
18	Garrison Creek @ 194th	20040501
19	Springbrook @ 192nd	20040501
2	Lk. Meridian Outlet	20040501
20	Springbrook @ E. Valley	20040501
20.5	Springbrk. @ 80th	20040513
21	Garrison Creek @ 218th	20040513
21.5	Garrison @ 208th	20040513
22	Springbrk. @ 180th	20040501
22.5	Springbrook @ SW 16th	20040513
23	Mill Crk.-Auburn @ 262nd	20040513
24	Mullen Slough @ SR 516	20040501
25	Midway Crk. @ Green Riv.	20040513
26	Olsen Crk. @ Green River	20040501
27	Johnson Crk. @ Green Riv	20040501
28	McSorley Crk. @ Pac. Hwy	20040513
29	Rock Crk. @ Kent-Kangley	20040513
31	Rock Crk. U/S Aug. Well	20040513
32	Rock Crk. Middle Reach	20040513
33	Rock Crk. U/S Augment	20040513
34	Cedar River U/S Rock Crk	20040513
35	Cedar River D/S Rock Crk	20040513
7	Meridian Val. @ 144th	20040501
9	Meridian Val. @ 240th	20040501

Figure 10. City of Kent continuous temperature monitoring locations (source: City of Kent).

Organization and Schedule

The Department of Ecology is responsible for submitting water quality cleanup plans (TMDLs) to EPA for approval. However, under the cooperative effort in Green/Newaukum, staff from Ecology, King County, and others will share monitoring program responsibility. Table 6 presents the schedule for completion and specific institutional responsibilities. Specific field programs are described under *Experimental Design.*

Table 6. Green/Newaukum data collection, model development, and TMDL development schedule and responsibilities.

Task	Schedule for Completion	Responsibility	
		Green River	Newaukum Creek
Continuous Temperature Monitoring	July and August 2006	Ecology	King County
Continuous Dissolved Oxygen Monitoring	July and August 2006	Ecology	King County
Synoptic Productivity Monitoring	July and August 2006	Ecology	King County
Synoptic Flow	August 2006	Ecology, with some support from partners	Ecology
Periphyton Monitoring	July and August 2006	Ecology, with optional support from field teams	Ecology, with optional support from field teams
Riparian Shade Development	July through September 2006	Ecology	NA
Temperature Model Development	Fall 2006 through Spring 2007	Ecology	NA
Dissolved Oxygen Model Development	Fall 2006 through Spring 2007	Ecology	NA
Draft TMDL Technical Report	July 2007	Ecology, with some support from King County	NA
Final TMDL Technical Report	October 2007	Ecology, with some support from King County	NA
TMDL Submittal Report	October 2007	Ecology	NA
Detailed Implementation Plan	October 2008	Ecology	NA
Final EIM Data Processing	December 2006	Ecology	Ecology

Environmental Information System (EIM) Data Set (If applicable)	
EIM Data Engineer	Trevor Swanson
EIM User Study ID	MROB003
EIM Study Name	Green/Newaukum Temperature and DO TMDL
EIM Completion Due	6-30-07
Final Report	
Report Author Lead	Pending, WQSU
Schedule	
Report Supervisor Draft Due	December 2007
Report Client/Peer Draft Due	January 2008
Report External Draft Due	February 2008
Report Final Due (Original)	June 2008

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

Experimental Design

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

Monitoring includes in-situ continuous data and instantaneous values as well as grab samples collected for laboratory analysis. Table 7 summarizes the experimental design. Appendix C describes specific monitoring locations.

Table 7. Station summary by monitoring program.

Program	Parameter	Type	Equipment	Green River	Newaukum Creek
Continuous Temperature and DO	Water temperature	Continuous	TidBit/Hobo	18 stations	8 stations
	Air temperature	Continuous	TidBit/Hobo	8 stations	1 station
	Relative humidity	Continuous	RH probe	4 stations	1 station
	DO, pH, temperature, conductivity	Continuous	YSI	8 stations	7 stations
Synoptic Productivity	DO, pH, temperature, conductivity	Instantaneous in situ	YSI and Hydrolabs	20* stations	8 stations
	Total nitrogen and total phosphorus	Grab samples, unfiltered	(laboratory)	20* stations	8 stations
	Dissolved nutrients (nitrate+nitrite, ammonia nitrogen, orthophosphorus)	Grab samples, filtered	(laboratory)	20* stations	8 stations
	Chlorophyll a	Grab samples	(laboratory)	20* stations	8 stations
	TOC, DOC, alkalinity	Grab samples	(laboratory)	20* stations	8 stations
	Periphyton	Grab samples	(see Methods)	8 stations	6 stations
Synoptic Flow	Discharge	Instantaneous in situ	Flow meter and wading rod	16 stations	8 stations
Shade	Riparian shade	Instantaneous in situ	HemiView camera	11 stations	4 stations

* Includes the mouth of Newaukum Creek split sample with King County Environmental Laboratory
DO – dissolved oxygen
TOC – total organic carbon
DOC – dissolved organic carbon
RH – relative humidity

Continuous Temperature and Dissolved Oxygen Monitoring

Continuous temperature data will provide daily minimum and maximum values for model calibration and validation. Both air temperature and water temperature are necessary to model creek conditions. Figure 11 identifies the relative humidity, air, and water temperature monitoring locations. Air temperature TidBits and relative humidity probes will be deployed at a subset of sites. Probes will be installed on or around July 15 and removed on or around August 15.

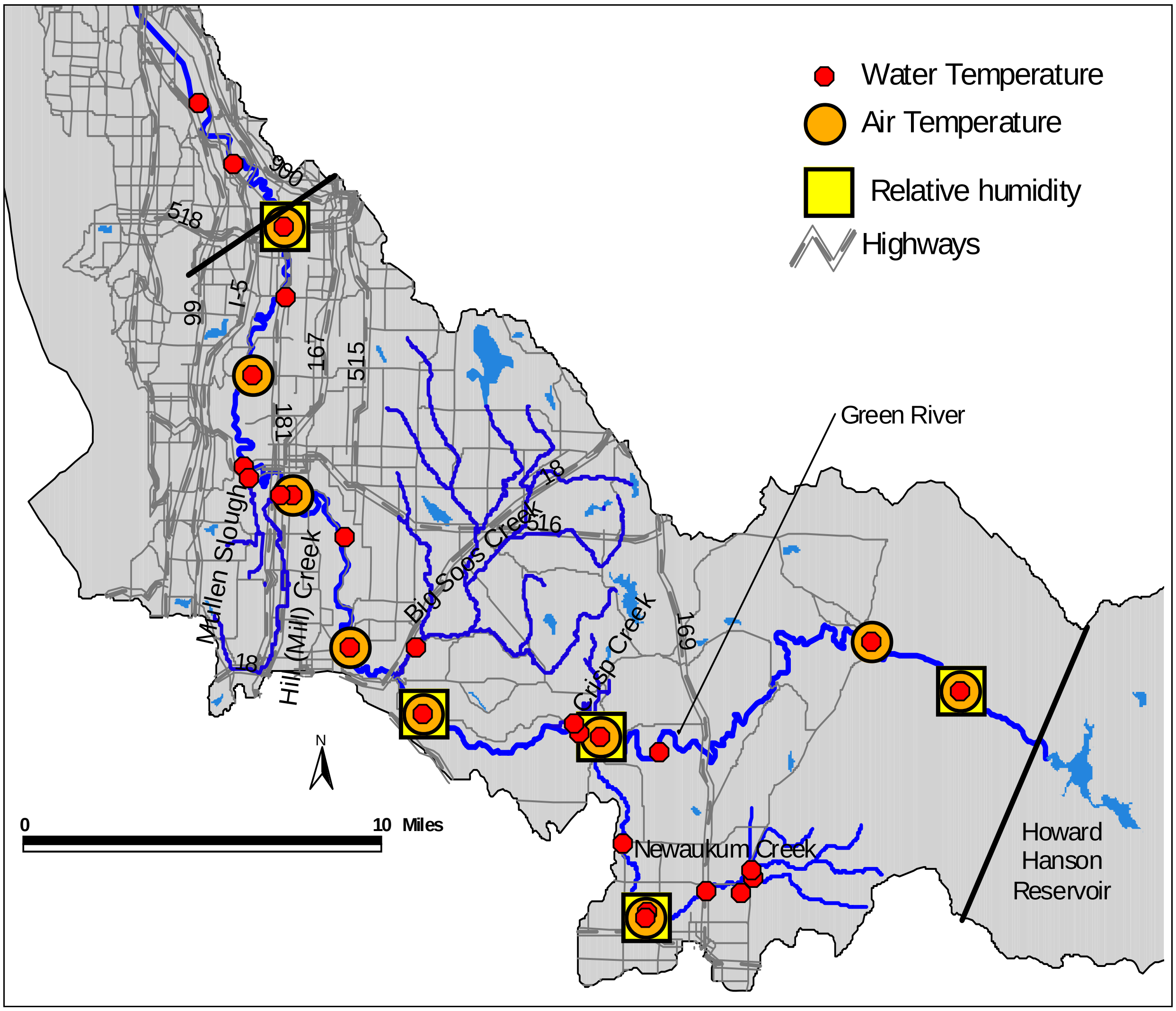


Figure 11. Monitoring locations for continuous water temperature, air temperature, and relative humidity.

