Lower White River
pH
Total Maximum Daily Load

Water Quality Study Design
(Quality Assurance Project Plan)

June 2012

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DEPARTMENT OF
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Publication and Contact Information

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

The plan for this study is available on the Department of Ecology's website at www.ecy.wa.gov/biblio/1203104.html.

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Study Codes

Data for this project are available at Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search User Study ID is GPEL0010.

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Federal Clean Water Act 2008 303(d) Listings Addressed in this Study

Water body: White River	
Parameter	Listing ID
pH	7524, 7525, 7526

Water body Number: WA-10-1030.

Cover photo: Lower White River substrate at river mile 25.

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MIT: Muckleshoot Indian Tribe
EAP: Environmental Assessment Program, Washington State Department of Ecology
EIM: Environmental Information Management database.

Table of Contents

List of Figures

List of Tables

Page

Abstract

Located in Pierce and King Counties of southwest Washington State, the White River originates from several glaciers of Mount Rainier and flows 68 miles to its confluence with the Puyallup River near the cities of Puyallup and Auburn. The Lower White River generally refers to the 28-mile stretch of river from the mouth to below Mud Mountain Reservoir.

Several areas of the Lower White River are on Washington State′s list of polluted waters (303(d) list) for pH and require a cleanup plan, or total maximum daily load (TMDL). Past studies have documented exceedances of the upper pH criteria (8.5) and suggest these conditions are the result of nutrient inputs to the river, which can cause excessive algal growth on the river bottom. Increased algal growth can increase the river’s pH levels, indirectly, through increased algal uptake of carbon dioxide in the water.

To develop a TMDL for the river, the Washington State Department of Ecology (Ecology) will conduct a series of water quality surveys between July and December of 2012. Ecology will use the data to develop and calibrate a numerical water quality model of the river to simulate continuous pH and other water quality parameters.

Ecology, the U.S. Environmental Protection Agency, and the Muckleshoot Indian Tribe will then use the model to determine the maximum level of nutrient inputs that will still allow the river to meet water quality criteria for pH.

This Quality Assurance Project Plan describes the methods, data quality procedures, study design, water quality modeling approach, and other details for the study.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act requirements

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

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

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

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

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

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

Category 2 – Waters of concern.

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

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

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

Further information is available at Ecology's Water Quality Assessment website.

The Clean Water Act requires that a Total Maximum Daily Load (TMDL) be developed for each of the water bodies on the 303(d) list. A TMDL is numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

TMDL process overview

Ecology uses the 303(d) list to prioritize and initiate TMDL studies across the state. The TMDL study identifies pollution problems in the watershed, and specifies how much pollution needs to be reduced or eliminated to achieve clean water.

Because the White River is both a state and tribal resource, Ecology, the Muckleshoot Indian Tribe, and EPA are working together to develop the TMDL. In October 2001, the three parties signed an agreement to jointly develop a pH TMDL for the White River (MIT et al., 2001).

The involved parties are working together to examine pH problems in the river and assess the level of pollutants that sources can discharge without violating pH criteria in the river. They will also work with local communities to develop an overall approach to control the pollution, called the Detailed Implementation Plan, and a monitoring plan to assess the success of the water quality improvement activities. The implementation plan identifies specific tasks, responsible parties, and timelines for achieving clean water. Together, the study and implementation strategy comprise the *Water Quality Improvement Report* (WQIR).

Once the U.S. Environmental Protection Agency (EPA) approves the WQIR, a *Water Quality Implementation Plan* (WQIP) is developed within one year. The WQIP identifies specific tasks, responsible parties, and timelines for reducing or eliminating pollution sources and achieving clean water.

Who should participate in this TMDL?

Nonpoint source pollutant load targets will likely be set in this TMDL. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices to reduce impacts to water quality. Similarly, all point source dischargers in the watershed must also comply with the TMDL.

Elements the Clean Water Act requires in a TMDL

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

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

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

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

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

Why is Ecology Conducting a TMDL Study in This Watershed?

Background

Multiple organizations have documented violations of the 8.5 pH standard in the Lower White River (LWR) from July 1971 to July 2010. These violations have occurred intermittently in all months except February at monitoring points from river miles (RM) 4.9 to 19.8.

In September and October of 1990, the Washington State Department of Ecology (Ecology) measured pH levels that exceeded Washington State water quality standards (WAC 173-201A) in the LWR at river mile (RM) 4.9, 6.3, and 8.0 during a Total Maximum Daily Load (TMDL) study conducted on the Puyallup River watershed (Pelletier, 1993). Subsequent monitoring, conducted from 1996-2003, documented continued exceedances of pH standards in the LWR (Pelletier, 1993; Erickson, 1999; Ecology, 2011b; Stuart, 2002; Ebbert, 2003). Based on these pH exceedances, the White River was placed on Washington State’s 303(d) list of impaired water bodies.

In 2001 EPA, the Muckleshoot Indian Tribe (MIT), and Ecology signed a memorandum of agreement (MOA) describing the process that would be used to respond to the 303(d) pH listings. The primary purpose of the MOA was to establish a TMDL drafting committee consisting of members of each party who would draft and finalize the TMDL. Subsequently, the MOA parties developed a periphyton and pH model for the LWR, in support of a TMDL, using a 2000-2001 dataset collected for a University of Washington thesis project (Stuart, 2002).

Since the 2000-01 dataset was collected, two major changes have occurred within the LWR.

1. The flow regime has changed dramatically now that Puget Sound Energy (PSE) has sold their water rights and is no longer diverting large amounts of water to Lake Tapps for power generation.
2. The Buckley and Enumclaw wastewater treatment plants (WWTPs), the 2 major point sources within the area of concern, have upgraded their nutrient removal capabilities.

Given these significant changes within the LWR, Ecology will conduct additional monitoring (in 2012) and modeling to provide a more current basis for TMDL allocations and recommendations. While Ecology will be the primary party collecting data and developing and calibrating the model, the TMDL drafting committee will provide review and input on a routine basis throughout the process. The current modeling effort will use either an updated version of Ecology’s QUAL2KW modeling framework (Pelletier et al., 2006; Chapra et al., 2008) or the USEPA’s Water Quality Analysis and Simulation Program (WASP)(EPA, 2009) as a dynamic water quality model to simulate water quality and assign TMDL allocations. This QAPP describes the methods that will be used for data collection and analysis (modeling).

The TMDL drafting committee has previously established several technical assumptions and decisions that will apply to the current modeling effort, including, but not limited to the following list:

1. The TMDL will focus on reducing phosphorus as a limiting nutrient to periphyton growth. Previous studies have shown that nitrogen and carbon sources are abundant and diffuse within the watershed and would be more difficult to control as limiting nutrients (Erickson, 1999; Stuart, 2002).
2. Limits will be developed for total phosphorus (TP). The TMDL loads for TP will be calculated by multiplying allowable orthophosphate, also known as soluble reactive phosphorus (SRP), from the model output by the ratio of SRP:TP.
3. Future growth allocations for the White River Hatchery discharge and the Muckleshoot Indian Tribe will be included in the analysis. The future growth allocation will be calculated using the Tribe's projections of population and economic growth that may occur on the reservation in the next 5 to 20 years and will assume discharge limits similar to the waste load allocations for the Cities of Enumclaw and Buckley.
4. Future MIT stormwater loads will be based on the flow estimates described in Appendix A. Concentrations for MIT stormwater loads will be similar to concentrations assigned to Auburn stormwater loads.
5. Future loads from the White River Hatchery and the future MIT Fish Facility will be based on the flows and SRP concentrations described in Appendix A.
6. River flows for simulations used to develop the load allocations should be based on the flows described in the 'Modeling Framework' section and Appendix A.
7. Future nutrient loading for tribal waters will be assumed to enter the White River at river mile 15.5, which is the farthest upstream point of the reservation reach.

Study area

The White River drains a 494 square-mile basin with a total length of 68 miles. Mud Mountain Dam, just upstream of river mile 28, provides flood control for the river valley and can affect flows in the river downstream. The study area for this project is approximately 90 square miles and extends from RM 28 to the mouth of the river near its confluence with the Puyallup River (Figure 1).

The Muckleshoot Indian Tribe owns and governs reservation land along the LWR within the study area. The White River flows through Muckleshoot land between river miles (RM) 16 and 9. Surface waters that flow into the reservation boundaries are considered waters of the state upstream of the boundary and tribal waters downstream of the boundary. The opposite applies to waters flowing out of tribal land.

Lake Tapps will not be directly included in the water quality model. The diversion from the White River at RM 24 will be treated as a withdrawal/abstraction in the model and the tailrace of the diversion near RM 4 of the river will be treated as a tributary input in the model.

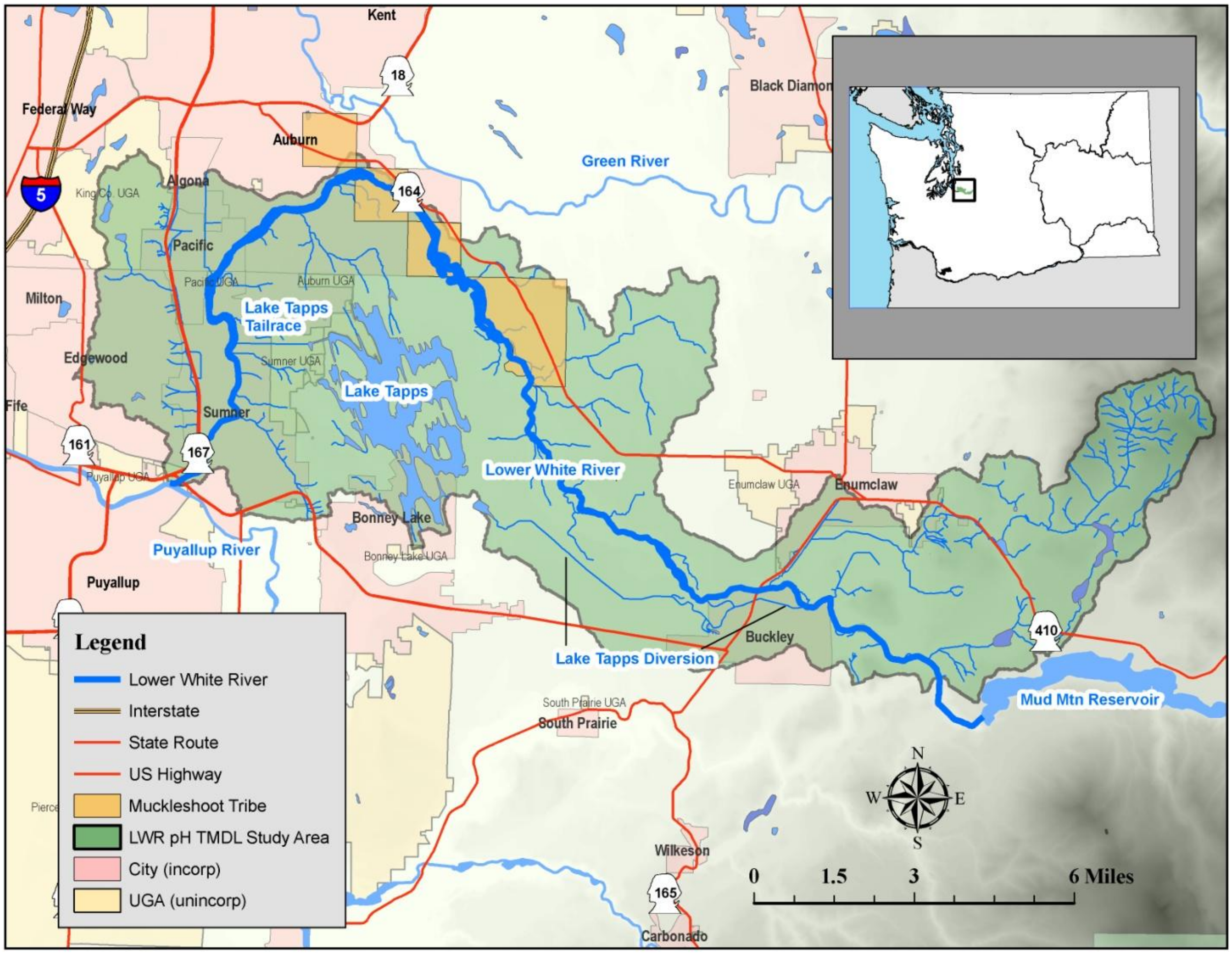

Figure 1. Study area for the Lower White River pH Total Maximum Daily Load study.

Why is pH a problem in the Lower White River?

High pH conditions in the White River likely result from point and nonpoint sources of nitrogen and phosphorus that cause excessive algal growth on the river bottom (Erickson, 1999; Stuart, 2002). When excess phosphorus or nitrogen is available, algae use it to build additional cell mass, obtaining carbon for new growth from carbon dioxide that is naturally present in river water. Because carbon dioxide affects the pH of the water, carbon uptake by algae causes the river to become less acidic and more basic. As a result, the pH of the river increases, at times to a level above the state water quality standard of 8.5.

The term *periphyton* categorizes a mixture of algal, microbial, and other organisms that attach to submerged surfaces in a water body. In the White River, periphyton are typically found attached to bottom substrates and consist primarily as a group of microscopic algae known as diatoms (Erickson, 1999; Stuart, 2002). Periphyton growth can be limited by the availability of carbon, nitrogen, phosphorus, or some combination of nutrients (known as co-limitation). Nitrogen and carbon loads from background and nonpoint sources are sufficiently high that it would be difficult to control these constituents to limit periphyton growth in the White River. Reducing phosphorus in the discharges from point and nonpoint sources would more effectively limit periphyton growth (Stuart, 2002; Welch, 1992).

Typically, the alkalinity of a river dampens the daily swings in pH. However, the volcanic nature of the Cascade Range and Mt. Rainier does not contribute significant amounts of dissolved material that might otherwise buffer changes in water quality. These naturally low levels of alkalinity make the White River sensitive to changes in river chemistry that affect pH, which can result in relatively large daily changes in pH levels (Erickson, 1999).

Glacial melt from Mt. Rainier delivers large sediment loads to the White River, which adds complexity to the nutrient problem. Periphyton requires light to grow. Suspended sediment reduces light penetration and helps limit periphyton growth. During warmer summer months, sediment is released from snow and glacial ice in the upper watershed. During autumn, winter and spring, cooler weather prevents the sediment release from glaciers. As a result, the river becomes clear and more light reaches the river bed to accelerate periphyton growth. The change in river clarity in the fall can be dramatic, along with the periphyton/pH response as shown by the data collected during 2002 by USGS (Ebbert, 2003) at RM 4.9. Over the course of two weeks in September 2002, after the river cleared, peak afternoon pH rose from 7.6 to 9.0 (Ebbert, 2003).

Although excess phosphorus and nitrogen cause pH violations in the White River, water diversions can significantly affect pH. Puget Sound Energy (PSE) has historically diverted water from the river into Lake Tapps upstream of the two municipal wastewater treatment plant (WWTP) discharges. Until January 2004, diversions for power generation resulted in lower river flows in 20 miles of river between Buckley and the powerhouse tailrace channel, located near the city of Sumner, which returns diverted water to the river. Lower flows resulted in reduced dilution of wastewater discharges, higher concentrations of phosphorus and nitrogen, and more periphyton growth. Since PSE ceased the hydropower operation, water diversions to Lake Tapps have decreased and river flows have increased accordingly.

The Cascade Water Alliance (CWA) recently purchased the water rights to the diversion from PSE (Puget Sound Energy and Cascade Water Alliance, 2008). CWA also reached an agreement with the Puyallup and Muckleshoot tribes that outlines future management of the White River and Lake Tapps for protection of fishery resources, providing municipal water supply in the future, and continuing recreational use of Lake Tapps (Cascade Water Alliance et al., 2008). The agreement sets new minimum flow targets for the White River below the diversion. The new minimum flow targets range from 500-650 cfs from late July through mid-March and from 725-800 cfs during the rest of the year.

Impairments addressed by this TMDL

The main beneficial uses protected by this TMDL are aquatic life uses including:

- Mouth to ~RM 4.4: Salmonid spawning, rearing, and migration.
- ~RM 4.4 to RM 28: Core summer salmonid habitat and salmonid spawning, rearing and migration.

These uses will be protected by ensuring that the following parameters meet water quality standards in the water body (Table 1).

Table 1. Study area water bodies on the 2008 303(d) list for pH.

Water body	Approximate Reach in River Miles (RM)	Parameter	Listing ID	NHD Reach Code	Township	Range	Section
White River	~RM 6.7 to 11.8	pH	7524	17110014005509	21N	5E	29
White River	~RM 5.3 to 6.7	pH	7525	17110014000437	21N	4E	36
White River	~RM 3.6 to 5.3	pH	7526	17110014000436	20N	4E	1

We will be looking at this watershed more thoroughly and may find other impaired water bodies for pH, dissolved oxygen, and temperature.

To meet the pH standards for the listings in Table 1, phosphorus loading will need to be decreased from both point and nonpoint sources in the watershed.

There are other 303(d) listed segments in the watershed, but this TMDL does not address them (Table 2). In addition, there are a number of segments of the White River and its tributaries on the 2008 303(d) list for fecal coliform. These segments should be re-categorized as 4a during the 2012 water quality assessment based on the recently approved Puyallup River Watershed Fecal Coliform TMDL (James and Mathieu, 2011).