Continuous dissolved oxygen data will provide minimum and maximum values for model calibration and validation. Figure 12 indicates monitoring locations where equipment will be deployed during a two-week period for three to four days at a time. Depending on equipment available, deployment may be staggered, with sites monitored in the Green River watershed during a different period than the sites in the Newaukum Creek watershed. However, all monitoring should occur during summer low-flow conditions, likely between July 15 and August 15, 2006. Equipment will record dissolved oxygen, temperature, pH, and conductivity.

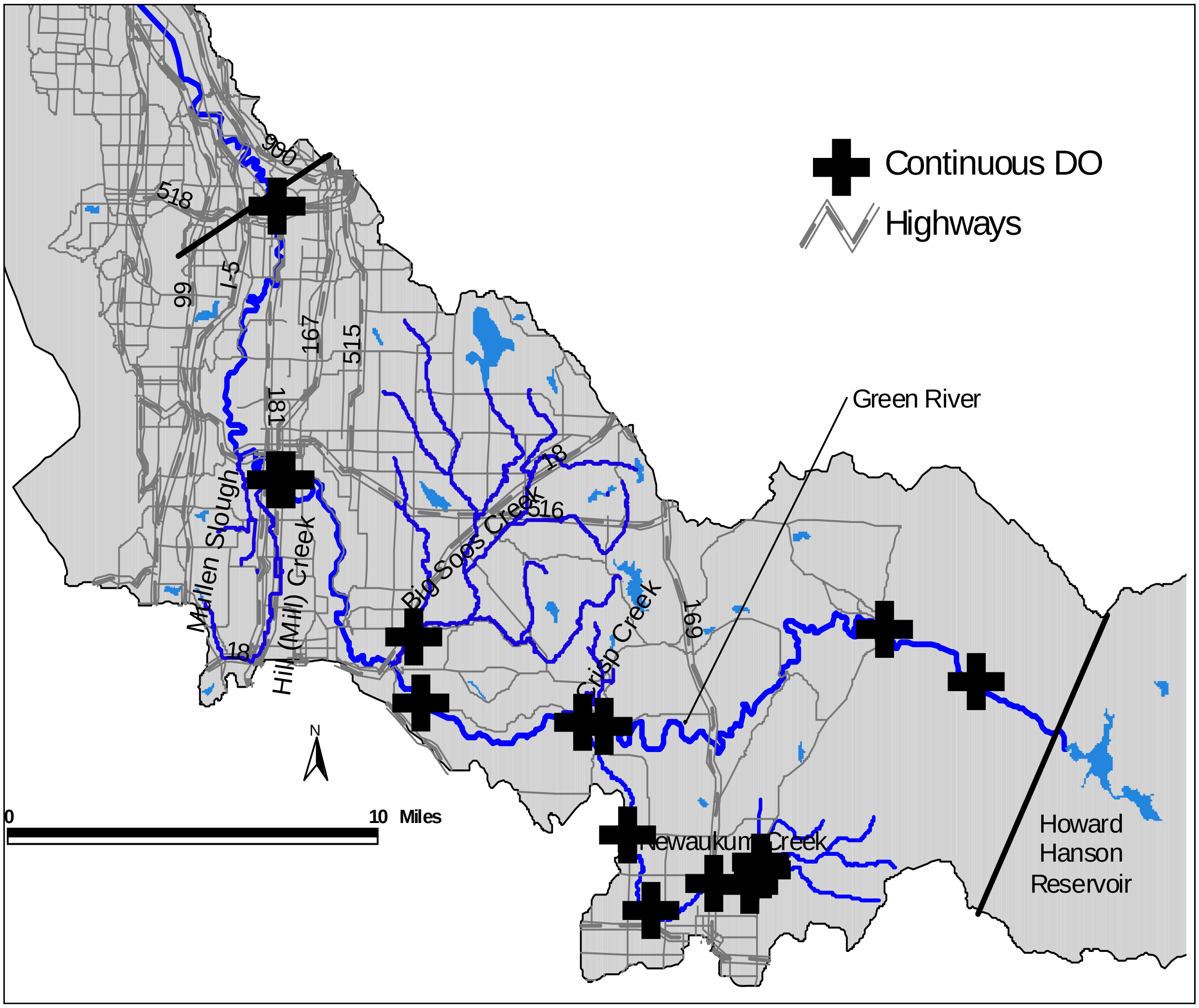


Figure 12. Monitoring locations for continuous dissolved oxygen monitoring.

Synoptic Productivity Monitoring

River temperature and dissolved oxygen generally reach critical levels during late July or early August, when discharge approaches summer low-flow conditions. A synoptic monitoring program will be conducted over a two-day period in the Green/Newaukum system to characterize water quality parameters relevant to modeling temperature and dissolved oxygen. Figure 13 presents the proposed monitoring locations.

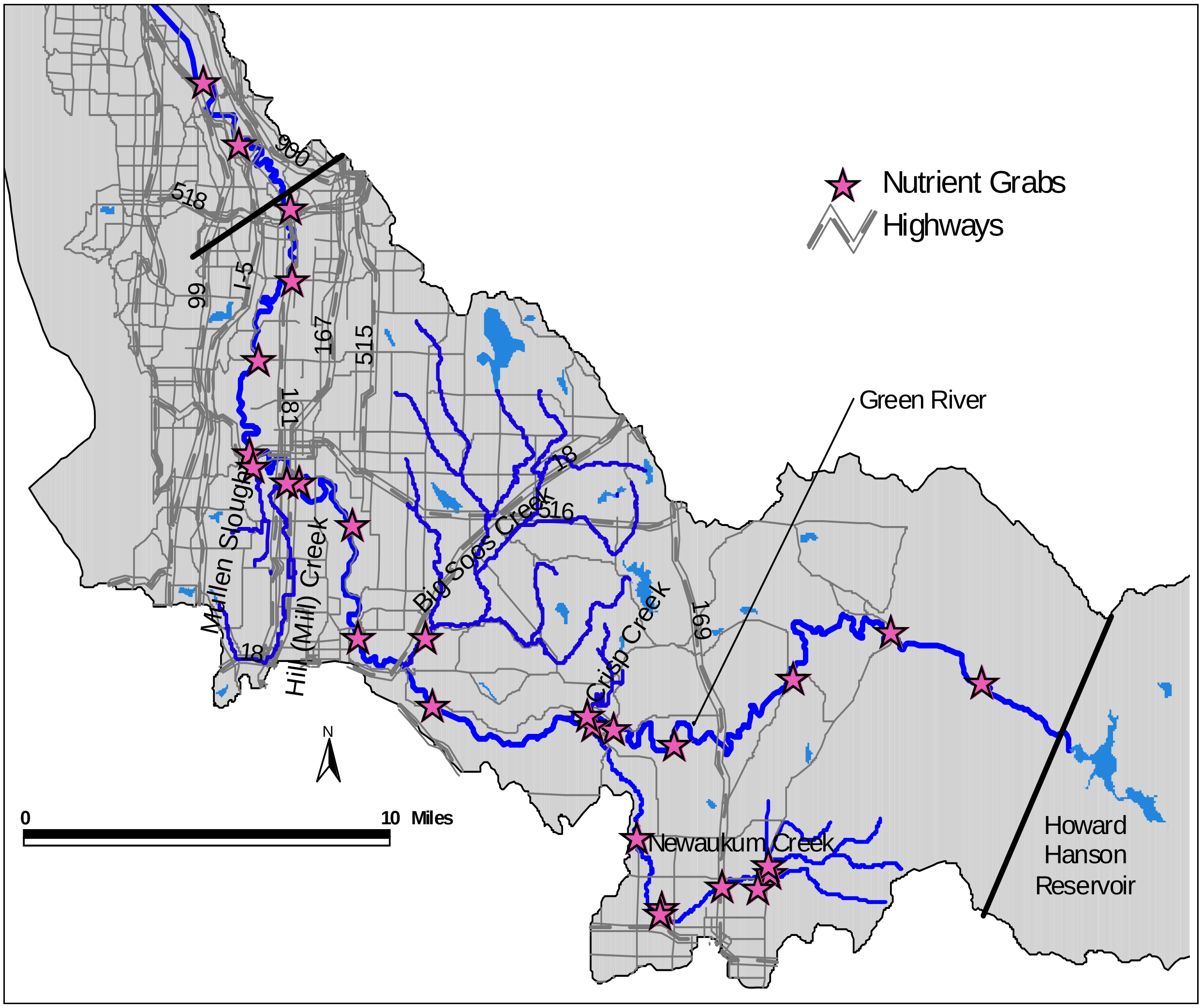


Figure 13. Synoptic monitoring locations.

Field teams will record in-situ parameters (temperature, dissolved oxygen, pH, and conductivity) and collect representative grab samples for laboratory analysis early in the morning and late in the afternoon on two consecutive days. Timing will depend on summer 2006 hydrologic conditions, but monitoring will be conducted near baseflow and outside periods influenced by storm events or unusual events at the Howard Hanson Dam. Grab samples will be analyzed for total nitrogen, nitrate plus nitrite, ammonium, total phosphorus, soluble reactive phosphorus, total organic carbon, dissolved organic carbon, alkalinity[1], and chlorophyll a. Samples will be delivered to the laboratory once per day.