Table 2. Study area water bodies on the 2008 303(d) list not addressed by this TMDL

Water body	Approximate Reach in River Miles (RM)	Parameter	Listing ID	NHD Reach Code	Township	Range	Section
White River	~RM 1.5 to 2.2	Temp	17513		20N	4E	42
White River	~RM 3.6 to 5.3	Temp	17515	17110014000436	20N	4E	1
White River	~RM 6.7 to 11.8	Temp	17517	17110014005509	21N	5E	29
White River	~RM 2.2 to 2.9	Temp	21301		20N	4E	13
White River	~RM 0.1 to 0.3	Temp	21302		20N	4E	23

How will the results of this study be used?

A TMDL study identifies how much pollution needs to be reduced or eliminated to achieve clean water. This is done by assessing the situation and then recommending practices to reduce pollution, and by establishing target limits for facilities that have permits. Since the study may also identify the main sources or source areas of pollution, Ecology and local partners use these results to figure out where to focus water quality improvement activities. Or, sometimes the study suggests areas for follow-up sampling to further pinpoint sources for cleanup.

Water Quality Standards and Numeric Targets

Washington's administrative code outlines water quality standards for the state of Washington (WAC 173-201A). The applicable criteria within the TMDL study area are outlined in Table 3 and described in further detail below.

Table 3. Washington State water quality criteria for pH in the Lower White River.

Segment of River	Parameter	Applicable Criteria
Mouth to ~RM 4.4: Salmonid spawning, rearing, and migration	pH	Must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.
~RM 4.4 to RM 28: Core summer salmonid habitat	pH	Must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

pH

The pH of natural waters is a measure of acid-base equilibrium achieved by the various dissolved compounds, salts, and gases. pH is an important factor in the chemical and biological systems of natural waters. pH both directly and indirectly affects the ability of waters to have healthy populations of fish and other aquatic species. Changes in pH affect the degree of dissociation of weak acids or bases. This effect is important because the toxicity of many compounds is affected by the degree of dissociation. While some compounds (e.g., cyanide) increase in toxicity at lower pH, others (e.g., ammonia) increase in toxicity at higher pH.

While there is no definite pH range within which aquatic life is unharmed and outside which it is damaged, there is a gradual deterioration as the pH values are further removed from the normal range. However, at the extremes of pH lethal conditions can develop. For example, extremely low pH values (<5.0) may liberate sufficient CO2 from bicarbonate in the water to be directly lethal to fish.

The state established pH criteria in the state water quality standards primarily to protect aquatic life and to protect domestic water supply sources. Water supplies with either extreme pH or that experience significant changes of pH even within otherwise acceptable ranges are more difficult and costly to treat for domestic water purposes. pH also directly affects the longevity of water collection and treatment systems, and low pH waters may cause compounds of human health concern to be released from the metal pipes of the distribution system.

In the state's water quality standards, two different pH criteria are established to protect six different categories of aquatic communities [WAC 173-201A-200, 2003 edition].

(1) To protect the designated aquatic life uses of “Char Spawning/Rearing” and “Core Summer Salmonid Habitat” pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.2 units.

(2) To protect the designated aquatic life uses of “Salmonid Spawning, Rearing, and Migration,” “Salmon and Trout Rearing and Migration Only,” “Non-anadromous Interior Redband Trout,” and “Indigenous Warm Water Species,” pH must be kept within the range of 6.5 to 8.5, with a human-caused variation within the above range of less than 0.5 units.

Within the TMDL study area, criteria 1 applies to RM 4.4 to 28 and criteria 2 applies to RM 0 to RM 4.4.

Global climate change

Changes in climate are expected to affect both water quantity and quality in the Pacific Northwest (Casola et al., 2005).

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

The predicted changes to our region’s climate highlight the importance of protecting and restoring the mechanisms that help to cool stream temperatures. Stream temperature improvements obtained by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflows may all help to minimize the changes anticipated from global climate change. It will take considerable time, however, to reverse human actions that contribute to elevated stream temperatures. The sooner such restoration actions begin and the more complete they are, the more effective the program will be in offsetting some of the detrimental effects on our stream resources.

Restoration efforts may not cause streams to meet the numeric temperature criteria everywhere or in all years. However, they will maximize the extent and frequency of healthy temperature conditions, creating long-term and crucial benefits for fish and other aquatic species.

Ecology is conducting this TMDL to meet Washington State’s surface water quality standards based on current climatic patterns. Potential changes in stream temperatures and river flows associated with global climate change could impact primary productivity in the White River. These changes may require further modifications to human-source allocations at some future time.

Increases in stream temperature generally increase the rate of a stream’s metabolic activity, which could result in increased periphyton uptake of inorganic carbon from the river. The increase in carbon uptake, in turn, would likely increase the river’s pH.

In the short term, glacial recession may increase baseflow. However in the long term, loss of glaciers could reduce the baseflow and turbidity of the White River, causing reduced water depths and increased light reaching periphyton, which could lead to an increase in pH.

Watershed Description

The TMDL study area is located in both Pierce and King Counties and encompasses parts of the Reservation of the Muckleshoot Indian Tribe and the cities of Buckley, Enumclaw, Auburn, Pacific, Edgewood, and Sumner.

Climate

The climate is dominated by the mild, wet maritime weather regime typical of lower elevation areas of western Washington. The air temperatures in Buckley reach an average daily high of 76.4°F (24.7°C) in July and August with the average daily low dropping to 32.4°F (0.2°C) in January. Buckley receives an average of 48 inches of precipitation annually, almost half of which falls from November through February (WRCC, 2012).

Higher elevations on Mount Rainier receive heavy snowfall throughout the late fall, winter, and spring, with an annual average of over 110 inches of precipitation and over 650 inches of snowfall at Paradise (WRCC, 2012).

Geology

During the Fraser glaciation, approximately 15,000 years ago, the advance of the Cordilleran ice sheet from British Columbia reached its maximum extent into Puget Sound. The Puget ice lobe that formed Puget Sound had several smaller advances and retreats. The Fraser glaciation ended approximately 10,000 years ago.

With the retreat of the glaciers the Puyallup and White Valleys were initially formed as subglacial meltwater channels that eroded the glacial deposits. At that time the Sound included the Puyallup and White River valley areas to Commencement Bay and north through Sumner and Auburn to Seattle. An area of higher elevation from Edgewood to West Seattle was an island in Puget Sound.

The arm of Puget Sound that covered Sumner and Auburn eventually filled with sediment transported by rivers and from lahars originating from Mount Rainier. The lahars deposited layers of volcanic sediment interspersed with the alluvial deposits from the rivers. This process formed a series of layers that gradually filled this arm of the sound with semi-consolidated material consisting of clay, silt, sand, and gravel. This process continued for approximately 6,000 years when the largest recorded lahar from Mount Rainier, the Osceola Mudflow, flowed through the White River valley.

The Osceola Mudflow began as a water-saturated avalanche or a series of avalanches during possible eruptions or magma flow at the summit of Mount Rainier. The mudflow filled valleys of the White River system to depths of 250 to 450 feet, flowed northward and westward more than 75 miles, covered more than 60,000 acres of the Puget Sound lowland, covered another 40,000 acres under the water of Puget Sound, and extended as much as 12 miles under water.

The communities of Buckley, Enumclaw, Auburn, Sumner, and Puyallup are wholly or partly located on top of Osceola Mudflow deposits.

The mudflow was composed of a mixture of clay-rich gravel, cobbles, and boulders that were also deposited on the drift plains surrounding the LWR and the slopes of the river valley between present day Auburn and Mud Mountain Dam. The mudflow deposits created a poorly drained confining layer which limits downward movement of groundwater.

Tooley (1997) speculated that the Osceola confining layer forced lateral movement of groundwater and nutrients to tributary streams, based on poor recharge rates measured by Dinicola (1990) within the mudflow deposits and observation of seeps along the White River bluffs.

The Lake Tapps Reservoir Uplands can provide recharge to the White River depending on the reach and seasonal conditions (CWA, 2010; PGG, 1999). In general, groundwater flows down-gradient, in all directions, outward from the reservoir/uplands through the two primary aquifer layers surrounding the reservoir: an upper course-grained unit Q(A)c and the Vashon Advance Outwash unit Qva (CWA, 2010). Groundwater from these units can discharge to the White River, the Puyallup River, and several larger springs within study area including Coal Creek Springs, West Hill Spring, Salmon Springs, Sumner Springs, Crystal/County Springs, and Elhi Springs. These springs generally discharge at the base of the down-slope for the Lake Tapps Uplands, along the north and west flanks of the plateau, and are used by the cities of Auburn, Sumner, and Puyallup for municipal water supply (CWA, 2010).

Soils and vegetation

The predominate soils in the TMDL study area are classified as Buckley and Alderwood series soils. The valley floor, however, consists of alluvial soils.

The Buckley series consists of moderately deep and poorly draining soils that formed in the Osceola Mudflow. The soils are nearly level plains at elevations 500 to 700 feet. The native vegetation is western red cedar, western hemlock, Sitka spruce, Douglas-fir, red alder, and bigleaf maple with an understory of vine maple, ferns, red huckleberry, trailing blackberry, and wild ginger. In many areas, the Buckley soils have been cleared and drained for use as pasture, hay, and grain.

The Alderwood series consists of moderately drained soils with depths of 24 to 40 inches underlain by consolidated glacial till. The underlying glacial till, also known as hardpan, has low permeability. These soils, located on glacially modified foothills and valleys with slopes of 0 to 65 %, formed in glacial deposits at elevations between 100 and 800 feet. These soils had native vegetation consisting of Douglas-fir, western hemlock, western red cedar, and red alder with understory of salal, Oregon-grape, ferns, and huckleberries. Presently the Alderwood series are used for woodland, field crops, hay, pasture, and non-farm uses.

Hydrology

Seasonal streamflow patterns in the bypass reach, under current water management, are heavily influenced by local precipitation in the late fall through early spring and by glacial melt from Mt. Rainier starting as early as late spring and lasting through as late as early fall. Typically the lowest flows (upstream of the diversion) occur in the month of October.

Snowmelt is measured near the upper White River watershed by the Snotel station at Morse Lake (elevation 5410 ft). In an average year, snowpack peaks at ~55 inches of snow water equivalent (SWE) in the month of March and is followed by rapid snowmelt in the months of May and June. Typically, there is less than 5 inches SWE by the start of July and, historically all the snowpack (at this elevation) has melted by the start of August. As of late April 2012, the snowpack is above average for the current year (Figure 2) (NOAA, 2012). Glacial melt continues from the Emmons, Winthrop, and Fryingpan glaciers of Mount Rainier intermittently through summer and early fall depending on daily temperatures, cloud cover, and solar radiation.

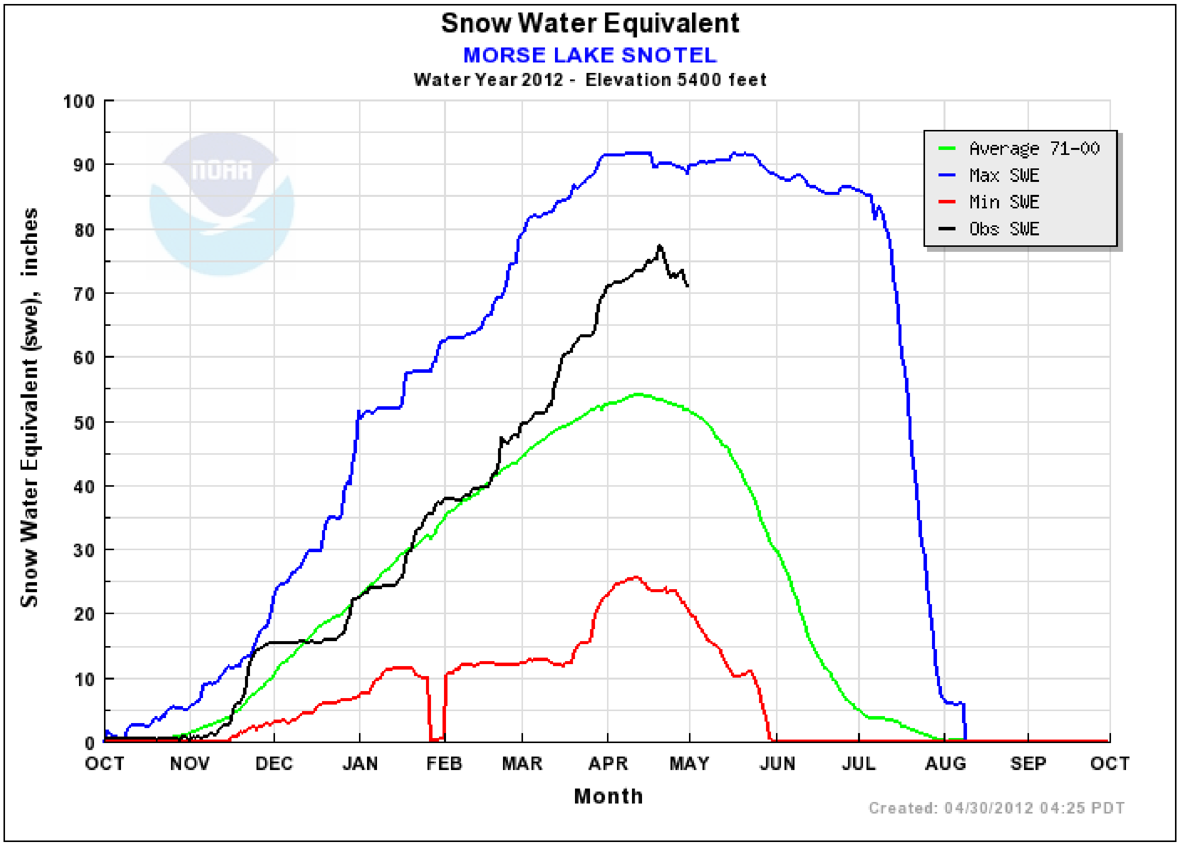

Figure 2. Minimum, maximum, average, and current snowpack levels at the Morse Lake Snotel station (NOAA, 2012).

Mud Mountain Dam provides flood control for the river valley and can affect flows in the river downstream; however, it is typically managed as a ‘run-of-the-river’ dam whereby the reservoir is left empty and flow is allowed to pass through the reservoir and dam. The U.S. Army Corps of Engineers (USACE) operates the dam to provide flood control for Puyallup River to limit peak discharge to below 45,000 cfs at the USGS station (12101500) on the Puyallup River at Puyallup, WA. USACE also operates the dam to avoid flooding in the White River valley by limiting releases to less than 12,000 cfs (Czuba et al., 2010). An intake tower within the reservoir directs water to a 9-foot-wide tunnel during normal flows and an additional 23-foot-wide tunnel during high flows and floods. In addition, the dam includes a spillway designed to allow excess floodwaters to be released (USACE, 2012).

As part of the agreement between Cascade Water Alliance and the Muckleshoot and Puyallup Tribes, flow may not be diverted from the river at the Lake Tapps diversion when upstream flows fall below a minimum range. The minimum flow ranges varies by time of year, with an absolute minimum low flow of 500 cfs. Previous calculations of the 7Q10 flow were 260 cfs and 302 cfs, depending on averaging period and season (Appendix A). Given that the 7Q10 is less than the minimum flow agreement, no diversions would be allowed during the most critical conditions in the river. The 7Q10 is a statistical estimate of the lowest 7-day average flow that can be expected to occur once every ten years on average.

Land use

Land use in the study area is mixed urban, residential, agricultural, and forest. The mixed urban residential areas include the cities of Auburn, Edgewood, Pacific, Algona, Sumner, Enumclaw, and Buckley, the Muckleshoot Indian Tribe Reservation, highway corridors and homes surrounding Lake Tapps. Agricultural areas are located on the remaining uplands of the Enumclaw plateau. Intermittent tree cover exists on the valley floor upstream of Auburn and forested areas cover the watershed upstream of the study area. The valley broadens from approximately 1/2 mile to 1 mile wide in the bypass reach as the river moves downstream, with steep forested hills partially covered by deciduous and coniferous trees, which rise 100 feet above the valley floor. The area is experiencing rapid residential growth, generally into areas that were previously agricultural.

The upper portion of the study area consists primarily of rural residential and agricultural land use, with relatively low housing densities. This includes areas of unincorporated King and Pierce Counties and areas of the cities of Buckley and Enumclaw.

Within the lower portion of the study area, housing densities are typically higher and mixed with more commercial and industrial properties. This includes the cities of Algona, Auburn, Edgewood, Pacific, and Sumner. A zone of large warehouses and industrial operations is concentrated around the final 6 miles of the LWR. This zone dominates the valley floor and extends from the mouth of the river in Sumner to the northern bounds of the study area in Auburn and Algona, in the Government Canal and Milwaukee Ditch drainage areas.

Muckleshoot Indian Tribe

The Muckleshoot Indian Tribe is a federally recognized tribe of the Upper Puyallup and Duwamish people, whose sovereignty was recognized by the Treaty of Medicine Creek and the Treaty of Point Elliot (www.muckleshoot.nsn.us/about-us/overview.aspx). The Muckleshoot Indian Tribe Reservation (MIT Reservation) is located on a rising plateau between the White and Green Rivers. The White River flows within the MIT Reservation from river miles 15.5 to 8.9. In addition, the White River is within the Muckleshoot Indian Tribe's Usual and Accustomed Fishing Area (U&A), as determined in the U.S. Supreme Court case, *U.S. v. Washington (1974)*, for fisheries resources over which the Tribe holds shared sovereignty for cultural and economical needs.

Puyallup Tribe of Indians

As part of ongoing efforts to protect treaty fisheries as well as recover endangered salmon fisheries in the Puyallup River watershed, the Puyallup Tribe has spent a large amount of time on the White River, conducting surveys, enumerating fish at the USACE Buckley fish trap (located at RM 24.3), working to restore habitat, and operating acclimation ponds on tributaries of the White River. The Puyallup Tribe of Indians also regulates downstream water quality through promulgated water quality standards, within the reservation reach of the Puyallup River, between RM 1 and approximately 7.3. The reservation reach is approximately 3 miles downstream of the confluence with the White River.

Potential nutrient sources

Point (permitted) sources

Municipal wastewater treatment plants for the cities of Buckley and Enumclaw discharge to the LWR within the study area. The wastewater treatment facility for the Rainier State School was connected to the Buckley WWTP in February 2011 and no longer discharges directly to the river. Both the Buckley and Enumclaw facilities operate under individual NPDES wastewater permits issued in 2003. New permits for both plants are under development. The plants have recently upgraded capacity and implemented biological phosphorus and nitrogen removal. In these systems, it can take some time to develop the biota in the treatment system and optimize operations, in order to provide the required level of phosphorus removal.

City of Enumclaw WWTP

The City of Enumclaw built a new WWTP in 2008 that replaced an aging rotating biological contactor system with an extended aeration activated sludge system. The new treatment system can remove phosphorus in addition to traditional secondary treatment. At this time, the WWTP employs biological phosphorus removal although there is currently no designated limit for phosphorus in the NPDES permit. The City designed a chemical phosphorus removal system as part of next construction phase. The WWTP uses ultraviolet (UV) light for disinfection.

In 2003, Washington Department of Ecology issued the City of Enumclaw NPDES permit number WA0020575 that expired in 2008. The old permit remains in effect while Ecology develops a new permit. The City added capacity to treat a maximum monthly average flow of 3.5 MGD in 2008 and the new permit will reflect the change.

City of Buckley WWTP

The City of Buckley upgraded its WWTP which went online in February 2009. The WWTP uses an extended aeration activated sludge system with UV disinfection. The City added a phosphorus (biological and chemical) removal system as part of the upgrade and expansion.

White River Fish Hatchery

Owned and operated by the Muckleshoot Indian Tribe, the Whiter River fish hatchery discharges process water at approximately RM 24 just downstream of the diversion dam. The hatchery is relatively small and is not currently defined as a point source by the NPDES program because it produces less than 20,000 pounds of fish per year and uses less than 5,000 pounds of feed in a month. Once the White River Hatchery receives an allocation, EPA will determine if the discharge is a significant source of pollution and needs a permit.

Municipal Stormwater

Within the study area, nine municipal entities maintain stormwater infrastructure covered under the general NPDES Phase 1 or Phase 2 municipal stormwater permits for western Washington, including King and Pierce counties (Phase 1), as well as the cities of Buckley, Enumclaw, Auburn, Algona, Pacific, Edgewood, and Sumner (Phase 2)(Figure 3).

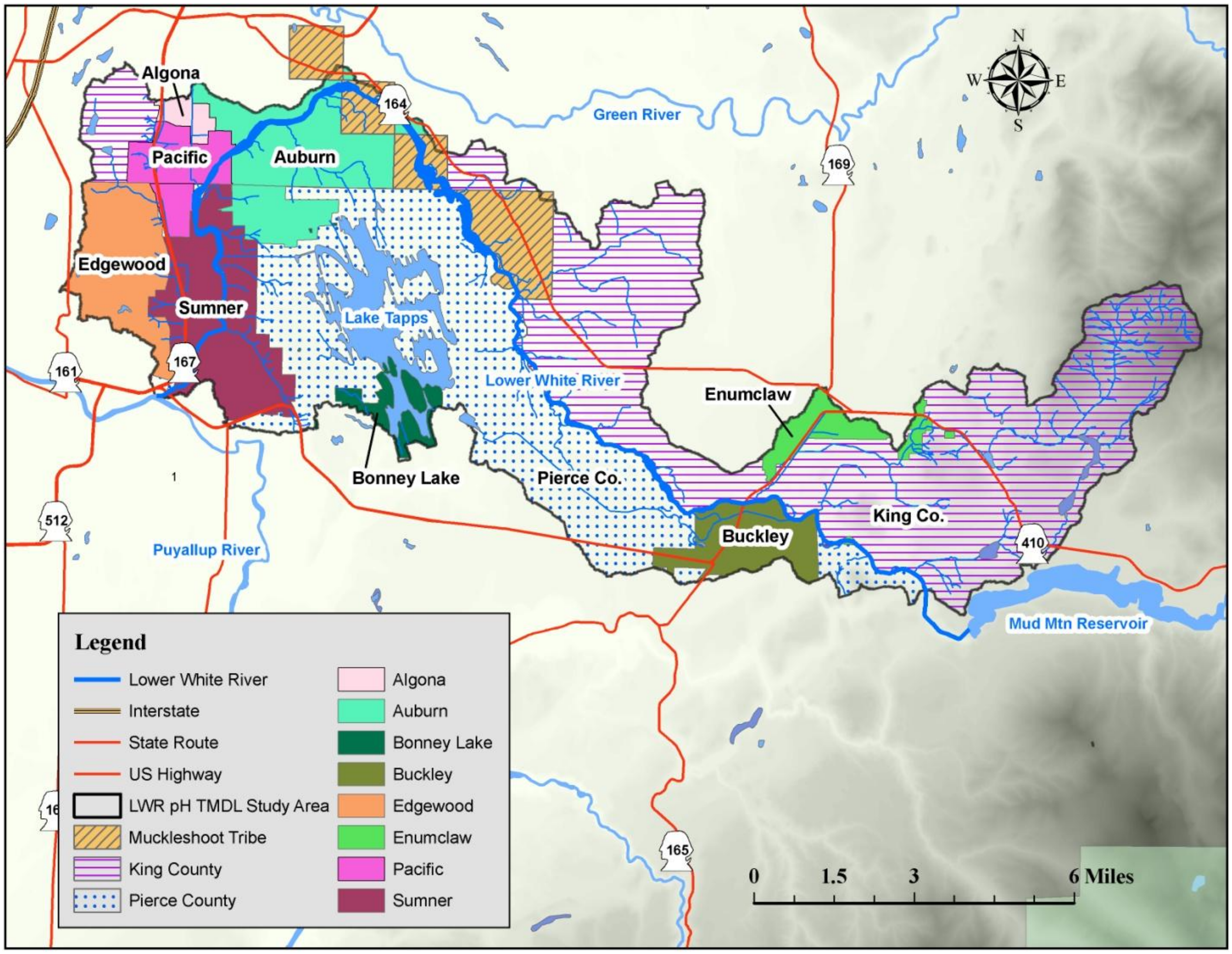

Figure 3. Municipal jurisdictions covered by a NPDES Phase 1 or Phase 2 municipal stormwater permit.

Other permitted facilities

Numerous other permitted facilities exist within the study area that operate under a variety of different permit types including NPDES or state individual industrial wastewater permits and general permits for industrial stormwater, confined animal feeding operations (CAFO), sand and gravel, and construction stormwater. Four industrial facilities in the study area discharge treated storm or wastewater (Table 4).

1. Sonoco Products Co. operates a recycled paperboard manufacturing facility that discharges secondary treatment wastewater from the pulp manufacturing process to a diffuser outfall in the White River at RM 1.4. The facility also discharges primary treatment (with oil separation) stormwater to the city of Sumner's stormwater collection system.

2. Fleischman's Vinegar Company Inc. operates a vinegar manufacturing facility that discharges treated process wastewater to the city of Sumner sanitary sewer and non-contact cooling water to the White River at RM 1.1.

3. Western Wood Preserving, a wood preservation treatment facility, discharges treated stormwater via two outfalls to the city of Sumner's stormwater collection system. Outfall 1 discharges stormwater from the treated wood storage area. The stormwater is first directed to a biotreatment pond, before discharging at outfall 1. Outfall 2 discharges stormwater from the untreated or "white wood" storage area. The stormwater is first directed to a bioswale, before discharging at outfall 2.

4. Manke Lumber Co. operates Superior Wood Treating, another wood preservation treatment facility located adjacent to the LWR at RM 4.9. Similar to Western Wood Preserving, Manke discharges treated stormwater from two bioswales: one for the treated wood storage area (Outfall 1) and one for the non-treated wood storage area (Outfall 2).

Table 4. Individual industrial wastewater NPDES permit holders in the study area.

Facility	NPDES Permit #	Discharge type	Receiving Water body
Fleischman's Vinegar Co.	WA0038598D	Treated wastewater (OF#1); non-contact cooling water (OF#2)	Sumner WWTP (OF#1); White River (OF#2)
Superior Wood Treating-Manke Lumber Co.	WA0040339B	Treated stormwater	White River (OF#1 & #2)
Sonoco Products	WA0000884D	Treated wastewater; (OF#1) Treated stormwater (OF#2).	White River (OF#1); Sumner storm sewer (OF#2)
Western Wood Preserving	WA0040738C	Treated stormwater	Sumner storm sewer (OF#1 & #2)

The Allan Thomas Dairy, located in the city of Enumclaw, operates under a general Confined Animal Feeding Operation (CAFO) permit as a medium sized CAFO. This dairy is currently the only permitted CAFO within the study area.

Twenty-three facilities within the study area are covered under the Industrial Stormwater General Permit for stormwater discharge to surface water bodies. Fifteen of these facilities discharge stormwater directly to the LWR, four facilities discharge to the Milwaukee Ditch system, three discharge to the Government Canal system, and one discharges to Boise Creek.

Eight companies operate under the Sand and Gravel General Permit within the study area. The permit regulates discharges of process water, stormwater, and mine dewatering water associated with sand and gravel operations, rock quarries, and similar mining operations, including stockpiles of mined materials. The permit requires that any discharge from these facilities meet water quality limits for turbidity, TSS, and pH (Ecology, 2011a). www.ecy.wa.gov/programs/wq/sand/index.html

Most of the sand and gravel facility outfalls are permitted for discharge to groundwater; however, there are several permitted surface water discharges (Table 5).

Table 5. Potential surface water discharges covered under the Sand and Gravel General Permit.

Permittee Name	Permit #	Discharge Type	Receiving Water body	Receiving NHD Reach Code
Jensen Sand & Gravel Nielson Pit	WAG503141	Stormwater	Unnamed trib to Boise Creek	17110014000651
410 Quarry Inc.	WAG501024	Stormwater	Boise Creek	17110014000475
Corliss Sumner Pit	WAG501174	Process water	Salmon Creek	17110014016030
Woodworth & Co. Inc.	WAG501480	Stormwater	Salmon Creek	17110014001345
Valley View Dieringer Pit	WAG501031	Stormwater	Unnamed trib to White R. at RM 2.6	17110014016764

At the time of writing this QAPP there were approximately 41 active permits within the study area covered under the Construction Stormwater General Permit. Permittees that discharge stormwater to 303(d) listed water bodies for turbidity, pH, and phosphorus are required to monitor water quality and meet permit limitations.

Given the large number of facilities with a general permit, limited project resources, and the fact that the pH violations in the LWR occur during steady-state baseflow conditions, these stormwater discharges will not be individually sampled during the TMDL study; however, many of these outfalls discharge to a tributary of the LWR or the municipal stormwater infrastructure, in which case, any discharge would be accounted for in the synoptic surveys. Ecology may sample direct general permit stormwater outfalls to the LWR during the synoptic surveys, if they have measurable discharge at the time of sampling.

Nonpoint Sources

Nonpoint sources are diffuse sources not covered by an NPDES permit. Nonpoint sources can include groundwater inflows, rainfall wash off processes, erosion, and direct discharges (such as from livestock standing in a stream).

Numerous potential nonpoint sources of nutrients are present within the watershed including:

- On-site septic systems, particularly those that are failing, poorly constructed, or poorly maintained.
- Range and pastured livestock with direct access to water bodies.
- Poor livestock or pet manure management on non-commercial, or “hobby” farms.
- Improperly stored or applied manure from commercial farms.
- Fertilization of landscaping.
- Sediment from erosion.
- Pet manure from residential areas.
- Wildlife.
- Background sources.

There are several thousand on-site septic systems within the study area which are located primarily within the rural areas of unincorporated King and Pierce counties, the City of Edgewood, and the area surrounding Lake Tapps. Failing and improperly maintained on-site septic systems can be sources of nutrients to surface or groundwater through leaching or ponding. Even properly functioning systems may leach nutrients to groundwater, depending on site-specific factors such as soil types, depth to water, etc.

As of 2003, approximately 16 commercial dairies operate within the study area, but they are currently not required to obtain CAFO permit coverage. Typically any discharge from a dairy would be considered a point source. However, given that they are not being directly monitored and are not covered under a permit, these dairies are included in the nonpoint source section. Improperly stored or applied manure can provide a source of nutrients to both groundwater and surface water, particularly during periods of heavy rainfall or seasonally high water tables. Most of the dairies are located in King County or Enumclaw north of the White River, between river miles 25 and 16.

Pet waste typically enters surface waters during periods of surface runoff, although direct discharge can occur. Within the study area, pet waste is most likely to enter the river through the municipal stormwater infrastructure.

A wide variety of perching birds, upland game birds, raptors, and waterfowl are found within the study area. Elk, deer, beaver, muskrat, and other mammalian wildlife species are also present. Open fields are attractive feeding grounds for some birds and wildlife whose presence can increase nutrient loading to streams. Usually these sources are dispersed and do not constitute a significant nutrient source, but sometimes animals are locally concentrated and can result in significant loading.

Background sources of nutrients, both within and upstream of the study area, include:

- Atmospheric deposition (rainfall, snow, particulates)
- Geologic weathering
- Decomposing plant, invertebrate, and animal material. In the LWR, this includes decomposing salmon carcasses during certain times of the year or certain years, particularly during the summer/fall in a year with a pink salmon run. Pink salmon runs in recent history have occurred every other year during odd years, thus 2012 is not anticipated to have a significant pink salmon run.

The nonpoint sources discussed in this section will not be monitored directly. Some of the nutrient loads from these sources will be captured by sampling tributaries.

Historical Data Review

Prior to January 2004 (steady-state, low-flow regime)

1990 Puyallup River BOD, Ammonia, and Chlorine TMDL - Ecology

In September and October of 1990, Ecology collected data on the Puyallup and White Rivers to develop a TMDL for Biological Oxygen Demand (BOD), Ammonia, and Chlorine (Pelletier, 1993). The study (see Table 6) found that:

- Afternoon pH values were consistently greater than 8.5 within the bypass reach of the White River based on *in situ* measurements.
- The highest measured pH values were 9.5 to 9.7 on 10/2/1990 between RMs 4.9 and 10.3.
- The median nutrient concentrations increased by approximately three-fold for soluble reactive phosphorus (SRP) (from 14 to 42 ug/L) and two-fold for dissolved inorganic nitrogen (DIN) (from 57 to 91.5 ug/L) between the stations at Highway 410 (RM 23.1) and downstream of Buckley (RM 20.4).

Table 6. Nutrient and pH data from the Puyallup River BOD, Ammonia, and Chlorine TMDL.

Location	Median NO2-NO3 (ug/L)	Median NH3 (ug/L)	Median DIN (ug/L)	Median SRP (ug/L)	Max* pH (S.U.)	Max pH* Date	Max* pH Time
White River RM 25.2	40.5	14.0	54.5	13.0	7.8	9/19/1990	14:40
White River RM 23.1	43.5	13.5	57	14.0	7.9	9/18/1990	14:20
White River RM 20.4	78.0	13.5	91.5	42.0	7.9	9/19/1990	15:40
White River RM 10.3	33.5	14.0	47.5	35.0	9.5	10/2/1990	13:10
White River RM 8.0	29.5	16.0	45.5	n/a	9.6	10/2/1990	13:40
White River RM 6.3	27.5	14.0	41.5	n/a	9.6	10/2/1990	14:00
White River RM 4.9	10.0	13.5	23.5	28.0	9.5	10/2/1990	18:40
Buckley WWTP	480	212.0	692	6,507.5	n/a	n/a	n/a
Enumclaw WWTP	15,315	393.0	15,708	7,743.0	n/a	n/a	n/a
Muckleshoot Hatchery	233.5	98.0	331.5	22.0	n/a	n/a	n/a
Rainier School WWTP	3,331.0	4,692.5	8023.5	1,424.0	n/a	n/a	n/a

* The maximum pH observed based on a single measurement, not indicative of the peak pH.

1996-97 Lower White River Assimilative Capacity Study – Ecology

In the summer and fall of 1996, Ecology collected nutrient, pH, and periphyton data from the LWR mainstem, the three WWTPs, four of the larger tributaries, and the Muckleshoot Fish Hatchery (Erickson, 1999). An additional survey collected flow, nutrients, and pH data from 9 smaller tributaries and springs within the bypass reach. Table 7 summarizes the nutrient and pH data collected during the study.

Table 7. Nutrient and pH data from a 1996-97 Ecology study.