Field teams will characterize periphyton density at a subset of sites located on the mainstem of the Green River and Newaukum Creek. Periphyton biomass will be estimated at sites within both the Green River and Newaukum Creek watersheds. Figure 14 presents the locations. Methods are described in *Sampling Procedures and In-situ Measurement Procedures.*

[1] For pH simulation

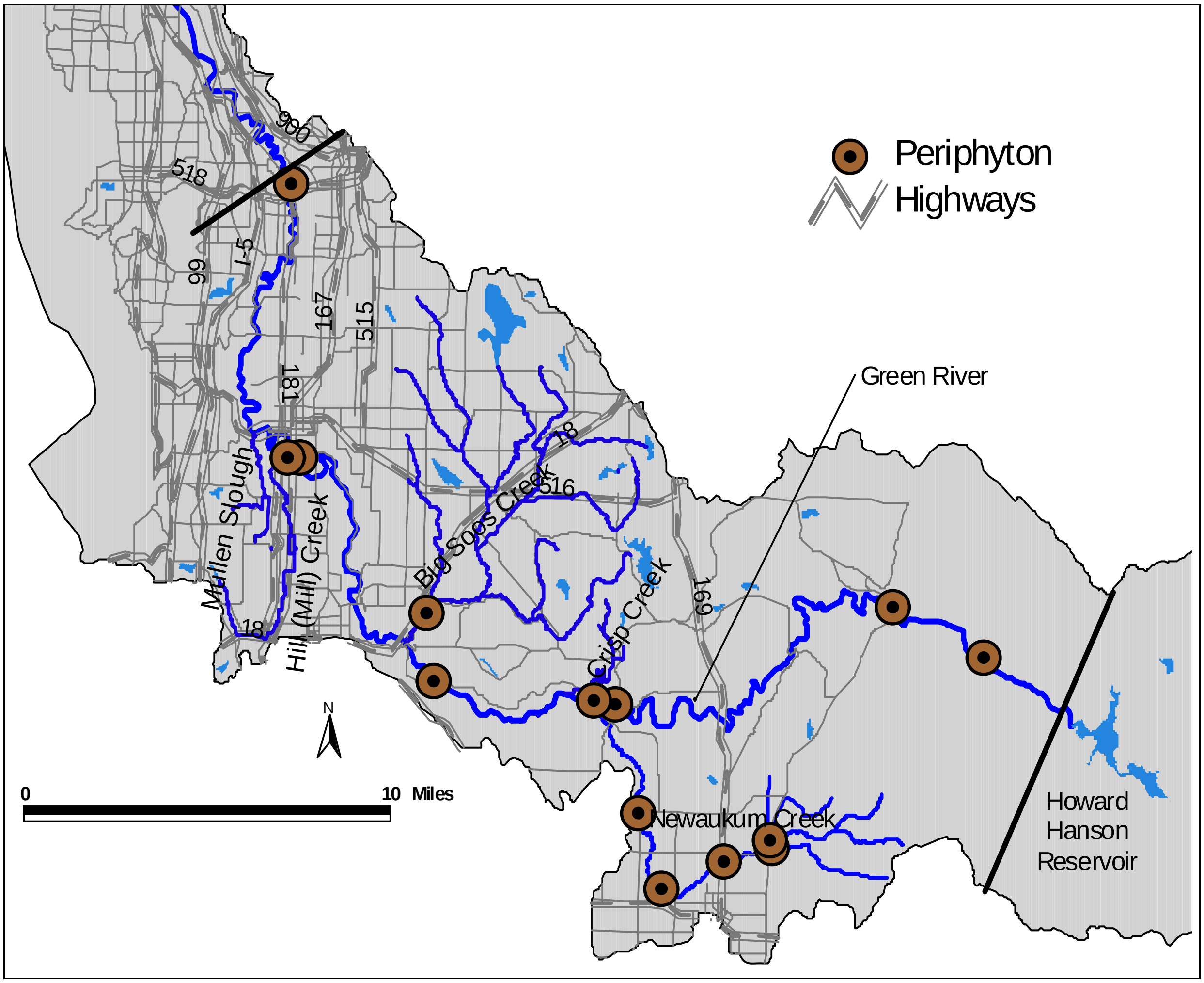


Figure 14. Periphyton monitoring locations.

Synoptic Flow

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

The flow distribution will be established during synoptic flow studies conducted during summer low-flow conditions. The fine-scale data at several sites will complement the long-term monitoring data at King County flow monitoring locations[2]. Figure 15 presents the monitoring locations where discharge will be recorded. If the number of field teams is limited, the survey can extend over two days; however, surveys must occur when baseflow conditions are present. Replicate flows will be measured to verify the comparability of field measurements at three sites,

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

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

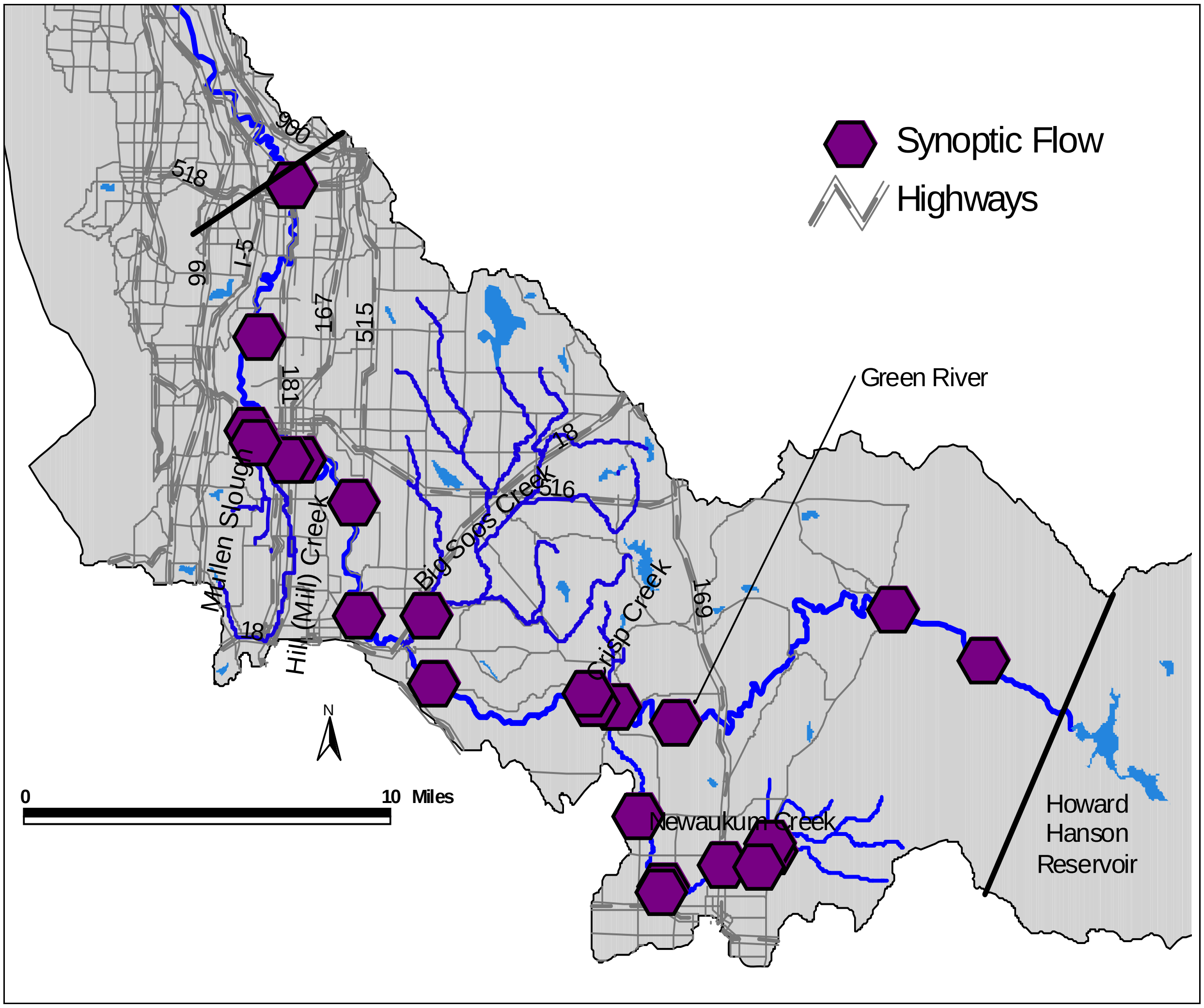


Figure 15. Synoptic flow monitoring locations.

Table 8 summarizes U.S. Army Corps of Engineers travel time estimates when the dam releases 400 cfs. This information will be used to compare with model results, and no dye study is proposed for the Green River.

Table 8. Approximate travel time characteristics.

From	To	Travel Time (hr)
Howard Hanson Dam	Auburn	12
Auburn	Tukwila	24

Riparian Shade Development

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

Riparian vegetation characteristics will be developed from imagery and field observations. Riparian vegetation patterns within 150 meters of the stream channel will be digitized from orthophotos. Vegetation classes, consisting of height and density, will be assigned based on orthophotos and field observations, possibly using the methods described in Roberts (2003). Hemispherical photography will be used to measure shade in situ at monitoring locations shown in Figure 16.