Location	Median NO2-NO3 (ug/L)	Median NH3 (ug/L)	Median DIN (ug/L)	Median SRP (ug/L)	Max[*] pH (S.U.)	Max pH[*] Date	Max[*] pH Time
White River RM 25.2	31	10	41	10	7.7[**]	9/12/96	13:00
White River RM 23.1	23	10	33	10	7.7	6/26/96	11:00
White River RM 20.4	67	10	77	19	8.0	6/26/96	12:30
White River RM 14.9	94	10	104	12	8.8	6/26/96	15:00
White River RM 10.3	65	10	75	13	8.2	9/12/96	13:45
White River RM 8.0	142	10	152	19	8.8[**]	10/9/96	16:00
White River RM 6.3	62	10	72	10	9.0	10/9/96	14:35
White River RM 4.9	63	11	73	10	8.8	10/9/96	15:00
Buckley WWTP	631	883	1,514	2,540	n/a	n/a	n/a
Enumclaw WWTP	12,200	1,500	13,700	4,160	n/a	n/a	n/a
Muckleshoot Hatchery	3,350	2,050	5,400	1,300	n/a	n/a	n/a
Rainier School WWTP	77	40	117	15	n/a	n/a	n/a

[*] The maximum pH observed based on a single measurement, not indicative of the peak pH.
[**] Represents the peak pH; based on continuous data.

During the 1996-97 study:

- Median nutrient concentrations increased by approximately two-fold for SRP (from 10 to 19 ug/L) and for DIN (from 33 to 76.5 ug/L) between river miles 23.1 and 20.4.
- The peak pH levels from RM 8 to 4.9 were lower during 1996-97, ranging from 8.8 to 9.0, compared to peaks of 9.5 to 9.6 during similar conditions in 1990.
- The critical turbidity level was estimated at approximately 30 NTU. For turbidities greater than this value, insufficient light is expected to reach the benthic layer and limit growth.

The study also involved a review of literature values and historical data to assess nutrient concentrations that might limit periphyton growth. The historical data showed high pH values on days with low nutrient concentrations (as low as 17 ug/L DIN and 11 ug/L SRP), suggesting that periphyton growth may not be limited at these levels. However, the data was limited and photosynthetic rates are not always dependent on the corresponding nutrient concentration. Periphyton has been shown to store nutrients through a process called luxury consumption.

Ultimately, the study recommended targeting phosphorus as the limiting nutrient for reduction to address pH exceedances in the river.

1999-2003 Ambient Monitoring at RM 8 – Ecology

Ecology's freshwater ambient monitoring program collected monthly samples and measurements at RM 8 from 1999-2008 (except for WY2007) (Ecology, 2011b). From 1999-2003:

- Measured pH ranged from 7.2 to 9.4, with a median of 7.9 and pH above 8.5 during 11 % of the measurements. Measurements were typically taken between 11:30 and 16:30, but do not represent a peak pH for the day.
- Nitrate levels ranged from 27 to 1,730 ug/L with a median of 177 ug/L.
- SRP levels ranged from 8 to 137 ug/L with a median of 21 ug/L.
- Median turbidity and total suspended solids levels were 7.8 NTU and 24.5 mg/L, respectively.

2000-01 Derek Stuart Thesis Study – University of Washington

In 2002, a University of Washington graduate student, Derek Stuart, completed a thesis project titled: *A study of periphyton induced pH spikes on the White River, Washington* (Stuart, 2002). In 2000 and 2001, Stuart collected the most comprehensive, to date, dataset on the LWR between the USGS gage below Mud Mountain Dam (RM 27.9) and 8th St (RM 4.9). Data collection included continuous pH measurements, periphyton biomass sampling, and extensive nutrient and water quality sampling, primarily from late September of 2000 to January of 2001. Three separate synoptic surveys of the municipal treatment plants, the Muckleshoot fish hatchery, and tributary inputs were subsequently conducted in March, June, and July of 2001. This dataset served as the primary data source for the initial periphyton and pH models developed by the TMDL drafting committee.

Observations, conclusions, and recommendations from the study included:

- Excessive primary production occurs due to a combination of "high inorganic nutrient concentrations, high periphyton biomass, intense solar radiation, and clear water."
- Point sources contributed the largest source of inorganic phosphorus, while nonpoint sources contributed the largest inorganic nitrogen load.
- Upstream of inputs, SRP and DIN averaged 13.2 and 95.3 ug/L, respectively. Downstream of major inputs (RM 20.3 below), these nutrients averaged 44 and 354 ug/L, respectively.
- Nutrient concentrations and periphyton biomass peaked immediately downstream of major inputs (RM 20.3) and gradually decreased at subsequent downstream stations, likely as a result of periphyton uptake of nutrients.
- On days where there was data from both RM 16.4 and RM 8, RM 8 experienced higher peak pH values and larger diurnal fluctuations despite lower periphyton biomass.
- Numerical modeling results indicate that if SRP concentrations were decreased to less than 20 ug/L in the river, then diurnal pH spikes would reduce to 8.0.
- The return of the bypass reach to a more natural flow regime, with large flow spikes and scouring events, would likely reduce periphyton biomass and diurnal pH spikes. Additional data collection, before and after scour events, and dynamic modeling of flow variability is needed to predict pH fluctuations under a dynamic flow regime.

2002 Lower White River and Puyallup River Estuary Study – USGS

From early August to mid-October of 2002, the United States Geological Survey (USGS) Tacoma Field office measured continuous pH, temperature, dissolved oxygen, and specific conductance at RMs 4.9 and 1.8 of the LWR (Ebbert, 2003).

Results showed that the peak pH was greater than 8.5 at RM 4.9 on all but three days between September 10 and October 15 (Figure 3). The peak pH values remained below 8.5 at RM 1.8 throughout the study period. Increased daily maximums and diurnal fluctuations began in early September after:

- Flows dropped dramatically, due to Lake Tapps water diversion, from ~800 cfs to ~300 cfs in late August 2002.
- Turbidity levels dropped below 200 NTU (based on limited turbidity data obtained from the US Army Corps of Engineers for RM 23).

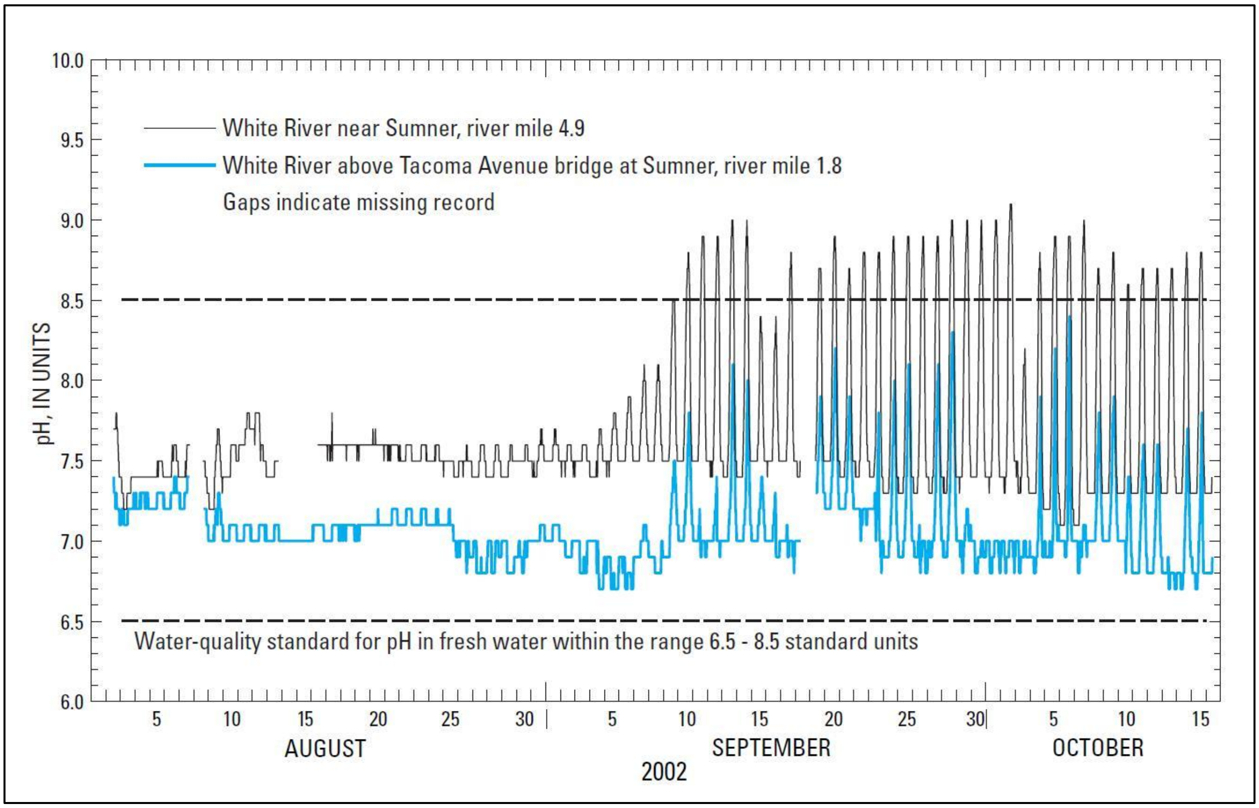

Figure 4. Continuous pH at RMs 4.9 and 1.8 of the Lower White River in 2002 (from Ebbert 2003).

Post-January 2004 (dynamic flow regime)

2004-2008 Ambient monitoring at RM 8 – Ecology

Ecology's freshwater ambient monitoring program collected monthly samples and measurements at RM 8 from 1999-2008 (except for WY2007). From 2004-08:

- Measured pH ranged from 7.1 to 8.2, with a median of 7.6 and no pH measurements above 8.5. In contrast to the 1999-2003 dataset, measurements were typically taken between 11:30 and 16:00 from January 2004 to June 2005. After June 2005, measurements were typically taken in the morning and could be well below the daily maximum pH.
- Nitrate levels ranged from 10 to 1,520 ug/L with a median of 149 ug/L.
- SRP levels ranged from 6 to 55 ug/L with a median of 16 ug/L.
- Median turbidity and total suspended solids levels were 10.1 NTU and 68.5 mg/L, respectively.
- The decrease in inorganic nutrient concentrations and increase in turbidity and suspended solids are likely at least partly due to the increased flow levels in the bypass reach.
- While measured pH values were typically much lower after January 2004, without measuring the diurnal pH range or, at a minimum, collecting pH measurements in the afternoon, it is difficult to draw any meaningful conclusions from the pH data.

2009 Lower White River pH Study – Ecology

In 2009, Ecology collected continuous pH and periphyton biomass data from 6 sites on the LWR during three 48-hour deployments, one in mid-September and two in October (Mathieu, 2010). Nutrient data was also collected from three sites during the deployments.

Observed pH measurements during the three 48-hour deployments conducted in September and October 2009 did not exceed the state water quality standards. Due to high flow conditions, continuous pH data collection ceased after the 10/19/2009 to 10/21/2009 deployment. The highest observed pH peak (8.11) and diurnal swing (0.40), as well as the lowest streamflows, occurred on 10/7/2009 at RM 8.5 (Figure 4). This may not represent the most critical period for pH during 2009. Flows continued to drop gradually during the following week and the pH may have increased during this period.

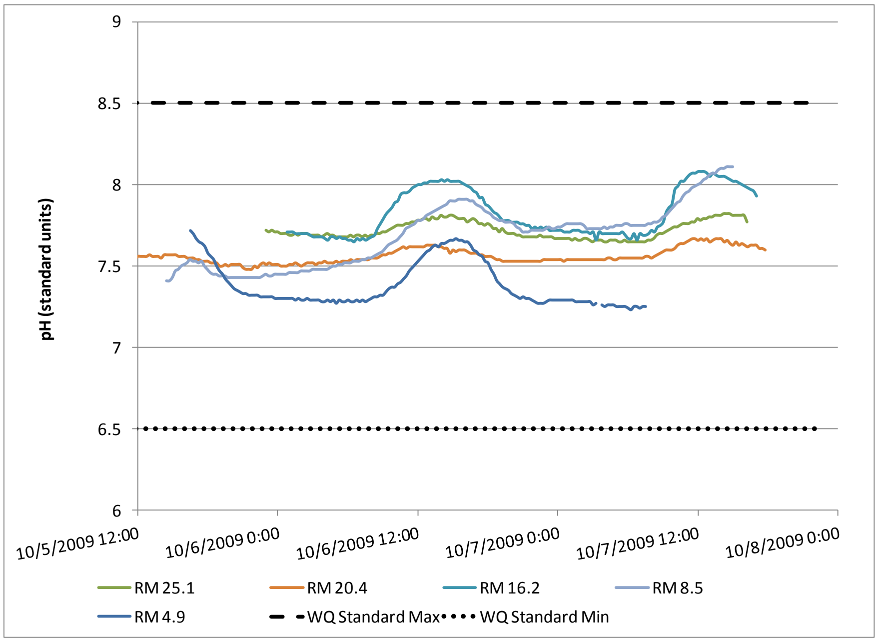

Figure 5. Continuous pH on the Lower White River in early October 2009.

Periphyton chlorophyll *a* generally increased from upstream to downstream stations; however, biomass was typically slightly lower at RM 20.4, compared to RM 25.2, then increased downstream and peaked at RM 4.9, the furthest downstream station. Compared to 2000 biomass data (Stuart 2002), the 2009 measured chlorophyll *a* levels were similar in the month of September and lower in the month of October (Figure 5). Multiple variables, relating to the conditions in which these two datasets were collected or methods used, might explain the difference in biomass. In the month of October, the median streamflow was approximately 300 cfs greater in 2009 and the 2009 TSS concentrations were more than double the 2000 levels.

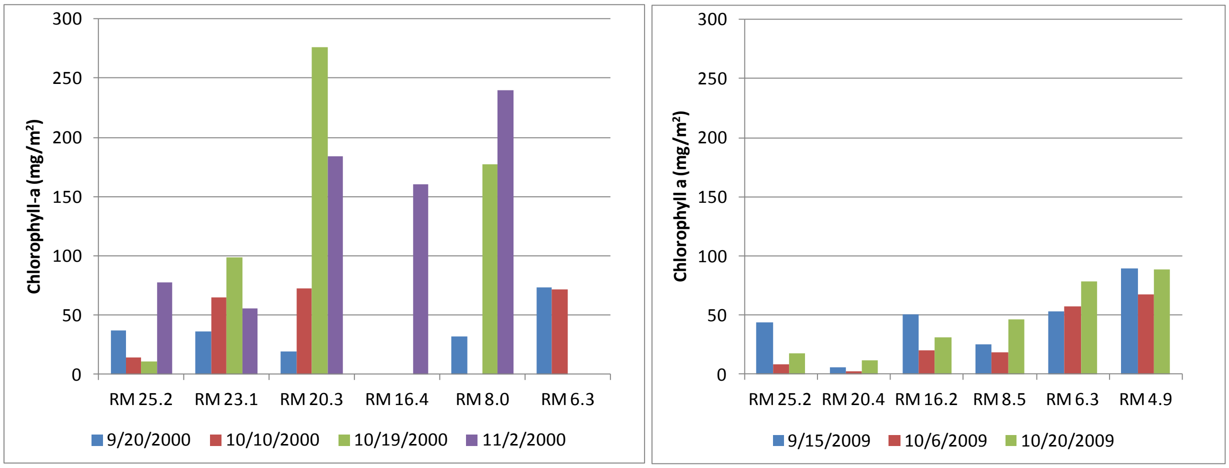

Figure 6. Comparison of periphyton biomass levels in 2000 (Stuart 2002) and 2009 (Mathieu 2010).

Median SRP levels were 23, 34, and 41 ug/L at RMs 25.2, 20.4, and 6.3, respectively. Median nitrate levels were 104, 141, and 198 ug/L at RMs 25.2, 20.4, and 6.3, respectively. Turbidity was lowest during the October 5-7 deployment, ranging from 13-16 NTU.

2010-Present Continuous pH Monitoring – USGS

In May of 2010, USGS installed three year-round continuous water quality stations at RM 24.4 (just upstream of the diversion), RM 7.6, and the Lake Tapps diversion tailrace. Each station records continuous pH, DO, temperature, specific conductance, and turbidity. Provisional data is uploaded to the USGS website in near real-time via satellite telemetry (USGS, 2011).

During the first year of deployment at RM 7.6, observed pH levels did not exceed 8.5 with a maximum pH value of 8.1 occurring during late August and early September (Figure 6). RM 7.6 exhibited a general inverse relationship between continuous pH and turbidity.

During the first year of deployment at RM 24.4, observed pH levels exceeded 8.5 on one day (7/28/2010) with a maximum pH value of 8.6 (Figure 7). RM 24.4 also exhibited a general inverse relationship between continuous pH and turbidity based on visual analysis. During the last two weeks of July, the daily maximum pH increased fairly rapidly during a period of consistently lower turbidity in a manner similar to RM 4.9 in 2002 (Ebbert, 2003). Of note, the flows were relatively high (~1000-1500 cfs), although consistently dropping, during the second half of July in 2010. The same increase in pH max and range was not observed downstream, during late July.

Figure 8 illustrates the daily maximum, minimum, and median pH at RM 24.4 from June 2010 through November 2011. Figure 9 illustrates the daily maximum, minimum, and median pH at RM 7.6 from June 2010 through November 2011.