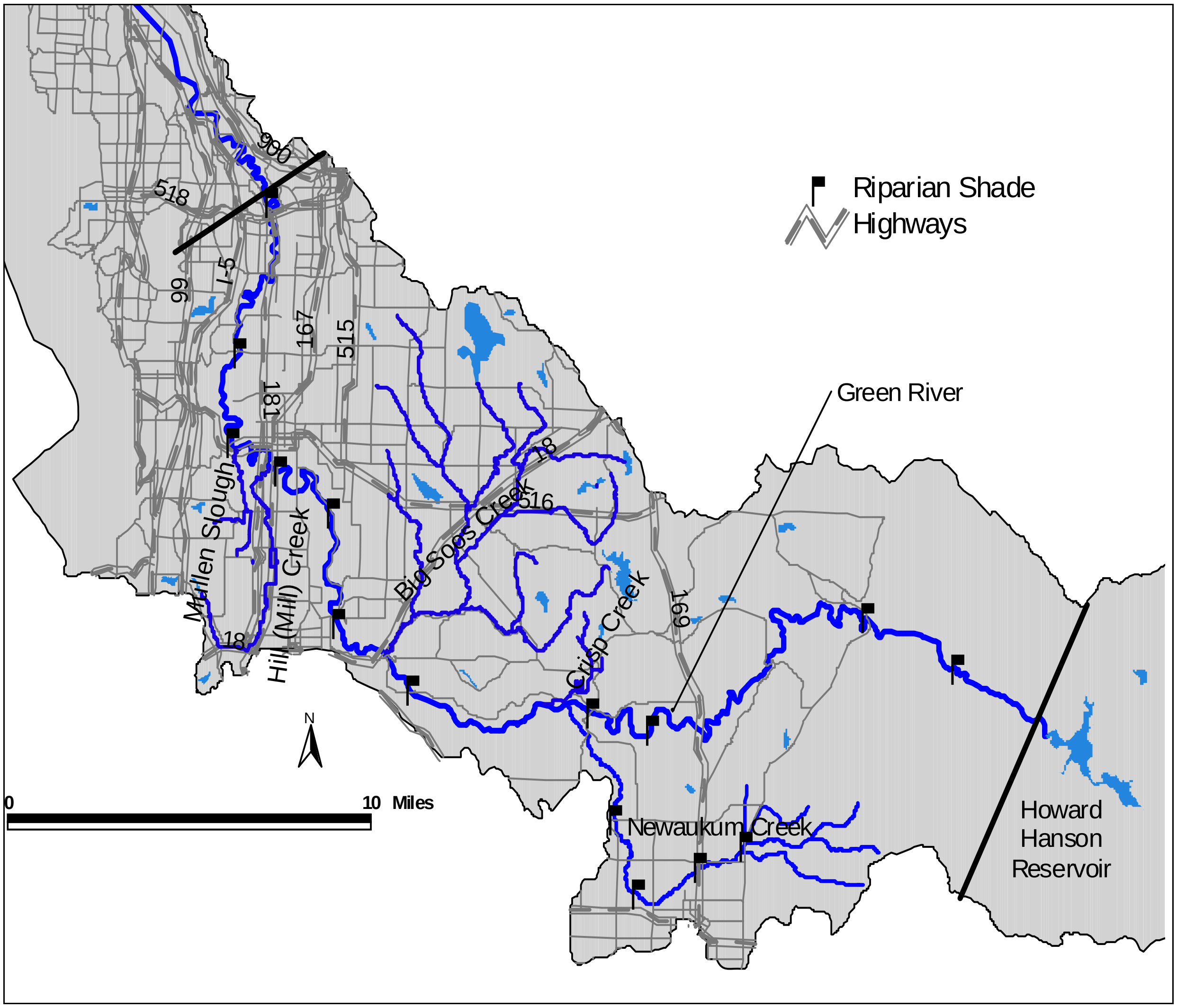


Figure 16. Locations for in-situ riparian shade measurements using hemispherical photography.

Quality Control

Measurement Quality Objectives

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

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

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

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

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

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

Sampling Procedures and In-situ Measurement Procedures

Discharge and Water Quality Monitoring

Field procedures will follow standard operating procedures (King County Environmental Lab, 2002a, 2002b, 2004, 2005a-f). Collecting replicate samples will assess total variation for field sampling and laboratory analysis and thereby provide an estimate of total precision. Table 9 summarizes the field and laboratory quality control program.

Table 9. Summary of field and laboratory quality control samples.

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

In-situ Measurements

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

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

One field replicate per 10 samples should be analyzed to assess precision of the temperature, dissolved oxygen, conductivity, and pH sensors. If any of the parameters are found to be outside of control limits, the sensors must be recalibrated before further use. Upon returning to the lab, a post-run analysis of dissolved oxygen, conductivity, and pH should be completed and documented in the Hydrolab quality control (QC) notebook. If QC results are found to be outside of control limits, results may be qualified according to standards documented in King County Environmental Laboratory's Quality Assurance Manual (King County Environmental Laboratory, 2006).

Continuous Temperature and Dissolved Oxygen Monitoring

The Onset StowAway TidBits will be pre- and post-calibrated by Ecology in accordance with standard Ecology protocols (Ward et al., 2001)[3] to document instrument bias and performance at representative temperatures. A NIST-certified reference thermometer will be used for the calibration. At the completion of monitoring, the raw data will be adjusted for instrument bias, based on the pre- and post-calibration results, if the bias is greater than +0.2°C. Variation for field sampling of instream temperatures will be addressed with a field check of the data loggers with a hand-held alcohol thermometer at all sites upon deployment, download events, and at TidBit removals at the end of the study period. Field sampling and measurements will follow standard Ecology quality control protocols.

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

Once in the field, conductivity and pH check standards will be run to assess accuracy and instrument drift in the Green River. In Newaukum Creek, a second YSI will be deployed to record replicate measurements at one of the YSI extended deployment locations. Acceptance

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

limits for the YSI parameters are described in King County Environmental Laboratory (2002a) and summarized in Table 10.

Table 10. Hydrolab and YSI quality control requirements.

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

YSI		
Parameter	Post-deployment Calibration Check Acceptance Limits	Replicate Samples
Dissolved Oxygen	±10 %	RPD ≤ 20%
Temperature	Not applicable	± 0.3 C
Conductivity	± 10 %	RPD ≤ 10%
pH	± 0.3 pH units	± 0.2 pH units

YSI and Hydrolab QC sheets are intended for documentation of YSI and Hydrolab QC samples. This includes initial calibration, field calibration check standards (Hydrolab synoptic monitoring only), replicates, and post-run calibration check. The analyst will include calibration and analysis date, standard lot numbers and concentrations, instrument readings, recovery calculations, and initials.

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

Flow Measurements

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

Sample Collection

Samples are collected by one of three methods.

1. Grab sampling by hand-dipping sample bottles is one method that does not require decontamination techniques. The cap is removed from the bottle and it is simply dipped into the stream or river.

2. Using a bucket with a bottom drain or a Richards bottle requires scrubbing with a brush and reverse osmosis water at the lab, followed by thoroughly rinsing three times with ambient stream water to be sampled.
3. Samples will be collected from the thalweg, within free-flowing stream sections, and away from channel boundaries. Where access is from a bridge, the sample will be collected from the upstream side.

These procedures are described in King County Environmental Lab's SOP (2005e).

Riparian Shade

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

Periphyton Biomass

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

Laboratory Measurement Procedures

All Newaukum Creek water samples will be analyzed by the King County Environmental Laboratory using standard operating procedures (SOPs) (King County Environmental Laboratory, 2006). Table 11 lists measurement procedures by parameters. The method detection limit (MDL) is defined as that concentration at which an analyte can be detected reliably. The reporting detection limit (RDL) is defined as that concentration at which an analyte can be quantified reliably.

Table 11. King County Environmental Laboratory measurement procedures.
Units are mg/L for all but alkalinity (mg-$CaCO_3$/L) and chlorophyll a (ug/L).

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

SM - standard method
EPA - U.S. Environmental Protection Agency
HDPE - high-density polyethylene bottle
CWM - clear wide-mouth bottle
VOA - volatile organics analysis bottle
CNM - clear narrow-mouth bottle
AWM - amber wide-mouth bottle

All remaining water samples will be analyzed by Ecology's Manchester Environmental Laboratory using standard protocols (MEL, 2005). Table 12 lists measurement procedures by parameter.

Table 12. Manchester Environmental Laboratory measurement procedures.
Units are mg/L for all but alkalinity (mg-$CaCO_3$/L) and chlorophyll a (ug/L).

Analyte	Analytical Method	Estimated Range	Sample Containers	Hold Time	Field Preservation Method
Total Persulfate Nitrogen	SM4500-NB	0.025 – 0.20	125 mL HDPE CWM	28 days	Cool to 4°C; H_2SO_4 to pH<2
Nitrate+Nitrite Nitrogen	SM4500-NO3I	0.01 – 0.10	125 mL HDPE CWM	28 days	Filter and cool to 4°C; H_2SO_4 to pH<2
Ammonia-Nitrogen	SM4500-NH3H	0.01 – 20	125 mL HDPE CWM	28 days	Filter and cool to 4°C; H_2SO_4 to pH<2
Total Phosphorus	EPA 200.8	0.01 – 10	125 mL HDPE CWM	28 days	Cool to 4°C; 1:1 HCl to pH<2
Orthophosphorus	SM4500-PG	0.003 – 0.5	125 mL HDPE CWM	2 days	Filter and cool to 4°C
Total Organic Carbon	EPA/415.1/ SM5310-B	1 – 20	60 mL CNM	28 days	Cool to 4°C; HCl to pH<2
Dissolved Organic Carbon	EPA/415.1/ SM5310-B	1 – 20	125 mL amber HDPE CNM	28 days	Filter and cool to 4°C; HCl to pH<2
Alkalinity	EPA310.2/ SM2320-B	5 – >100	500 mL HDPE CWM	14 days	Cool to 4°C
Chlorophyll a	SM10300H3M	<1 – 100	1 L HDPE AWM	1 day	Filter, freeze filters in 90% acetone

SM - standard method
EPA - U.S. Environmental Protection Agency
HDPE - high-density polyethylene bottle
CNM - clear narrow-mouth bottle
CWM - clear wide-mouth bottle
VOA - volatile organics analysis bottle
CNM - clear narrow-mouth bottle
AWM - amber wide-mouth bottle

Because laboratory protocols vary slightly between the two laboratories, field personnel will collect split samples at the mouth of Newaukum Creek, and samples will be analyzed for the full suite of parameters at both laboratories.

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

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

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

At the analytical laboratory, the sample manager should oversee:

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

King County Environmental Services staff will maintain custody of all Newaukum Creek samples until delivery to the laboratory. Samples will be delivered on the same day as they are collected and the sample tracking logs will document the date and time of arrival of all samples. Table 13 summarizes quality control requirements.

Table 13. King County Environmental Laboratory quality control requirements.

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

MDL – method detection limit

Manchester Environmental Laboratory will follow standard protocols for sample handling.

Data Verification and Validation

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

Ecology Environmental Assessment Program staff will verify and validate field and laboratory data before entering into Ecology's Environmental Information Management (EIM) database. Ecology's verification/validation will occur after data have been received from the King County Environmental Laboratory and Ecology's Manchester Environmental Laboratory.

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

Once data review is complete and all data quality issues have been resolved or corrected, the status of the data in Ecology's Laboratory Information Management System (LIMS) will be changed to "approved". Once a data set has been approved, it is "posted" or transferred to the portion of the LIMS database known as the Environmental Data System (EDS) where all historical LIMS data are maintained. Signatures or initials of the lab lead and reviewer(s) indicate formal approval of hardcopy data or reports (non-LIMS), typically on the review checklist. A copy of this approved checklist should be stored with the final hardcopy data package.

Table 14 presents laboratory data qualifiers for King County Environmental Laboratory and Manchester Environmental Laboratory. When data are entered into Ecology's EIM system, the standard EIM qualifiers, which differ from those used by King County, will be used.

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

Table 14. King County Environmental Laboratory and Manchester Environmental Laboratory data qualifiers.

Qualifier	Description
King County Environmental Laboratory	
General	
H	Indicates that a sample handling criterion was not met in some manner prior to analysis. The sample may have been compromised during the sampling procedure or may not comply with holding times, storage conditions, or preservation requirements. The qualifier will be applied to applicable analyses for a sample.
R	Indicates that the data are judged unusable by the data reviewer. The qualifier is applied based on the professional judgment of the data reviewer rather than any specific set of QC parameters and is applied when the reviewer feels that the data may not or will not provide any useful information to the data user. This qualifier may or may not be analyte-specific.
<MDL	Applied when a target analyte is not detected or detected at a concentration less than the associated method detection limit (MDL). MDL is defined as the lowest concentration at which an analyte can be detected. The MDL is the lowest concentration at which a sample result will be reported.
<RDL	Applied when a target analyte is detected at a concentration greater than or equal to the associated MDL but less than the associated reporting detection limit (RDL). RDL is defined as the lowest concentration at which an analyte can reliably be quantified. The RDL represents the minimum concentration at which method performance becomes quantitative and is not subject to the degree of variation observed at concentrations between the MDL and RDL.
RDL	Applied when a target analyte is detected at a concentration that, in the raw data, is equal to the RDL.
TA	Applied to a sample result when additional narrative information is available in the text field. The additional information may help to qualify the sample result but is not necessarily covered by any of the standard qualifiers.
Chemistry	
B	Applied to a sample result when an analyte was detected at a concentration greater than the MDL in the associated batch method blank. The qualifier is applied in organics analyses when the sample analyte concentration is less than five times the blank concentration and is applied in conventionals and metals analysis when the sample concentration is less than ten times the blank concentration. The qualifier indicates that the analyte concentration in the sample may include laboratory contamination. This is an analyte-specific qualifier.
J#	Applied to tentatively identified compounds (TICs) reported for organics analysis. A TIC is a non-target analyte that appears on a chromatogram during sample analysis. The analyst compares the analyte peak to a reference library to obtain the best possible match. The number associated with the J qualifier is the confidence level of the analyte library match. The confidence level varies from 1 (highest confidence) to 4 (lowest confidence). The reported concentration is an estimated value.
P	Applied to indicate the presence of the reported analyte above the regulatory reporting limit for the test method.
>MR	Applied when a target analyte concentration exceeds the instrument or method capacity to measure accurately. The qualifier is primarily in the organics section. It is applied when the detected analyte concentration exceeds the upper instrument calibration limit and further dilution is not feasible. The reported value is an estimated analyte concentration.
Manchester Environmental Laboratory	
E	Reported result is an estimate because it exceeds the calibration range.
G	Value is likely greater than result reported; result is an estimated minimum value.
J	The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
N	The analysis indicates the presence of an analyte for which there is presumptive evidence to make a “tentative identification.”
NJ	The analysis indicates the presence of an analyte that has been “tentatively identified” and the associated numerical value represents its approximate concentration.
NAF	Not analyzed for.
NC	Not calculated.
R	The sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet quality control criteria. The presence or absence of the analyte cannot be verified.
U	The analyte was not detected at or above the reported sample quantitation limit.
UJ	The analyte was not detected at or above the reported sample quantitation limit. However, the reported quantitation limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately measure the analyte in the sample.

Corrective Action Procedures

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

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

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

Logbooks

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

Data Packages

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

Storage of Lab Data

Procedures for the storage and disposal of hardcopy lab data are summarized in King County Environmental Lab's SOP # 11-01-005-000 (Records Storage) which is based on King County and Washington State governmental records storage requirements. It is the policy of the lab to store all data packages, supporting documentation, and project records for a minimum of 10 years, based on the date of sample collection or field data measurement. The subcontract lab is responsible for its own records storage which should be at least 10 years.

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

Data Management Procedures

Two phases of data management will occur. King County Environmental Laboratory and Manchester Environmental Laboratory follow standard data management protocols and will submit the data to Ecology Environmental Assessment Program staff. Ecology will complete data management as described below.

King County Environmental Laboratory

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

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

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

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

Sample result data received from King County Environmental Laboratory will be exported prior to entry into EIM and added to a cumulative spreadsheet for laboratory results. This spreadsheet will be used to informally review and analyze data during the course of the project. Manchester Laboratory data will be transmitted directly through LIMS.

An EIM user study (MROB003) has been created for this TMDL study, and all monitoring data will be available via the internet once the project data have been validated. The URL address for this geospatial database is: apps.ecy.wa.gov/eimreporting. All data will be uploaded to EIM by the EIM data engineer once the data have been reviewed for quality assurance and finalized.

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

Laboratory Budget

King County Environmental Laboratory will analyze all samples collected from Newaukum Creek, while Ecology's Manchester Environmental Laboratory will analyze all samples from the Green River and its tributaries. Table 15 summarizes the total number of samples, approximate costs for King County, and costs for Manchester.

Table 15. Summary of laboratory analyses performed by King County Environmental Laboratory and Manchester Environmental Laboratory.

	KCEL	MEL
Number of samples		
Number of stations	8	20
Number of days	2	2
Number of samples per day	2	2
Total	**32**	**80**
Cost per sample		
Total nitrogen	16	16
NO23N, NH4N, OP	38	38
TP	25	25
TOC	32	32
DOC	30	30
Chlorophyll a	48	48
Alkalinity	0	16
Total	**$189**	**$205**
Total Analytical Costs	**$6,048**	**$18,040**

NO23N Nitrate+nitrite nitrogen
NH4N Ammonia nitrogen
OP Orthophosphate
TP Total phosphorus
TOC Total organic carbon
DOC Dissolved organic carbon
BOD5 5-day biological oxygen demand

*Costs include 50% discount for Manchester Laboratory.

Data Analysis and Use

Model Descriptions

Three models will be used to evaluate the loading capacity and to determine the wasteload and load allocations necessary to meet the water quality standards. These are described below and will be applied to the waterbodies and parameters listed in Table 16.

Table 16. Analyses and models used by waterbody and parameter.

Waterbody	Parameter	Model	Reference
Green River	Temperature	TTools, Shade, QUAL2K	Ecology (2003a and 2003b)
Newaukum Creek			
Green River	Nutrients, DO, pH	QUAL2K	Ecology (2003b)
Newaukum Creek			

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

TTools

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

Shade Model

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

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

All data will be assembled from field surveys. Table 17 summarizes specific data requirements.