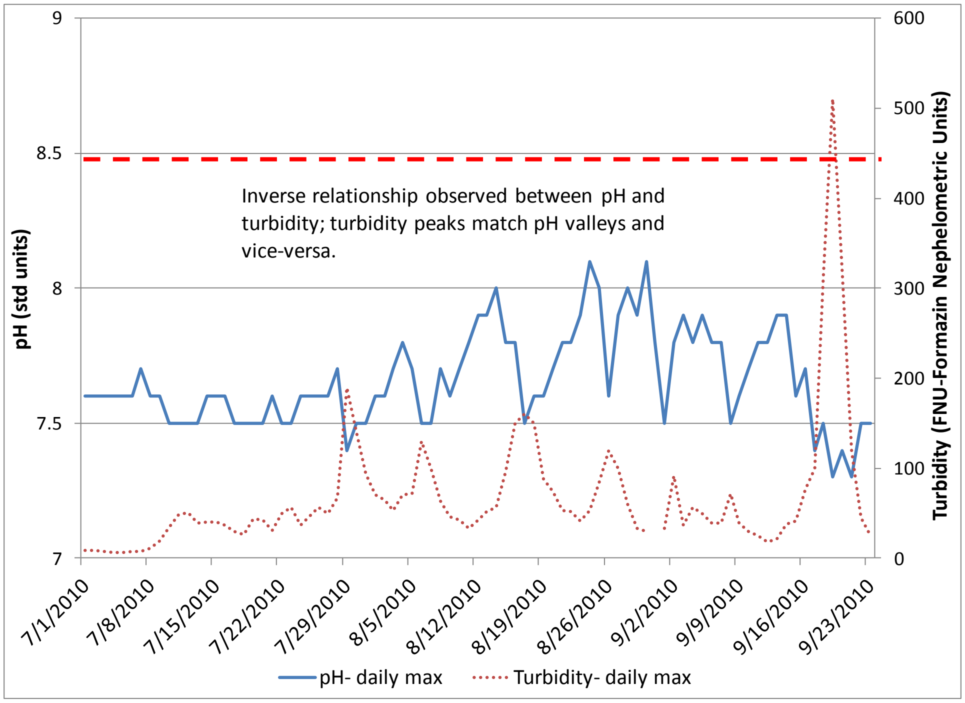

Figure 7. USGS daily maximum pH and turbidity data at RM 7.6 – July to September 2011.

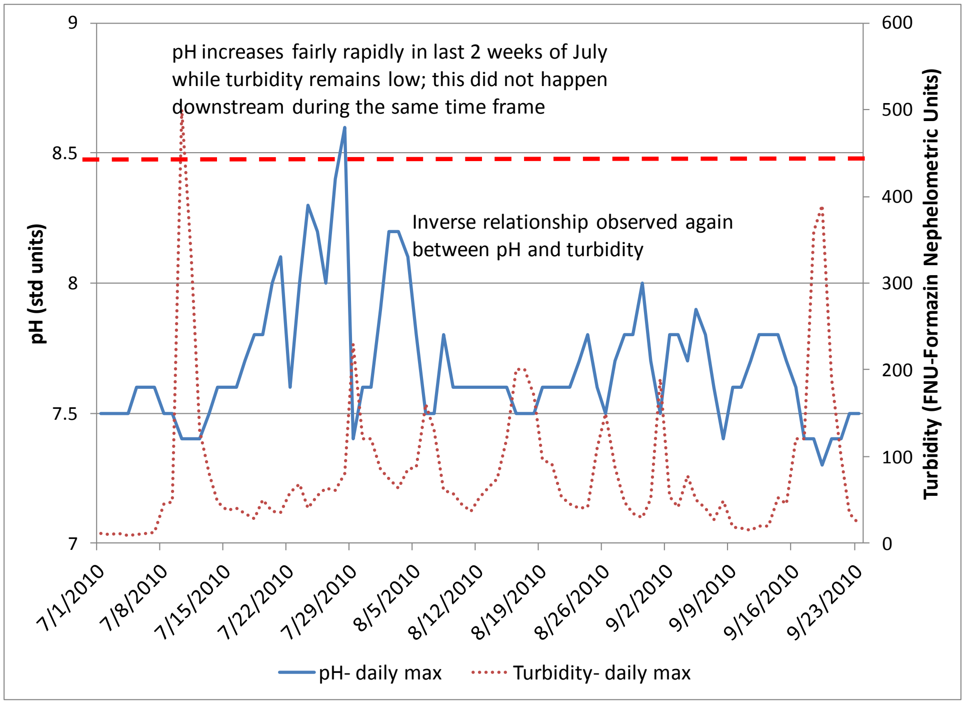

Figure 8. USGS continuous pH and turbidity data at RM 24.4 – July to September 2011.

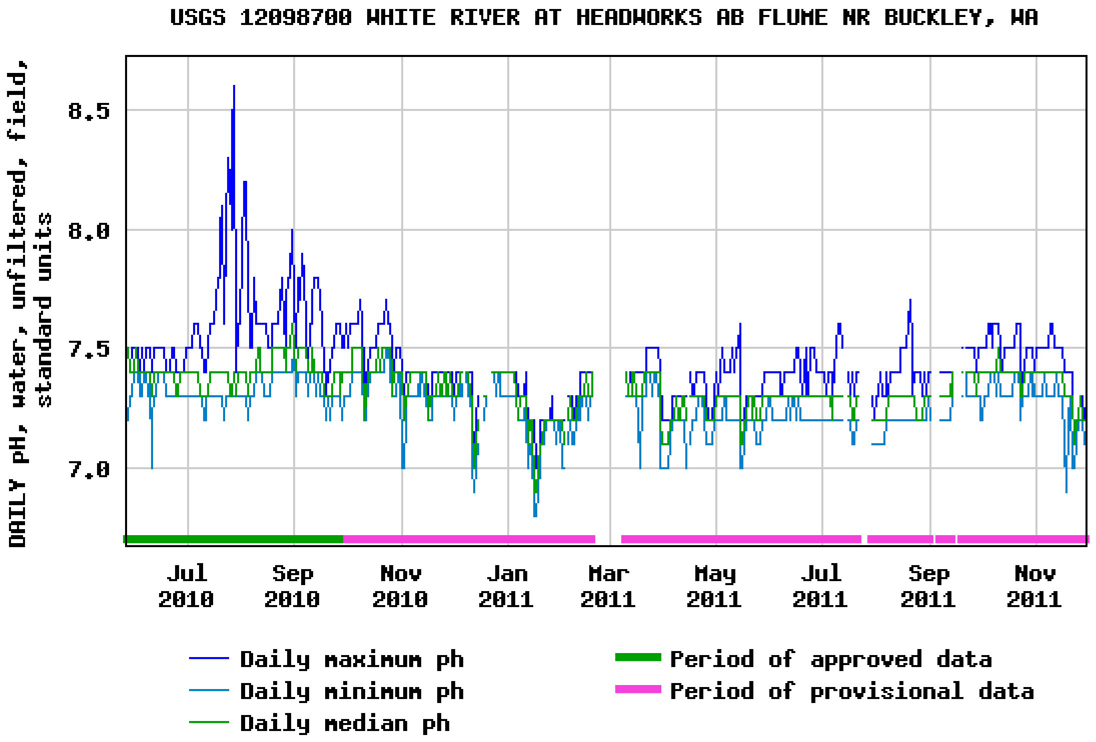

Figure 9. Daily pH statistics from USGS continuous station #12098700 at RM 24.4 (USGS, 2011).

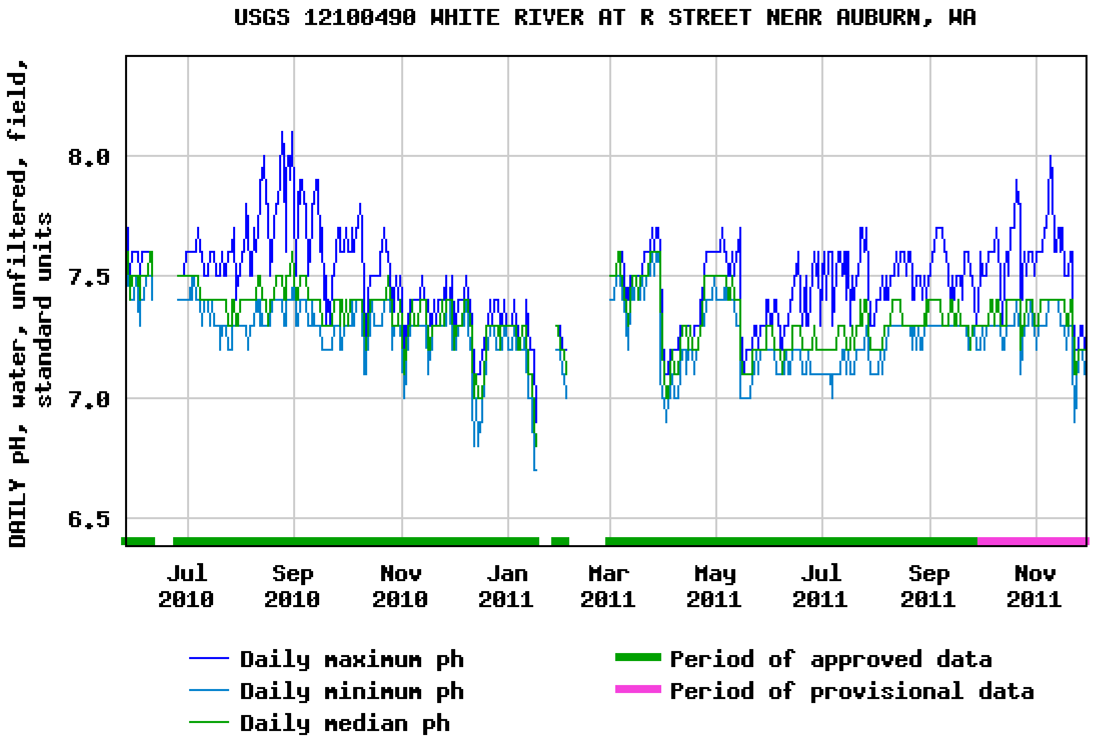

Figure 10. Daily pH statistics from USGS continuous station #12100490 at RM 7.6 (USGS, 2011).

Goals and Objectives

Project goals

The goal of this TMDL study is to provide a best estimate of the total maximum daily load for phosphorus and propose load and wasteload allocations for current and future sources that will allow the LWR to meet the water quality standards for pH.

Study objectives

Objectives for the study are:

- Collect a dataset of sufficient quality and quantity to calibrate a water quality model of the LWR.
- Characterize current processes governing pH in the Lower Whiter River including the influence of tributaries, nonpoint sources, point sources, and groundwater.
- Develop a water quality model capable of simulating productivity in the LWR.
- Use critical conditions in the model to determine the capacity to assimilate nutrients.
- Use the calibrated model to evaluate future water quality management decisions in the LWR basin.

Study Design

Overview

The study is designed to meet the project goals and objectives by collecting an environmental dataset of sufficient resolution and quality to develop and calibrate a water quality model. The model should be capable of reasonably predicting pH response in the LWR under dynamic flow conditions over the course of several months.

Data collection will occur from July through December of 2012 and include synoptic sampling surveys to characterize nutrient loads, periphyton productivity, and water quality within the study area. Additional temperature, riparian buffer, channel dimension, substrate, streamflow, groundwater, and other data will be collected to improve simulation of temperature, hydrodynamics, and water quality within the model.

Ecology will use a numerical water quality model to simulate water quality and assign TMDL allocations. Once Ecology has calibrated the numerical water quality model to field data, it will be used to evaluate water quality in the LWR in response to various alternative scenarios of pollutant loading. In addition, load allocations for nonpoint sources and wasteload allocations for point sources will be evaluated. The TMDL drafting committee will use the model to determine the amount of allowable phosphorus loading to meet pH water quality criteria under critical conditions in the river. Components and descriptions of the model are summarized in the following section.

Modeling and analysis framework

Ecology is considering using either of two numerical modeling frameworks to develop the model of water quality:

- Ecology's QUAL2KW modeling framework (Pelletier et al., 2006; Chapra et al., 2008)
- USEPA's WASP modeling framework (www.epa.gov/athens/wwqtsc/html/wasp.html)

The current version of Ecology's QUAL2KW modeling framework is a dynamic model that assumes flows are constant, and other boundary conditions are represented by a repeating diel pattern. Ecology is planning to update QUAL2KW to include use of the kinematic wave (KW) method of flow routing (Chapra, 1997) for simulation of continuously changing channel velocity and depth in response to changing flows. In addition, the updated QUAL2KW framework will allow input of continuous changes in other boundary conditions (e.g., tributary loading and meteorology). Incorporation of KW transport and continuous boundary forcing will allow QUAL2KW to be used to simulate continuous changes in water quality for up to a year.

If the updated version of QUAL2KW with KW transport and continuous boundary forcing is not available, then Ecology will use EPA's Water Quality Analysis Simulation Program (WASP) (EPA, 2009), a one- to three-dimensional dynamic model, to simulate water quality and assign TMDL allocations as the primary modeling tool, including for development of load and wasteload allocations. In addition, if WASP is used as the primary modeling tool, then QUAL2KW may be used as a screening tool if the WASP model is selected for use.

The QUAL2KW and WASP frameworks were selected because the dominant primary producers in the LWR are bottom algae and it was considered necessary to simulate continuous changes in nutrients, biomass, and pH over the entire growing season, including representation of diel variations. Both QUAL2KW (with KW transport), and WASP are capable of dynamic simulation of river pH and include kinetics that are representative of bottom algae as the dominant primary producers.

The current version of WASP (7.5) contains separate kinetic modules for simulation of temperature and advanced eutrophication (Ambrose et al., 2010). In addition to the conventional water quality parameters simulated in the basic eutrophication module, the advanced module in WASP is capable of simulating pH, inorganic carbon, alkalinity, and bottom algae biomass and stoichiometry based on algorithms adapted from QUAL2KW.

The most upstream monitoring site, at RM 28, will serve as the boundary condition for the LWR mainstem in the model. Located just below Mud Mountain Dam, RM 28 represented background conditions in the original TMDL data collection. No pH water quality violations have been documented at this site and there are very few potential anthropogenic sources of nutrients upstream. Tributary inflows, groundwater inflows/outflows, and point source inflows will be handled as boundary inputs to the mainstem model. Nutrient loads from diffuse inputs, such as groundwater, and direct inputs, such as treatment plants and tributaries, will be measured directly in the field during synoptic surveys and estimated between surveys. Some loads may be estimated based on interpolation, where appropriate.

The modeled extent of the river will be from RM 28 to RM 0.1. The number of segments used within the model is dependent on a number of variables and may be adjusted during model development. Based on segment lengths of 0.5 to 1 km per segment, that model would contain approximately 45 to 90 segments.

Within QUAL2KW and WASP, hydrodynamics for each reach are simulated based on channel characteristics and user supplied flow parameters. WASP has an option to use the same one-dimensional KW method that will be included in QUAL2KW to simulate hydrodynamics which will be used in this application. The KW equation is used to drive advective transport through free-flowing segments and to calculate flows, volumes, depths, and velocities resulting from variable upstream inflow. Ecology will collect travel time data from several reaches to check the hydrodynamic calculations in QUAL2KW or WASP.

QUAL2KW simulates temperature and eutrophication simultaneously. In contrast, WASP has separate modules for temperature and eutrophication and is not capable of simulating both simultaneously. In WASP an approximation of the temperatures from output of the temperature module are used as input to the eutrophication module. If WASP is used, then the WASP temperature module will be used to simulate water column temperatures based on atmospheric conditions and heat exchange processes. Accurate temperature simulation is important for pH, as temperature influences the rates of reactions within the eutrophication module.

Water quality variables will be simulated continuously, with a time step on the order of minutes, for the course of the 2012 growing season. The beginning, end, and length of the 2012 growing season will depend on conditions, but are generally expected to fall between July and December of 2012. The model will simulate diel water quality and periphyton biomass and growth over the course of the season, starting with the first synoptic survey representing initial conditions.

The list of water quality variables in either QUAL2KW or WASP with the advanced eutrophication module includes the following that will be used in the LWR model:

- ammonia
- nitrate
- organic nitrogen
- orthophosphate/SRP
- organic phosphorus
- dissolved oxygen
- CBOD
- detrital carbon/ nitrogen/ phosphorus
- pH
- alkalinity
- inorganic solids
- phytoplankton (chlorophyll *a*)
- bottom algae biomass
- bottom algae internal cell nitrogen and phosphorus

The scenarios used to develop load allocations will be developed prior to model calibration by the TMDL drafting committee. Load allocations may be applied seasonally or annually based on results of model application and chosen scenarios. A margin of safety will be built into the model implicitly through conservative assumptions in the development and application of model and inputs. The TMDL drafting committee will discuss and decide upon the conservative assumptions used and the final report will include a description of these assumptions. An explicit margin of safety may or may not be applied to wasteload or load allocations.

The critical flow condition will be calculated as either the annual 7Q10, or seasonally calculated 7 day low-flow (recurrence interval dependent on length of season; Cusimano, 1994), for the White River upstream of the diversion, based on the USGS gage #12098500 and data from 1977-2003. The appropriate critical flow condition will be identified based on a number of factors, including whether or not seasonal permit limits are necessary for point source discharges.

The 2012 dataset, collected in a manner to support a dynamic model, will provide the primary information for model calibration. Ecology may also evaluate the QUAL2KW or WASP model calibration using the 2000-01 dataset (Stuart, 2002) to provide general information on model corroboration over a wider range of flow and meteorological conditions. Given that this dataset was not designed to calibrate a dynamic-flow, continuous water quality model over the course of several months, there will be limitations to this evaluation.