Table 17. Temperature model data requirements and field data collection parameters.

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

QUAL2K

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

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

The QUAL2Kw framework includes the following new elements:

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

Temperature Approach

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

- Oregon Department of Environmental Quality's TTools extension for ArcView (ODEQ, 2001) will be used to sample and process GIS data for input to the Shade and QUAL2Kw models.
- Ecology's Shade model (Ecology, 2003a) will be used to estimate effective shade along the Green River and Newaukum Creek. Effective shade will be calculated at 100-meter (328-ft) intervals along the streams and then averaged over 500-meter (1,628-ft) intervals for input to the QUAL2Kw model.
- The QUAL2Kw model (Chapra, 2001; Ecology, 2003b) will be used to calculate the components of the heat budget and simulate water temperatures. QUAL2Kw simulates diurnal variations in stream temperature for a steady flow condition. QUAL2Kw will be applied by assuming that flow remains constant for a given condition such as a seven-day or one-day period, but key variables are allowed to vary with time over the course of a day. For temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions. QUAL2Kw uses the kinetic formulations for the components of the surface water heat budget described in Chapra (1997). Diurnally varying water temperatures at 500-meter (1,640 ft) intervals along the streams in the basin will be simulated using a finite difference numerical method. The water temperature model will be calibrated to instream data along the creeks. Groundwater contributions will be quantified from the synoptic flow study in consultation with previous hydrologic flow modeling conducted by King County using HSPF.

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

Dissolved Oxygen, Nutrients, and pH Approach

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

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

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

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Appendix A. Glossary of Terms

DO	Dissolved oxygen
DOC	Dissolved organic carbon
Ecology	Washington State Department of Ecology
EDS	Environmental Data System
EIM	Environmental Information Management
EPA	U.S. Environmental Protection Agency
GIS	Geographic Information System
HDPE	High-density polyethylene bottle
LiDAR	Light Detection and Ranging
LIMS	Laboratory Information Management System
MDL	Method detection limit
MQOs	Measurement quality objectives
QC	Quality control
RDL	Reporting detection limit
RM	River mile
RPD	Relative percent difference
RSD	Relative standard deviation
SOP	Standard operating procedure
TMDL	Total maximum daily load
TOC	Total organic carbon
WBID	Waterbody Identification
WRIA	Water Resource Inventory Number

Appendix B. King County Monitoring Program Historical Data

In these figures, WDOE = Washington State Department of Ecology

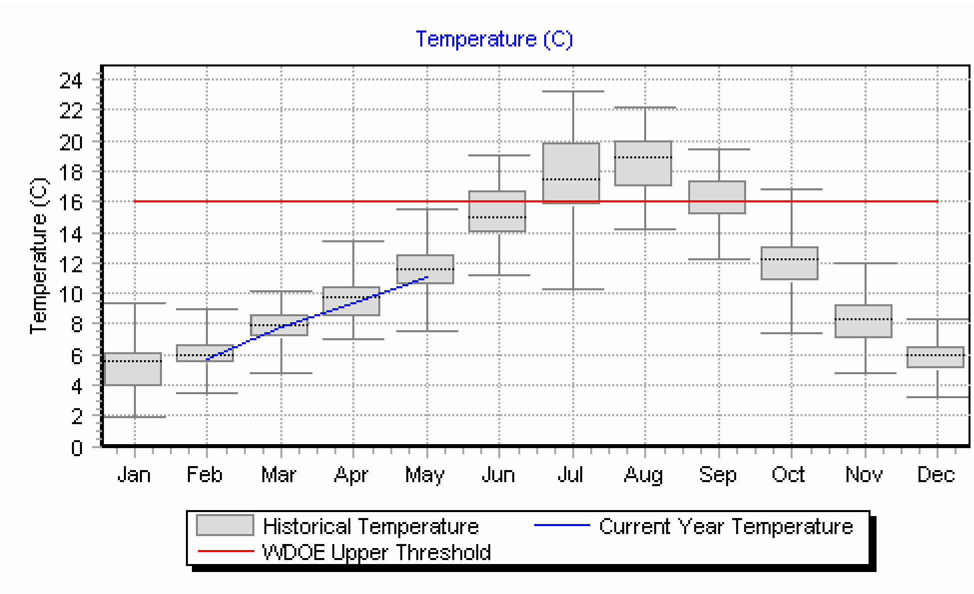

Figure B-1. Station 0309, Duwamish River, temperature record for 1970 to present.

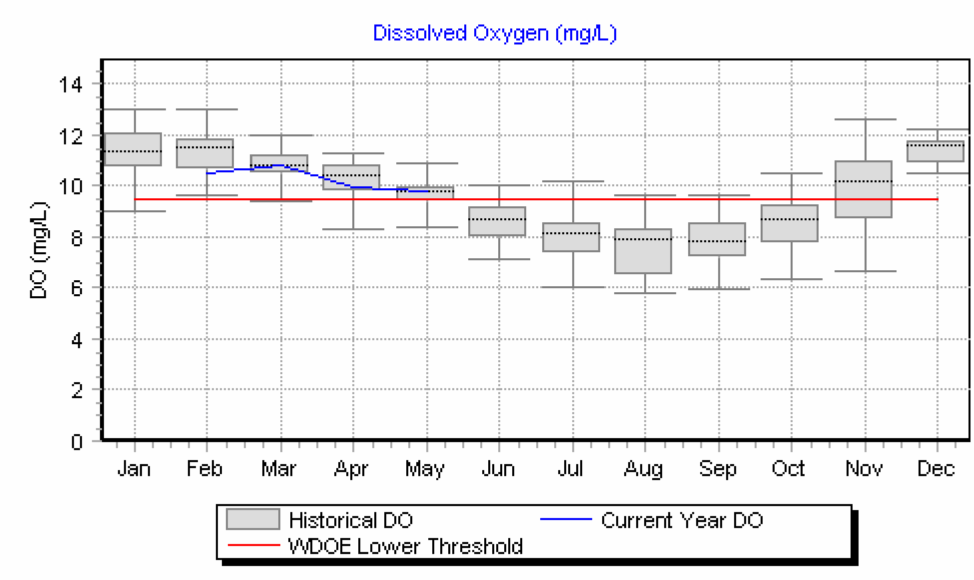

Figure B-2. Station 0309, Duwamish River, dissolved oxygen record for 1970 to present.

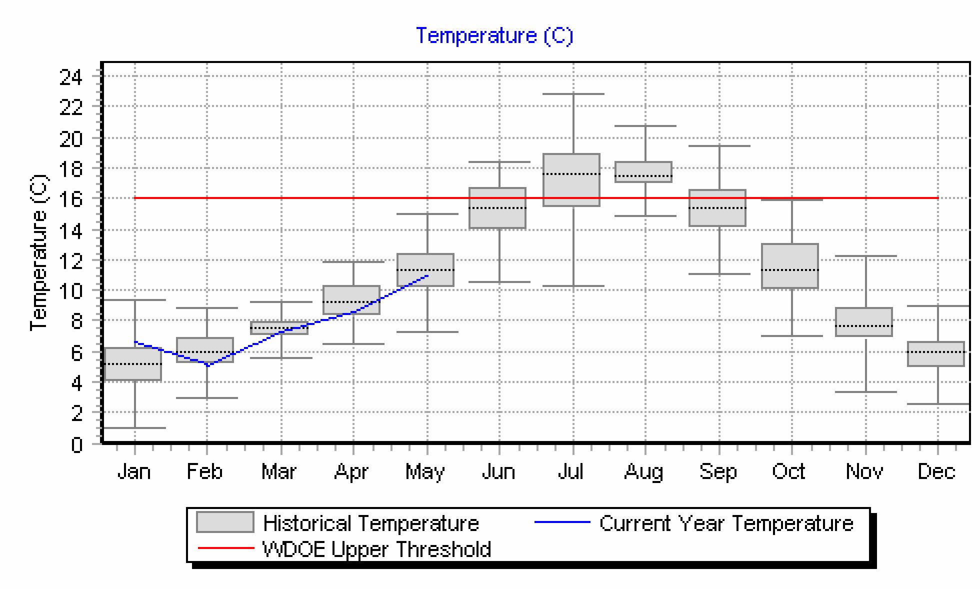

Figure B-3. Station 3106, Lower Green River, temperature record for 1970 to present.

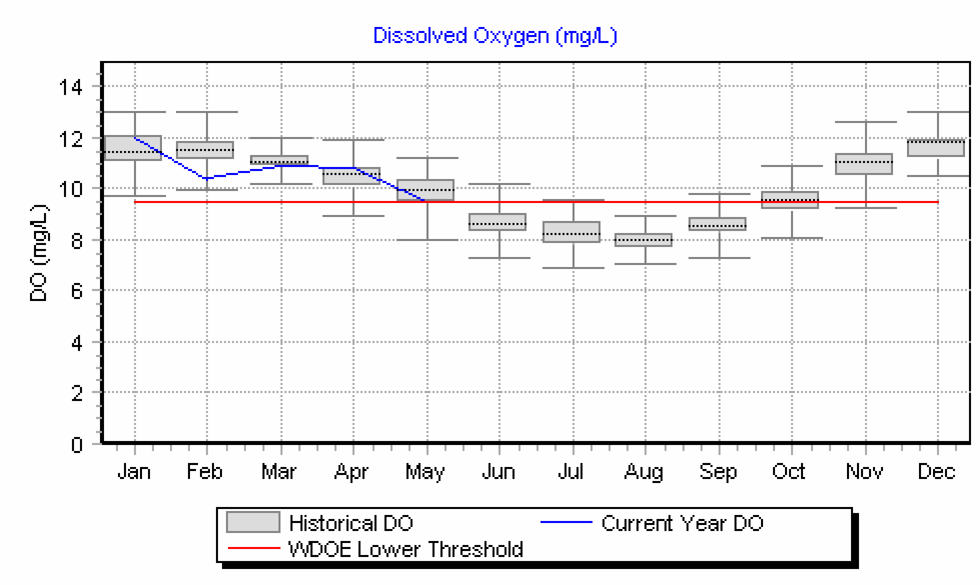

Figure B-4. Station 3106, Lower Green River, dissolved oxygen record for 1970 to present.

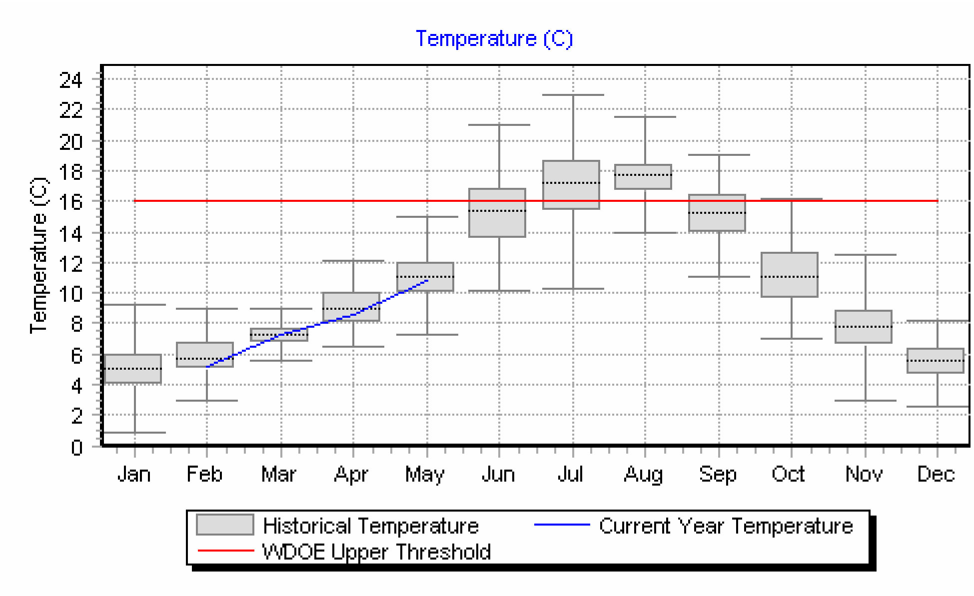

Figure B-5. Station 0311, Lower Green River, temperature record for 1970 to present.

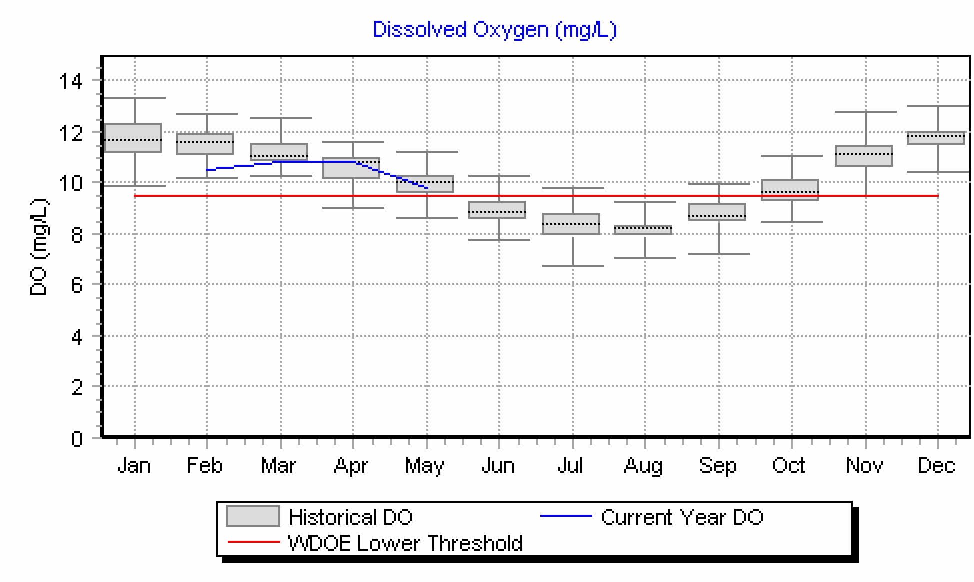

Figure B-6. Station 0311, Lower Green River, dissolved oxygen record for 1970 to present.

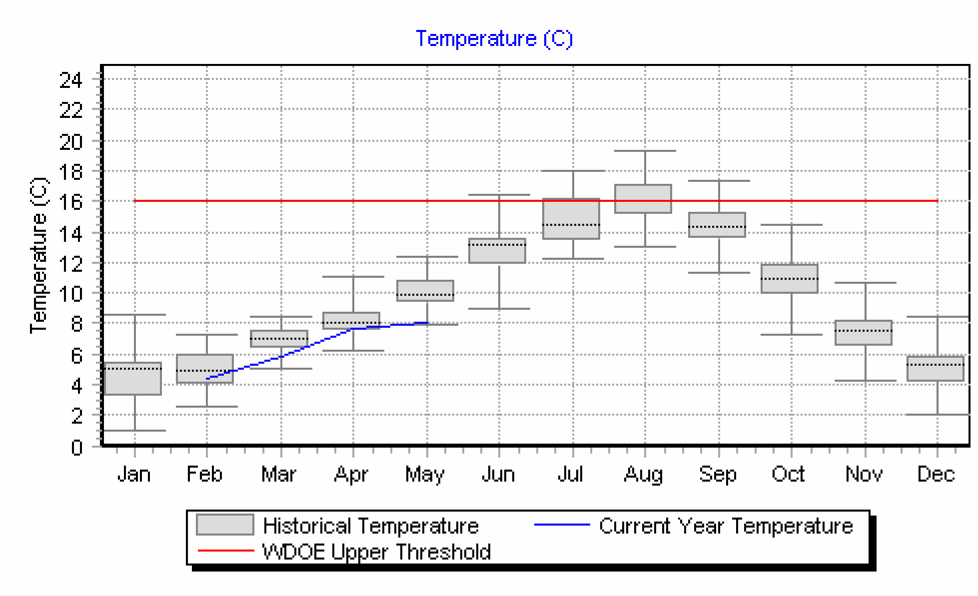

Figure B-7. Station A319, Middle Green River, temperature record for 1976 to present.

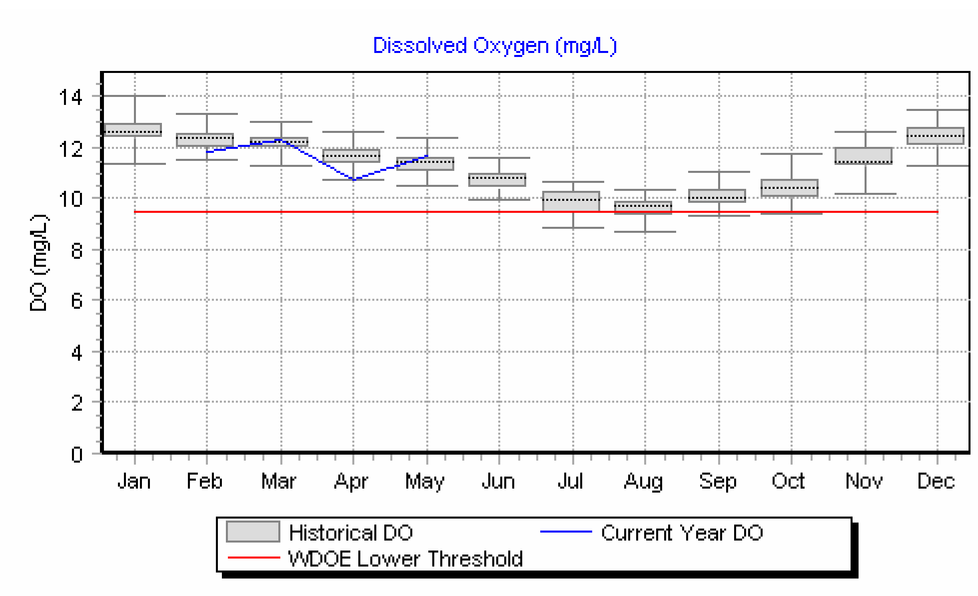

Figure B-8. Station A319, Middle Green River, dissolved oxygen record for 1976 to present.