Two potential model scenarios would be simulated with this data set:

1. A short term simulation of water quality from November 22-28, 2000. This scenario would use:
    - The periphyton biomass and distribution collected in November of 2000 (average of results from November 15 and 28).

    - Continuous water quality data from RM 28 and 16.4. Given uncertainty about the quality of this data, both the raw and corrected measurement values from RM 28 would be used as model inputs and the simulated pH outputs would be compared to both raw and corrected measurement values at RM 16.4.
    - Nonpoint and point source inputs from the 2001 synoptic surveys. The variability from this dataset would be used to produce a range of model inputs and outputs.

2. A multiple month simulation of periphyton growth and biomass only (no water quality/pH). This scenario would:
    - Use initial periphyton biomass conditions from October 10, 2000. This date was chosen as a start date, because it occurred after a high-flow event in late September.
    - Use streamflows and meteorology from 2000.
    - Use nonpoint and point source inputs from the 2001 synoptic surveys. The variability from this dataset would be used to produce a range of model inputs and outputs.
    - Simulate biomass up until November 28, 2000 to compare model predictions to observed 2000 biomass.

The use of the 2000-01 dataset is tentative based on the following contingency:

- If the 2012 data is collected in conditions similar to critical conditions (including flow and meteorological conditions), then the model evaluation with the 2000-01 dataset may not be required. The TMDL drafting committee can meet after 2012 data collection to compare conditions in 2000-01 and 2012 and determine whether the 2000-01 model evaluation will be conducted.

Data collection

Overview

Data collection will involve:

- Continuous hydrology, meteorology, and water quality data collection within the study area to provide continuous inputs to the water quality model over the course of the 2012 growing season.
- Four intensive eutrophication synoptic surveys to collect higher resolution data to characterize nutrients, water quality, hydrology, and bottom algae biomass on the mainstem white river, tributaries, and point sources.
- Continuous temperature monitoring combined with additional surveys to characterize effective shade, channel geometry, riparian vegetation, and instream habitat.
- Groundwater nutrient sampling and water quality measurements.
- Time of travel studies to determine reach specific velocities.
- Light extinction surveys to develop light extinction coefficients for a range of flow and turbidity conditions.

Sampling networks

The overall study design will consist of several sampling networks (Table 8) (Figure 11):

- **The mainstem network:** 10 mainstem sampling locations on the LWR.
- **The point source network:** the four major point source facilities within the study area.
- **The trib/spring network:** all significant tributaries/springs that discharge directly to the LWR within the study area.
    - This network also includes the Lake Tapps diversion canal, tailrace, and fish return sites.
    - Based on previous studies, many of these sites will likely not have measureable flow and will not be sampled during some or all synoptic surveys.
    - Field staff will perform reconnaissance on these sites prior to the first synoptic survey. In order to conserve project resources, sites with no or insignificant flow during recon will not be visited during the first synoptic survey (under the assumption that tributary flows will not increase during the course of the project). Likewise, sites with no flow during the first synoptic will not be visited during the second synoptic, and so on.
- **The stormwater network:** all known or significant permitted NPDES stormwater discharges to the LWR within the study area. The stormwater network will be developed by the TMDL drafting committee with assistance from Phase 1 and 2 permitted municipal stormwater jurisdictions.

Table 8. Sampling location information for the 2012 Lower White River pH TMDL study.

Station ID	Map #	Synoptic water quality	Synoptic Hydrolab	Periphyton surveys	Riparian/Shade Surveys	Water & Air Temp	rH probe	Instream piezometer	ECY Continuous WQ	USGS Continuous WQ	USGS Continuous Flow	Description	NAD83 Latitude	NAD83 Longitude
Mainstem Stations														
10-WHT-28.0	1	x	X	x	x	x	x	x	x			White River below Mud Mtn Dam	47.150709	-121.950375
10-WHT-24.5	2	x	X		x	x		x		x		White River above diversion	47.169977	-122.002393
10-WHT-20.4	3	x	X	x	x	x		x				White River below Buckley	47.187727	-122.068919
10-WHT-16.2	4	x	X	x	x	x		x				White River above Muckleshoot	47.225095	-122.112797
10-WHT-10.3	5	x	X		x	x		x				White River d/s end of Tribal reach		
10-WHT-8.0	6	x	X	x	x	x	x	x		x	x	White River at R Street	47.274822	-122.208588
10-WHT-6.2	7	x	X		x	x		x				White River at A Street	47.266400	-122.228836
10-WHT-4.9	8	x	X		x	x		x	x			White River at 8th St	47.249867	-122.243828
10-WHT-1.4	9	x	X		x	x		x				White River above Fryar Ave	47.213016	-122.241886
10-WHT-0.1	10	x	X	x	x	x	x	x				White River at mouth	47.200209	-122.255270
Lake Tapps Diversion Stations (Trib/Spring Network)														
10-LTD-Diversion	11	x				x						Lake Tapps Diversion Canal at diversion	47.169745	-122.006965
10-LTD-Tailrace	12	x				x						Lake Tapps Tailrace at E.Valley Hwy	47.238185	-122.225537
10-LTD-FishRtrn	13	x										Fish Return at Diversion Canal Rd	47.169874	-122.032950
Point Source Stations														
10-EC-WWTP-Eff	14	x										Enumclaw WWTP effluent at plant	47.188147	-122.004970
10-BK-WWTP-Eff	15	x										Buckley WWTP effluent at plant	47.167985	-122.034964
10-MuckFishHatch	16	x										Muckleshoot Fish Hatchery effluent	47.171960	-122.003000
10-Sonoco-Eff	17	x										Sonoco effluent at outfall	0.000000	0.000000
Significant Tributaries (Trib/Spring Network)														
10-WHT-Trib27.6	18	x				x						Red Creek at Mud Mtn Rd	47.158603	-121.951724
10-BOI-0.1	19	x				x						Boise Creek at Mud Mtn Rd	47.176027	-122.018478
10-WHT-Trib15.6	20	x				x						Unnamed trib to LWR at RM Hwy 164	47.230721	-122.111808
10-WHT-Trib8.0	21	x				x						Bowman Creek at Kersey Wy	47.273133	-122.207703
10-WHT-Trib5.3	22	x				x						Government Canal at Butte Ave	47.256174	-122.242636
10-WHT-Trib2.1	23	x				x						Salmon Creek at E. Valley Hwy	47.217216	-122.225333
10-WHT-Trib1.3	24	x				x						Milwaukee Ditch near mouth	47.213420	-122.247654
Minor Tributaries/Springs(Trib/Spring Network)														
10-WHT-Trib26.4	25	x										Unnamed trib/spring to LWR at RM 26.4	47.160579	47.160579
10-WHT-Trib25.6	27	x										Unnamed trib/spring to LWR at RM 25.6	47.164289	47.164289
10-WHT-Trib24.8	28	x										Unnamed trib/spring to LWR at RM 24.8	47.172886	47.172886
10-WHT-Trib23.3	29	x										Unnamed trib/spring to LWR at RM 23.3	47.174894	47.174894
10-WHT-Trib22.0	30	x										Unnamed trib/spring to LWR at RM 22.0	47.171146	47.171146
10-WHT-Trib21.2	31	x										Unnamed trib/spring to LWR at RM 21.2	47.177604	47.177604
10-WHT-Trib20.6	32	x										Unnamed trib/spring to LWR at RM 20.6	47.183509	47.183509
10-WHT-Trib19.3	33	x										Unnamed trib/spring to LWR at RM 19.3	47.193318	47.193318
10-WHT-Trib18.3	34	x										Unnamed trib/spring to LWR at RM 18.3	47.201415	47.201415
10-WHT-Trib16.9	35	x										Unnamed trib/spring to LWR at RM 16.9	47.213538	47.213538
10-WHT-Trib16.8	36	x										Unnamed trib/spring to LWR at RM 16.8	47.215644	47.215644
10-WHT-Trib15.7	37	x										Unnamed trib/spring to LWR at RM 15.7	47.229197	47.229197
10-WHT-Trib14.35	38	x										Unnamed trib/spring to LWR at RM 14.35	47.241700	47.241700
10-WHT-Trib14.2	39	x										Unnamed trib/spring to LWR at RM 14.2	47.243956	47.243956
10-WHT-Trib13.2	40	x										Unnamed trib/spring to LWR at RM 13.2	47.257647	47.257647
10-WHT-Trib8.8	41	x										Unnamed trib/spring to LWR at RM 8.8	47.281737	47.281737
10-WHT-Trib6.3	42	x										Unnamed trib/spring to LWR at RM 6.3	47.269199	47.269199
10-WHT-Trib5.1	43	x										Unnamed trib/spring to LWR at RM 5.1	47.253182	47.253182
10-WHT-Trib4.0	44	x										Unnamed trib/spring to LWR at RM 4.0	47.244469	47.244469
10-WHT-Trib3.3	45	x										Unnamed trib/spring to LWR at RM 3.3	47.235234	47.235234
10-WHT-Trib2.9	46	x										Unnamed trib/spring to LWR at RM 2.9	47.230050	47.230050
10-WHT-Trib2.6	47	x										Unnamed trib/spring to LWR at RM 2.6	47.224606	47.224606
10-WHT-Trib26.4	25	x										Unnamed trib/spring to LWR at RM 26.4	47.160579	47.160579
10-WHT-Trib25.6	27	x										Unnamed trib/spring to LWR at RM 25.6	47.164289	47.164289

Sampling locations are tentative. Some locations may be dropped or moved based on whether access is available or logistically feasible.

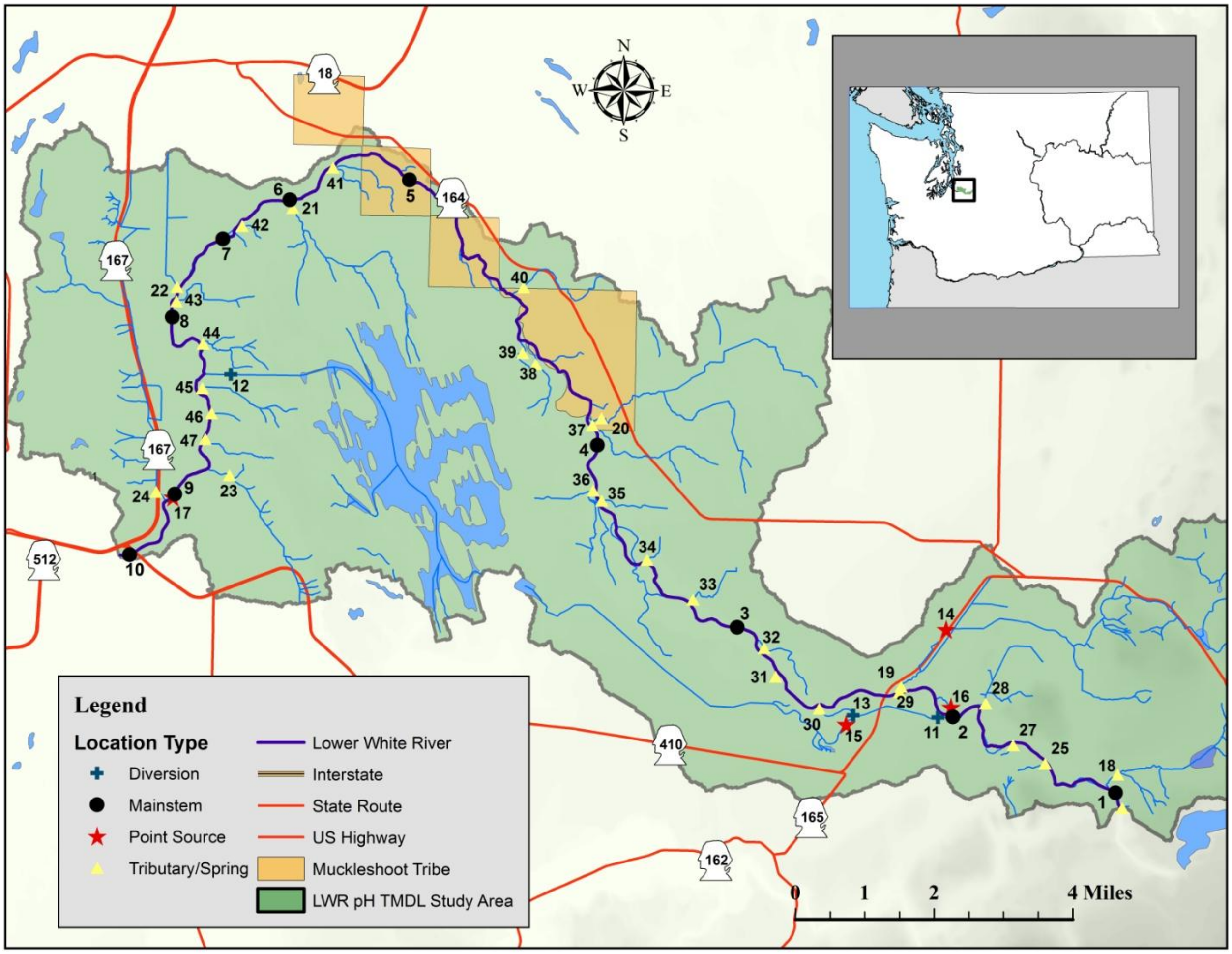

Figure 11. Mainstem, point source, and tributary/spring sampling locations for the 2012 Lower White River pH TMDL study.

Meteorology and hydrology

Air temperature and relative humidity data will be recorded at various stations along the mainstem of the White River (Table 9). Supplemental meteorological data including precipitation, cloud cover, wind direction, wind speed, and solar radiation, will be obtained from various sources including the NWS station at SeaTac Airport (KSEA), the AgWeatherNet station at WSU Puyallup, USGS Station #12095000 at South Prairie Creek, and several locally maintained stations within the University of Utah's MesoWest network. Table 9 summarizes weather stations and available data.

Table 9. Summary of weather stations, location, and available data.

Station ID	Location	Network/ Origin	Air Temp	Dew Point	Relative Humidity	Precipitation	Wind Direction	Wind Speed	Cloud Cover	Solar Radiation
KSEA	SeaTac Airport	NCDC - NWS	x	x	x	x	x	x	x	
12095000	South Prairie Creek	USGS	x			x				
N7CGR	Auburn	MesoWest	x	x	x	x	x	x		
DW2276	Buckley	MesoWest	x	x	x	x	x	x		
TABRN	Auburn at C St	WA DOT	x	x	x		x	x		
WSU Puyallup	Puyallup	AgWeatherNet	x	x	x	x	x	x		x
UW Rooftop	Seattle	UW								x

Continuous hydrology data for the mainstem White River will be obtained from the two USGS flow gages within the study area at RM 7.6 (#12100490) and RM 23.9 (#12099200). In addition, streamflows for RM 28 will be estimated based on continuous stage measurement at the USGS gage installed at that site (#12098500). A stage discharge relationship will be developed by manually measuring streamflow at the site over the range of flows represented during the study duration. Measurement may not be logistically feasible at this site during higher flow conditions.

Additional continuous hydrology data for tributary inputs and abstractions will be obtained or estimated from various sources. Flow data for Boise Creek (#12099600), the Lake Tapps Diversion Canal in Buckley (#12098920), and the Lake Tapps tailrace at Dieringer (#12101100) will also be obtained from USGS-operated flow gages. Ecology will estimate continuous flow at Salmon Creek at East Valley Highway based on continuous stage and velocity measurements collected by the City of Sumner.

Ecology will estimate continuous hydrology for the remaining major tributaries based on regression with either the upper (Boise Creek) or lower (Salmon Creek) reference stream. In addition to flows measured during the synoptic surveys, additional flows will be measured at the major tributaries in order to obtain enough data points to establish regression relationships. For small tributaries measured during the synoptic surveys, if a regression relationship cannot be established from a continuous record at Boise or Salmon Creek, flows will be interpolated between surveys.

Ecology will use flow data from the Daily Monitoring Reports (DMR), supplemented with the WWTP databases to estimate continuous flow records for the WWTPs. Known water withdrawals will be subtracted from the flow balance. Groundwater inputs (or streamflow losses to groundwater) will be estimated as the residual in the flow balance based on all other measured/estimated sources. Evaporation may be estimated based on available hydrology, vegetation, and meteorology data or lumped within the groundwater term.

Eutrophication synoptic surveys

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

Approximately one survey will be conducted per month, depending on conditions. Conditions from July through September are expected to be more turbid with higher flows; however, non-turbid conditions resulting in elevated pH levels have occurred during these months in previous years. If significant precipitation or dramatic glacial melt occurs immediately before a scheduled survey, the survey will be canceled and rescheduled during a back-up week.

Synoptic data collection will include:

- Multi-probe deployments to collect continuous diel data (at 5 or 10 minute intervals) for temperature, pH, DO, and specific conductance at the mainstem network sites.
  - Deployments may be extended by a period of days to weeks, or additional deployments may occur during non-synoptic weeks, if equipment is available.
- Water sample collection at all four networks of sites for the following parameters:
  - Alkalinity, ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate (soluble reactive phosphorus), total phosphorus, dissolved and total organic carbon, chloride, chlorophyll *a*, total suspended solids, total non-volatile suspended solids, and turbidity.
  - Composite samples from major point sources using an auto sampler. Samples will be collected at regular time intervals and composited over a 24-hour period.
  - Biochemical Oxygen Demand (BOD) samples will be collected from select point source, mainstem, and tributary sites.
- Periphyton biomass and chlorophyll *a* samples from a subset of six mainstem network sites during each synoptic survey at RMs 0.1, 3.3, 8, 16, 20.4, and 28.
  - At periphyton sites, profiles of photosynthetically active radiation (PAR) vs. depth will be measured to estimate vertical light extinction using an underwater irradiameter.
- Streamflow measurements:
  - Manually at all synoptic input and stormwater network sites sampled.

    - Manually at mainstem network sites when and where logistically feasible, depending on safe conditions for measurement.
    - Point source flows are measured by each facility and will be obtained from the facility managers or from monthly DMRs.
    - Mainstem flows at RM 7.6 and RM 23.9 will be obtained from the USGS continuous flow gages #12100490 and #12099200.

Temperature, shade, and channel geometry data

In order to develop an accurate temperature model, Ecology will collect instream temperature, riparian vegetation, effective shade, channel geometry, and other data during the 2012 growing season. Data collection will include:

- Continuous temperature dataloggers (thermistors) deployment at all mainstem network sites for the length of the 2012 growing season.
    - At each site one logger will be deployed for water temperature and one for air temperature. Some sites may have a data logger for relative humidity.
    - Loggers will be programmed to record temperature at 10-minute intervals.
    - Water thermistors will be deployed in the thalweg of a stream, suspended off the stream bottom, and in a well-mixed area, typically in riffles or swift glides.
- Effective shade estimates of the aerial density of vegetation shading the stream, including:
    - Hemispherical images of the sky, overhanging vegetation, and topography at stream center. These photographs will be taken at each mainstem network site and at a few reference reaches to verify existing riparian vegetation compared to aerial photos. The digital images will be processed and analyzed using the HemiView© software program (Stohr, 2008).
    - Effective shade data at each site using a Solar Pathfinder™ that uses a polished, transparent, convex plastic dome to estimate shade from a given obstacle to the stream at different hours of the day and months of the year.
- Channel geometry and habitat data following Timber-Fish-Wildlife methods for thermal reach surveys (Schuett-Hames et al., 1999).
    - The surveys will be conducted during the summer of 2012 at the mainstem network sites. When feasible, measurements will be taken at 10 locations per site.
    - Measurements will consist of bankfull width and depth, wetted width and depth, substrate composition, canopy density, and channel type.
- Riparian vegetation data within 150 feet of both banks of the LWR (Johnston et al., 2005).
    - Vegetation heights will be measured in the field using a laser range/ height finder.
    - Comparing the field data collected to aerial photos, a GIS map layer will be made and will include vegetation type, general height class, and vegetation density.
    - Additional Riparian Management Zone characteristics, such as active channel width, effective shade, bank incision, and bank erosion will be recorded during the thermal reach surveys.

Continuous water quality monitoring

Ecology's Freshwater Monitoring Unit will install two continuous water quality stations on the LWR, one below Mud Mountain Dam (RM 28) and one at 8th St (RM 4.9), for the duration of the 2012 growing season. These stations will collect continuous measurements for temperature, DO, pH, and specific conductance. The continuous water quality monitoring will be installed and maintained following a separate QAPP and set of protocols for Ecology's statewide ambient monitoring program (Hallock, 2009).

Ecology may also use any approved continuous water quality data collected by the USGS at RMs 7.6 (#12100490) and 24.2 (#12098700), as well as for the Lake Tapps tailrace at Dieringer (#12101100). Water quality parameters collected at these locations include temperature, pH, DO, specific conductance, and turbidity.

Groundwater data

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

Where site conditions allow[1], instream piezometers will be installed in July 2012 at each of the mainstem network sites to monitor surface-water and groundwater head relationships and streambed water temperatures (Figure 11 and Table 8).

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

Each piezometer will be instrumented with up to three thermistors for continuous monitoring of streambed water temperatures (Figure 12). In a typical installation, one thermistor will be located near the bottom of the piezometer, one at a depth of approximately 0.5 feet below the streambed, and one will be located roughly equidistant between the upper and lower thermistors. The piezometers will be accessed monthly to download thermistors and to make spot measurements of stream and groundwater temperatures for later comparison against and validation of the thermistor data. The monthly spot measurements will be made with properly maintained and calibrated field meters in accordance with standard Ecology Environmental Assessment (EA) Program methodology (Ward, 2007).

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[1] Piezometer installation may not be possible at some sites due to the presence of near-surface bedrock or consolidated streambed sediments.

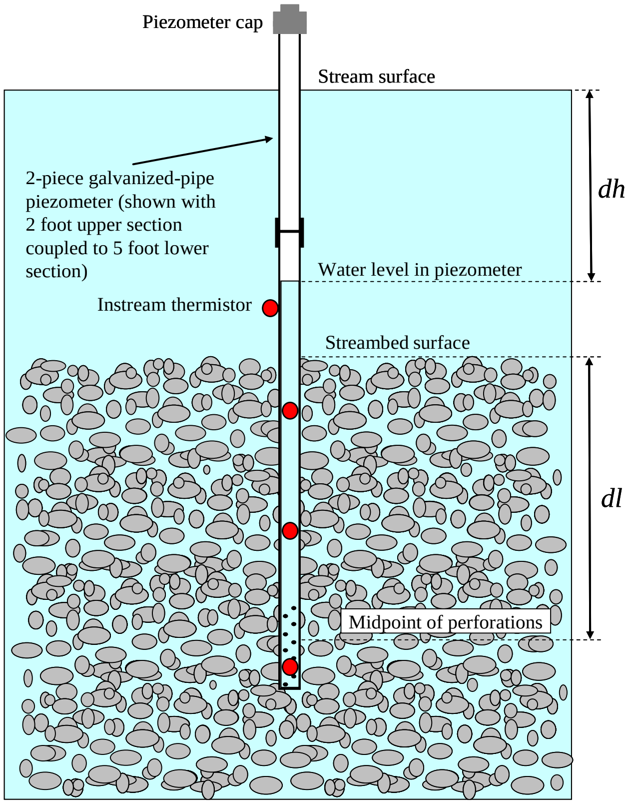

Figure 12. Instream piezometer conceptual diagram (diagram not to scale).

During the monthly site visits, surface water stage and instream piezometer water levels will be measured using a calibrated electric well probe, a steel tape, or a manometer board (as appropriate) in accordance with standard EAP methodology (Sinclair and Pitz, 2010). The water level (head) difference between the piezometer and the river provides an indication of the vertical hydraulic gradient and the direction of flow between the river and groundwater. When the piezometer head exceeds the river stage, groundwater discharge into the river can be inferred. Similarly, when the river stage exceeds the head in the piezometer, loss of water from the river to groundwater storage can be inferred.

Field staff will conduct two groundwater quality sampling events (scheduled to coincide with synoptic surface-water sampling events), one in either July or August and one in October. During these synoptic surveys, groundwater samples will be collected from instream piezometers located along gaining reaches and from defined seeps and springs that discharge directly to the White River. The samples will be submitted to the laboratory for analysis of alkalinity, chloride, orthophosphate, total phosphorus, nitrate/nitrite, ammonia, total persulfate nitrogen, iron, and dissolved organic carbon analysis. Groundwater temperature, water level, conductivity, pH, and dissolved oxygen will also be measured during the surveys.

If feasible, Ecology will monitor several shallow off-stream domestic wells to assess "regional" groundwater levels, temperatures, and groundwater quality. When selecting wells, preference will be given to shallow, properly documented wells in close proximity to the LWR. Where owner’s permission is granted and site conditions allow, logging thermistors may also be deployed in the wells.

Time of travel to determine average stream velocities

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

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

Two studies will take place at different streamflow levels during summer and fall, to capture time of travel during typical high (~1000 cfs) and low (~500 cfs) flow conditions for the study period. An extreme low-flow time of travel study was conducted in October of 1990 (Pelletier, 1996), when streamflow was less than 200 cfs, between RM 23.1 and 4.9. Results of the three studies may be used to establish a relationship between velocity and flow. Dye studies will coincide with the synoptic surveys, if feasible.

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

Light extinction surveys

Light limitation is a significant factor in simulation of primary production by bottom algae. Water quality models such as WASP and QUAL2KW require estimation of the light extinction coefficient to allow the model to estimate the limitation of growth that is caused by exposure to diel variations in light intensity. The light extinction coefficient is the slope of the natural log of ambient light intensity in the water versus depth. The LWR exhibits a wide range of turbidity which is likely to cause significant variations in the light extinction coefficient.

In order to develop relationships between light extinction, turbidity, and suspended solids, we will measure the light extinction at a reference location at the downstream end of the study area where there is sufficient depth to measure profiles of light intensity. Profiles of ambient PAR at various depths will be measured in the water column from the surface to the bottom. At the same time samples will be collected for determination of turbidity, total suspended solids, and total nonvolatile suspended solids. This will be repeated on each of the four synoptic surveys, plus an additional 6 special surveys to represent the entire range of turbidity variations that occur during the study period.

Storm monitoring

Given that critical conditions in the LWR occur during steady-state low-flow conditions, Ecology will not conduct targeted stormwater monitoring during runoff events. However, “stormwater” baseflow from municipal stormwater infrastructure may still discharge to the LWR during non-runoff conditions. During the synoptic surveys, nutrient loading will be characterized at the stormwater network of sites for any known or significant municipal stormwater discharges with measurable flow.

Sampling and Measurement Procedures

Field sampling and measurement protocols will follow Standard Operating Procedures (SOP) developed by the Environmental Assessment Program for TMDL development (Table 10). Field measurements for pH, DO, conductivity, and temperature will be collected using a calibrated Hydrolab® sonde (Datasonde or Minisonde; Series 4 or 5). DO samples will be hand-collected using a displacement sampler and analyzed using the Winkler titration method (APHA, 2005; Ward and Mathieu, 2011).

Table 10. Field sampling and measurement methods and protocols

Parameter	Measurement/ Sample Type	Lab Method	Field Protocol #
Water quality samples (see Table 8 for list)	Grab samples	See Table 11	EAP015 (Joy, 2006)
Dissolved Oxygen	Displacement Sample	SM 4500 OC	EAP023 (Ward and Mathieu, 2011)
DO, pH, Conductivity, ORP, Chl *a*, and Temperature	Hydrolab® multi-parameter sonde	n/a	EAP033 (Swanson, 2010)
Flow	Instantaneous	n/a	EAP024 (Sullivan, 2007); EAP055 (Shedd et al., 2008)
Continuous temperature	Thermistor/ logger	n/a	EAP044 (Bilhimer and Stohr, 2009)
Well depth/water level	In situ	n/a	EAP052 (Marti, 2009); EAP061 (Sinclair and Pitz, 2010)

Field staff will measure instantaneous flows with either a Marsh McBirney Flow-mate meter (Sullivan, 2007) or using Teledyne RDI's StreamPro ADCP (Shedd et al., 2008). For continuous temperature monitoring, field staff will follow deployment, maintenance, and QA/QC procedures developed by Ecology (Bilhimer and Stohr, 2009).

Field staff will measure PAR, using a Kahl Scientific Underwater Irradiameter (Model 268WD305), above the water surface, immediately below the water surface, and at various depths from the surface to the stream bottom to obtain a depth profile of PAR. The light extinction coefficient will be calculated as the slope of the natural log of PAR at various depths versus the sampling depth in meters.

For continuous temperature monitoring, field staff will follow deployment, maintenance, and QA/QC procedures developed by Ecology (Bilhimer and Stohr, 2009).

Field staff will collect grab samples directly into pre-cleaned/sterilized containers supplied by Manchester Environmental Laboratory (MEL) and described in the MEL User's Manual (2008). Table 11 lists the sample parameters, containers, volumes, preservation requirements, and holding times. Field staff will store samples for laboratory analysis on ice and deliver to MEL within 24 hours of collection via either the Ecology courier or direct drop-off after sampling. MEL follows standard analytical methods outlined in the MEL *Lab Users Manual* (MEL, 2008).

Table 11. Containers, preservation techniques, and holding times for sampled parameters.

Parameter	Sample Method	Container	Preservative	Holding Time
Alkalinity	SM 2320B	500 mL poly – NO Headspace	Cool to 0-6ºC; Fill bottle *completely*; Don't agitate sample.	14 days
Ammonia	SM4500NH3H	125 mL clear poly	H_2SO_4 to pH<2 ; Cool to 0-6°C.	28 days
Biochemical Oxygen Demand 5-day (BOD5)	SM5210B	1 gallon cubitainer	Cool to ≤6°C; keep in dark.	48 hours
Chloride	EPA300.0/ SM4110C	500 mL w/m poly bottle	Cool to ≤6°C.	28 days
Chlorophyll *a*	SM10200H(3)	1000 mL amber poly bottle	Cool to ≤6°C; keep in dark.	24 hr pre-filtration; 28 day post.
Ash-Free Dry Weight-plant tissue	SM10300C(5)	1000 mL amber poly bottle	Cool to ≤6°C; keep in dark.	24 hr pre-filtration; 28 day post.
Total Carbon & Nitrogen – plant tissue	EPA440.0	1000 mL amber poly bottle	Cool slurry to ≤4°C; keep in dark; dry filter at 103-105°C & store in desiccator	24 hr pre-filtration; 100 days post
Total Phosphorus- plant tissue	EPA200.7	1000 mL amber poly bottle	Cool to ≤6°C; keep in dark.	14 days pre-acidification; 6 months post
Dissolved Organic Carbon	SM5310B	60 mL poly with: 0.45 um pore size filters[1]	Field filter with 0.45 um pore size filter; 1:1 HCl to pH<2; Cool to 0-6°C.	28 days
Nitrate/Nitrite	SM4500NO3I	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0-6°C.	28 days
Total Persulfate Nitrogen	SM4500NO3 B	125 mL clear poly	H_2SO_4 to pH<2; Cool to 0-6°C.	28 days
Orthophosphate	SM4500PG	125 mL amber poly w/ 0.45 um pore size filters[2]	Filter in field with 0.45 um pore size filter; Cool to 0-6°C.	48 hours
Total Phosphorus	SM4500PF	60 mL clear poly	1:1 HCl to pH<2; Cool to 0-6°C.	28 days
Total Organic Carbon	SM5310B	60 mL clear poly	1:1 HCl to pH<2; Cool to 70-6°C.	28 days
Total Suspended Solids	SM2540D	1000 mL clear poly bottle	Cool to ≤6°C	7 days
Total Non-Volatile Suspended Solids	SM 540B & E	1000 mL clear poly bottle	Cool to ≤6°C	7 days
Turbidity	SM2130	500 mL w/m poly bottle	Cool to ≤6°C	48 hours

[1] Whatman PuradiscTM 25 pp or equivalent, with a polypropylene media filter designed for aqueous and organic solutions containing high debris levels and for hard-to-filter solutions;

[2] Whatman GD/X 25 mm or equivalent, with a cellulose acetate filter membrane. A glass microfiber prefilter may be used for "hard to filter" OP samples.

Periphyton samples will be collected following methods adapted from Ecology's *Quality Assurance Monitoring Plan: Ambient Biological Monitoring in Rivers and Streams: Benthic Macroinvertebrates and Periphyton* (Adams, 2010).

At the end of each field visit, field staff will clean field gear in accordance with the SOP for minimizing the spread of invasive species for areas of moderate concern and extreme concern. This document is available at www.ecy.wa.gov/programs/eap/InvasiveSpecies/AIS-PublicVersion.html.

A Hydrolab® multi-parameter sonde will be used to measure water conductivity, pH, DO, and temperature of groundwater in piezometers and the adjacent river water. Table 12 summarizes analytical methods and detection limits for groundwater sampling and measurements.

Table 12. Groundwater sampling parameters, including test methods and detection limits.

Parameter	Equipment Type and Test Method	Detection limit
Field Measurements		
Water level	Calibrated E-tape	0.01 foot
Temperature	Hydrolab® multi-parameter sonde	0.1°C
Specific Conductance	Hydrolab® multi-parameter sonde	1 µS/cm
pH	Hydrolab® multi-parameter sonde	0.1 SU
Dissolved Oxygen	Hydrolab® multi-parameter sonde	0.1 mg/L
Laboratory Analyses		
Alkalinity	SM 2320B	5 mg/L
Chloride	EPA 300.0	0.1 mg/L
Orthophosphate[1]	SM 4500-P G	0.003 mg/L
Total phosphorus[1]	SM 4500-P F	0.005 mg/L
Nitrate+nitrite-N[1]	SM 4500 NO_3^- I	0.01 mg/L
Ammonia[1]	SM 4500-NH_3 H	0.01 mg/L
Total persulfate nitrogen-N[1]	SM 4500NB	0.025 mg/L
Dissolved organic carbon[1]	EPA 415.1	1 mg/L

[1] Dissolved fraction.
SU: Standard units.

Quality Control Procedures

Field

Field sampling and measurements will follow quality control protocols described in Ecology's field sampling protocols (Table 10). Ecology will collect duplicate field samples, in a side-by-side manner, for 10 % of all samples to assess field and lab variability. Field staff will duplicate field measurements at 10 % of the sites by:

1. Allowing all parameters to equilibrate and recording an initial measurement.
2. Removing the sonde from the water for approximately 30 seconds.
3. Returning the sonde to the water near the initial location.
4. Allowing all parameters to re-equilibrate and recording a second measurement.