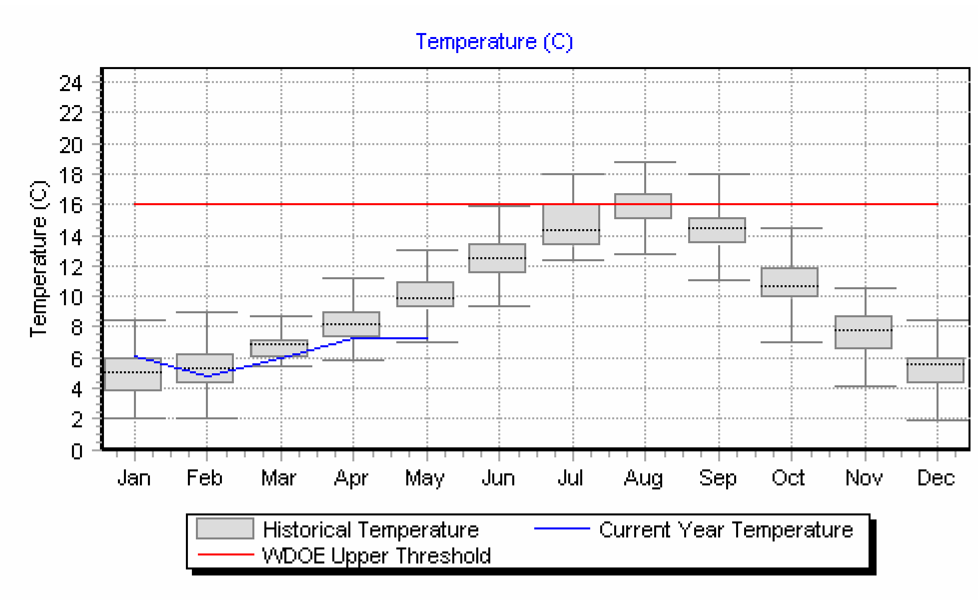

Figure B-9. Station B319, Middle Green River, temperature record for 1972 to present.

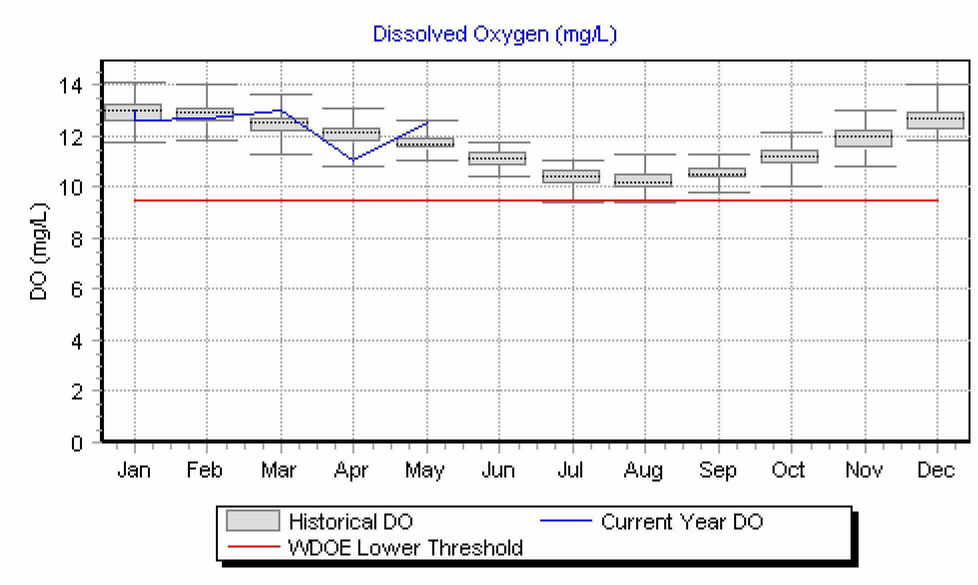

Figure B-10. Station B319, Middle Green River, dissolved oxygen record for 1972 to present.

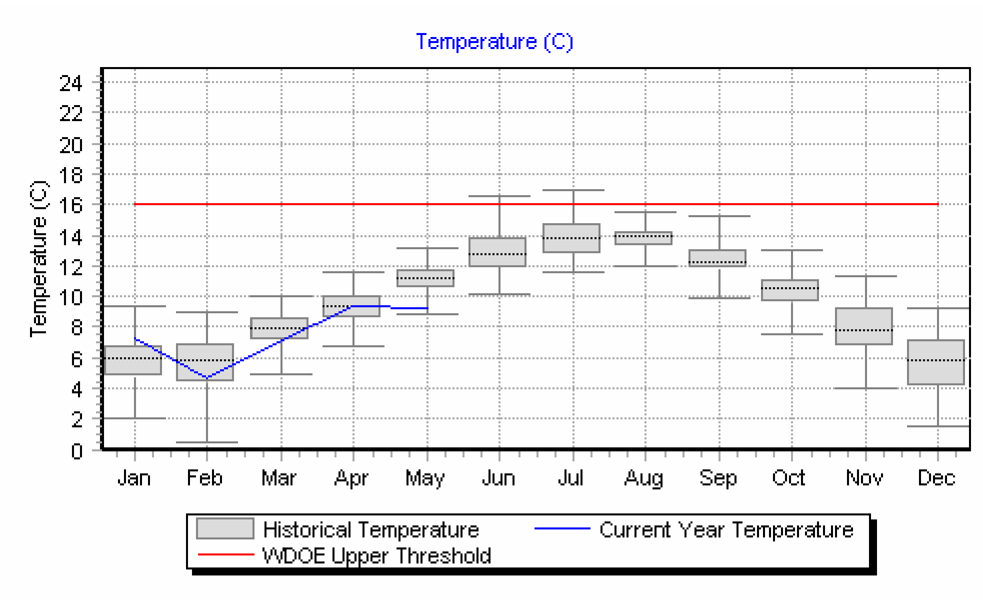

Figure B-11. Station 0322, Newaukum Creek, temperature record for 1972 to present.

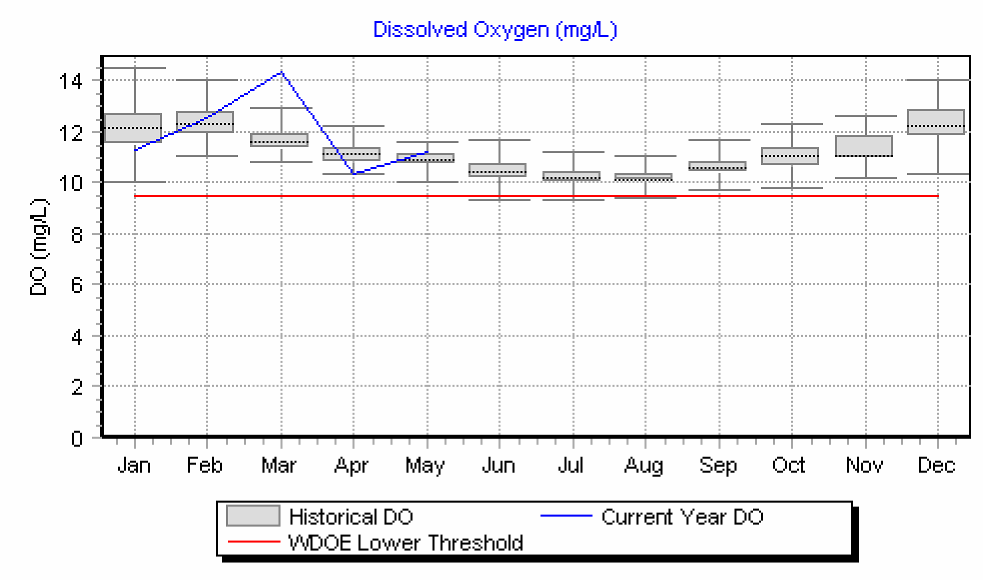

Figure B-12. Station 0322, Newaukum Creek, dissolved oxygen record for 1972 to present

Appendix C. Descriptions of Monitoring Locations

Location	Temperature	DO/pH	Nutrients
Green River			
Green River at Tacoma at Small dam	x	x	x
Kanasket	x	x	x
Mobile home park			x
Downstream of Christy Crk (Flaming Geyser Park)	x		x
212th Way SE/218th	x	x	x
Green Valley Rd	x	x	x
Gaging Sta/Lea Hill 8th Avenue	x		x
277th St	x		x
Upstream of Mill Crk (Highway 167)	x	x	x
W Meeker or gaging sta	x		x
S 212th St	x		x
SE 180th St	x		x
Interurban Avenue @ Fort Dent	x	x	x
Tukwila Community Center	x		x
Downstream of 102nd Street (Boeing)	x		x
Green River Tributaries			
Newaukum @ mouth	x	x	x
Crisp Crk at Green Valley Road	x		x
Soos @ gage	x	x	x
Mill Crk nr mouth	x	x	x
Mullen Slough nr mouth	x		x
Newaukum Creek (King County stations)			
Newaukum creek near the mouth off of 358th SE	x	x	x
Newaukum creek at SE 400 St bridge	x	x	x
Trib upstream of confluence with Newaukum at 236th St SE	x	x	x
Newaukum Creek just upstream of confluence with trib at 236th St SE	x	x	x
Newaukum Creek at bridge on SE 424th ST	x	x	x
Newaukum Creek off 416th ST, down pipeline trail	x	x	x
Newaukum Creek at Veazie Cumberland Rd crossing	x	x	x
Newaukum trib off Veazie Cumberland Rd, ditch north of TPU trail	x	x	x