Prior to each synoptic survey, field staff will calibrate the check probes and short term deployment probes by:

- For pH, using a two-point calibration with NIST-certified pH 7 and pH 10 standards. A linearity check will then be performed with a third pH 4 buffer.
- For conductivity, using a one-point calibration with NIST-certified 100 uS/cm conductivity standards. A zero conductivity check will also be performed.
- For DO, using the water saturated air calibration method, as recommended by manufacturer.
- For temperature, probes must be factory calibrated. Instead of calibration, probes will be checked against a NIST-certified thermometer.
- For chlorophyll *a*, using a secondary standard calibrated to a sample collected from the White River.

During synoptic surveys, check probes will be re-calibrated for pH twice daily, once mid-day and once in the evening or morning of the following day.

For short term Hydrolab deployments, field staff will compare deployed probes to check probes immediately following deployment, mid-deployment, and upon retrieval. Field staff will post-check deployed sondes against buffers, National Institute of Standards and Technology (NIST) thermometer, and 100% saturation within 24 hours of retrieval. Probes will not be calibrated during post-check.

For long term Hydrolab deployments at RM 28 and RM 4.9, field staff will follow procedures outlined by Hallock (2009). For this study, the maintenance routine will involve:

- Site visits at least once a month, scheduled the week before each synoptic survey, that include:
  - Removal of sonde from slant pipe and cleaning of probes.
  - Removal of any debris from station and cleaning/flushing of slant pipe.
  - Comparison with freshly calibrated check probe, buffer check, and a Winkler DO check (for data correction purposes).
  - Download of data.
  - Re-calibration of probes.

- If noticeable fouling is occurring during monthly visit, the frequency of service visits will be increased accordingly for the remainder of the study.
- Additional service visits will be triggered by reviewing the real-time record for suspect data. Examples of suspect data include: appearance of drift, sudden spikes or drops, large deviations from other sondes in the basin. The principal investigator will review online records at least once a week.

Field staff will duplicate instantaneous streamflow measurements during each synoptic survey to check precision. Staff will perform flow duplicates both within teams (the same team measures flow at the same transect twice consecutively) and between teams (all teams measure the same transect at as close to the same time as possible with different flow meters). If a significant difference is found between flow meters (>5%RSD), or a particular meter has a large duplicate error, the instruments will be zeroed out or not used at all. Instantaneous flows may also be compared to USGS continuous stream gage results as an additional QA/QC measure.

The Hobo Water Temp Pro© instruments will have a calibration check both pre- and post-study in accordance with Ecology Temperature Monitoring Protocols (Ward, 2003). Ecology performs this check, using a NIST-certified reference thermometer, to document instrument accuracy at representative temperatures. The calibration check may show that the temperature datalogger differs from the NIST-certified thermometer by more than the manufacturer-stated accuracy of the instrument (range greater than ±0.2°C or ±0.4°C).

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

Variation for field sampling of instream temperatures and potential thermal stratification will be addressed with a field check of stream temperature at all monitoring sites upon deployment, during regular site visits, and during instrument retrieval at the end of the 2012 study period. Air temperature data and instream temperature data for each site will be compared to determine if the instream temperature instrument was exposed to the air due to stream stage falling below the installed depth of the stream temperature instrument.

Laboratory

MEL will analyze all samples for this study, with a few exceptions:

- Rhithron Associates, Inc. will analyze periphyton and macroinvertebrate identification samples.
- A contract laboratory (to be determined) will analyze samples for carbon and nitrogen in periphyton tissue.

The MEL Quality Assurance Manual (MEL, 2006) documents the laboratory's quality control procedures in detail. If any of these quality control procedures are not met, the associated results will be qualified and used with caution, or not used at all. Table 13 outlines the quality objectives associated with MEL's quality control procedures.

Quality Objectives

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

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

Table 13 outlines analytical methods, expected precision of sample duplicates, and method reporting limits. The targets for precision of field duplicates are based on historical performance by MEL for environmental samples taken around the state by EAP (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives.

Table 13. Measurement quality objectives for laboratory analysis parameters.

Analysis	Method	Method Lower Reporting Limit[2]	Lab Blank Limit	Check Standard (% recovery limits)	Matrix Spikes (% recovery limits)	Precision – Lab Duplicates (RPD)	Precision – Field Duplicates (median)[1]
Total Alkalinity	SM2320B	5 mg/L	<½ RL	80-120%	n/a	20%	10% RSD
Biological Oxygen Demand (5-day)	SM5210B	2 mg/L	<0.2 mg/L	70-125%	n/a	20%	25% RSD
Chloride	EPA 300.0	0.1 mg/L	<MDL	90-110%	75-125%	20%	5% RSD
Chlorophyll *a* – water	SM10200H3	0.05 ug/L	n/a	n/a	n/a	20%	20% RSD
Chlorophyll *a* – plant tissue	SM10200H3	0.05 ug/L	n/a	n/a	n/a	20%	50% RSD
Ash Free Dry Weight –Plant tissue	SM10300C(5)	0.05 ug/L	n/a	n/a	n/a	20%	50% RSD
Total Nitrogen – Plant Tissue	EPA 440.0	0.01% of DW	n/a	85-115%	75-125%	20%	50% RSD
Total Carbon – Plant Tissue	EPA 440.0	0.1% of DW	n/a	85-115%	75-125%	20%	50% RSD
Total Phosphorus – Plant Tissue	EPA 200.7	0.01% of DW	n/a	85-115%	75-125%	20%	50% RSD
Dissolved Oxygen (Winkler)	SM4500OC	0.05 mg/L	n/a	n/a	n/a	n/a	± 0.1 mg/L
Dissolved Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Organic Carbon	SM5310B	1 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Persulfate Nitrogen	SM4500NB	0.025 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Ammonia	SM4500NH3H	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Nitrate/Nitrite	SM4500NO3I	0.01 mg/L	<½ RL	80-120%	75-125%	20%	10% RSD
Orthophosphate	SM4500PG	0.003 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Total Phosphorus	SM4500PF	0.005 mg/L	<MDL	80-120%	75-125%	20%	10% RSD
Turbidity	SM2130	0.5 NTU	< 1/10th RL	90-105%	n/a	20%	15% RSD
Total Suspended Solids	SM2540D	1 mg/L	±0.3 mg	80-120%	n/a	20%	15% RSD

RL: reporting limit
MDL: method detection limit
DW: dry weight

[1] field duplicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately

[2] reporting limit may vary depending on dilutions

Table 14 summarizes field measurement MQOs for precision and bias, as well as the manufacturer’s stated accuracy, resolution, and range for the equipment used in this study.

Table 14. Measurement quality objectives and resolution for field measurements and equipment.

Parameter	Equipment/ Method	Bias (median)	Precision–Field Duplicates (median)	Equipment Accuracy	Equipment Resolution	Equipment Range	Expected Range
Water Quality Measurements							
Water Temperature	Hydrolab®	See Table 15	± 0.2°C	± 0.1°C	0.01° C	-5 to 50° C	0 to 30° C
Specific Conductance	Hydrolab®	See Table 15	5% RSD	± (0.5% + 1 uS/cm)	1 uS/cm	0 to 100,000 uS/cm	20 to 500 uS/cm
pH	Hydrolab®	See Table 15	± 0.2 s.u.	± 0.2 units	0.01 s.u.	0 to 14 s.u.	6 to 10 s.u.
Dissolved Oxygen – Luminescent (LDO)	Hydrolab®	See Table 15	5% RSD	± 0.1 mg/L at <8 mg/L; ± 0.2 mg/L at 8 to <20 mg/L[b]	0.01 mg/L	0 to 60[c] mg/L	0.1 to 15 mg/L
Dissolved Oxygen – Clark Cell	Hydrolab®	See Table 15	5% RSD	± 0.2 mg/L at <20mg/L[b]	0.01 mg/L	0 to 50[c] mg/L	0.1 to 15 mg/L
Chlorophyll *a* - *in vivo*	Hydrolab®		10% RSD	± 3%	0.01 ug/L	0.03 to 50 ug/L[d]	0.1 to 50 ug/L
Oxidation-Reduction Potential	Hydrolab®		10% RSD	± 20 mV	1 mV	-999 to 999 mV	-999 to 999 mV
Flow Measurements							
Streamflow	EAP SOP#024	n/a	10% RSD	n/a	n/a	n/a	0.01 to 2,000 cfs
Velocity	Marsh McBirney	±0.05 ft/s[e]	n/a	±2% + zero stability[e]	0.01 ft/s	-0.5 to +20 ft/s	0.01 to 10 ft/s
Velocity	StreamPro ADCP	n/a	n/a	±1.0% or ±0.007 ft/sc	0.003 ft/s	-16 to +16 ft/s	0.01 to 10 ft/s
Continuous Temperature Monitoring							
Water Temperature	Hobo Water Temp Pro v2	n/a	n/a	±0.2°C at 0° to 50°C[bf]	0.02°C at 25°C	-40° to +50°C	0 to 30°C
Air Temperature	Hobo Water Temp Pro v2 or v1	n/a	n/a	±0.2°C at 0° to 50°C[bf]	0.02°C at 25°C	-40° to 70°C	-5 to 40°C
Relative Humidity	Hobo Pro	n/a	n/a	±3%	0.03%	0.03% to 100%	30% to 100%

[a] sum of bias due to fouling bias and calibration bias
[b] accuracy is diminished outside of listed range
[c] greater than natural range
[d] equipment range is dynamic, listed range is for medium sensitivity setting
[e] zero stability check criteria, not a measurement of bias
[f] also the MQO for accuracy assessed by pre and post deployment water bath checks

Precision

Precision is defined as the measure of variability in the results of duplicate measurements due to random error. Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for duplicates will be expressed as %RSD and assessed following the MQOs outlined in Tables 13 and 14.

Bias

Bias is defined as the difference between the population mean and true value of the parameter being measured. Field and laboratory QC procedures, such as blanks, check standards, and spiked samples, provide a measure of any bias affecting sampling and analytical procedures. Field staff will minimize bias in field measurements and samples by strictly following measurement, sampling, and handling protocols.

EAP staff will assess bias in field samples by submitting field blanks. Field staff will prepare blanks in the field by:

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

For field measurements, EAP staff will:

- Minimize bias in the Hydrolab® sonde field measurements by pre-calibrating before each run.
- Assess any potential bias from instrument drift in probe measurements by:
    - For pH and conductivity, post-checking the probes against NIST-certified pH and conductivity standards.
    - For DO, post-checking the probe against 100% saturation and comparing Winkler DO samples to field measured DO values.
    - For temperature, checking the probe's temperature readings before and after each run using an NIST-certified thermometer.
- Assess bias from instrument fouling by:
    - Collecting a final measurement upon retrieval of a deployed sonde,
    - Then immediately cleaning the sensors at the site,
    - And finally taking another measurement immediately after cleaning.

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

Table 15 contains the data quality bias objectives for both instrument drift and fouling checks.

Table 15. Measurement quality objectives for Hydrolab post-deployment and fouling checks.

Parameter	Units	Accept	Qualify	Reject
pH	std. units	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8
Conductivity*	uS/cm	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%
Temperature	° C	< or = ± 0.2	> ± 0.2 and < or = ± 0.8	> ± 0.8
Dissolved Oxygen**	% saturation	< or = ± 5%	> ± 5% and < or = ± 15%	> ± 15%

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

Corrected data will be assigned an accuracy rating based on combined fouling and calibration corrections applied to the record (Table 16). Data assigned a 'poor' rating will not be used in data analysis. For qualified data where a data correction could not be confidently applied, the project manager may choose to exclude the data from data analysis based on a thorough QC review.

Table 16. Ratings of accuracy for data corrections based on combined fouling and calibration drift corrections applied to record.

Measured field parameter	Ratings of accuracy for data corrections			
	Excellent	Good	Fair	Poor
Water temperature	≤ ± 0.2 °C	> ± 0.2 – 0.5 °C	> ± 0.5 – 0.8 °C	> ± 0.8 °C
Specific conductance	≤ ± 3%	> ± 3 – 10%	> ± 10 – 15%	> ± 15 %
Dissolved oxygen	≤ ± 0.3 mg/L or ≤ ± 5%, whichever is greater	> ± 0.3 – 0.5 mg/L or > ± 5 – 10%, whichever is greater	> ± 0.5 – 0.8 mg/L or > ± 10 – 15%, whichever is greater	> ± 0.8 mg/L or > ± 15%, whichever is greater
pH	≤ ± 0.2 units	> ± 0.2 – 0.5 units	> ± 0.5 – 0.8 units	> ± 0.8 units

Comparability

Comparability to previously collected Ecology data will be established by strictly following EAP protocols and adhering to data quality criteria. Comparability to USGS water quality data will be evaluated by conducting side-by-side short-term deployments at the USGS stations.

Representativeness

The study is designed to collect enough measurements and samples to adequately assess spatial and temporal variability of the measured parameters throughout the study area. Sample locations are distributed along the river and throughout the watershed strategically to represent different conditions and land uses. The representativeness of a sample location will be assessed by periodic measurements across both width and depth of channel. A sample location will be considered representative if it meets the ‘accept’ criteria in Table 15.

Completeness

EPA has defined completeness as a measure of the amount of valid data needed to be obtained from a measurement system (Lombard and Kirchmer, 2004). The goal for this study is to correctly collect and analyze a minimum of 95% of the samples and measurements for all sites. Problems occasionally arise during sample collection that cannot be controlled, including flooding, stagnant or no flow during dry periods, equipment failure, or samples damaged in transit.

If equipment fails or samples are damaged, Ecology will attempt to recollect the data the following day, if possible. In general, the study is designed to accommodate some data loss and still meet project goals and objectives.

Quality objectives for modeling or other analysis

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

Model bias will be assessed either mathematically or graphically. Bias is the systematic deviation between a measured (i.e., observed) and a computed value. Bias in this context could result from uncertainty in modeling or from the choice of parameters used in calibration. Mathematically, bias is calculated as % RPD. This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

$RPD = (| P_i – O_i | * 2) / (O_i + P_i)$, where
P_i = ith prediction
O_i = ith observation

QUAL2KW and WASP graphically represent observed and measured values along the length of the modeled stream segment. Therefore, bias will also be evaluated by observing modeled trends and over- or under-prediction between computed vs. measured values.

Data Management Procedures

Field measurement data will be entered into a field book with waterproof paper in the field and then entered into Excel® spreadsheets (Microsoft, 2001) as soon as practical after returning from the field. Alternatively, Ecology will collect some field data electronically using a rugged, hand-held field computer. Data will be combined into an Excel database that will be used for preliminary analysis and to create a table to upload data into Ecology's Environmental Information Management (EIM) System.

Sample result data received from MEL by Ecology's Laboratory Information Management System (LIMS) will be exported prior to entry into EIM and added to a cumulative spreadsheet for laboratory results. This spreadsheet will be used to informally review and analyze data during the course of the project.

An EIM user study (GPEL0010) has been created for this study and all monitoring data will be available via the internet once the project data has been validated. The URL address for this geospatial database is: www.ecy.wa.gov/eim/. All data will be uploaded to EIM by the EIM data engineer once it has been reviewed for quality assurance and finalized.

All spreadsheet files, paper field notes, and Geographic Information System software products created as part of the data analysis will be kept with the project data files.

Audits and Reports

Audits on field work and data analysis may be conducted at any time during the course of the project, by unit supervisors for the project team. The project manager will be responsible for submitting quarterly reports as well as the draft technical sections of the report to the TMDL drafting committee according to the project schedule.

Data Verification and Validation

MEL will provide verification for laboratory-generated data. Data reduction, review, and reporting will follow the procedures outlined in the MEL *QA Manual* (MEL, 2006). Lab results will be checked for missing or improbable data. Variability in lab duplicates will be quantified using the procedures outlined in the MEL *QA Manual* (MEL, 2006). Any estimated results will be qualified and their use restricted as appropriate. A standard case narrative of laboratory Quality Assurance/ Quality Control (QA/QC) results will be sent to the project manager for each set of samples.

Field notebooks will be checked for missing or improbable measurements before leaving each site. The Excel® Workbook file containing field data will be labeled "DRAFT" until data verification and validation are completed. Data entry will be checked against the field notebook data for errors and omissions.

Field duplicate sample results will be compared to quality objectives in Table 14. Data requiring additional qualifiers will be reviewed and verified by the project manager.

The project manager will additionally verify data received from LIMS by:

- Checking for omissions against the “Request for Analysis” forms.
- Checking result values against expected range of results and data from previous surveys.

After data verification is complete, all field, laboratory, and flow data will be entered into Ecology’s EIM system. An independent data reviewer will validate the EIM data by checking for errors following standard EAP protocols.

Once the EIM data has been verified, the project manager will compile all project data in a data summary report. Internal (within Ecology) and external (project stakeholders) reviewers will provide validation of the report.

Data Quality (Usability Assessment)

Study data usability

The project manager will verify that all measurement and data quality objectives have been met for each monitoring station. If the objectives have not been met (such as the %RSD for sample duplicates exceeds the MQO), then the project manager will decide how to qualify the data and how it should be used in the analysis or whether it should be rejected. Documentation of the data quality assessment will be summarized in the final report and all assessment files will be archived with the project data.

During data analysis, the project manager will evaluate the adequacy of the study design, based on the results, to draw conclusions and make recommendations.

The project manager will handle any non-detects (sample results below the reporting limit) using methods described in Chapter 13, "Methods for Data Below the Reporting Limit," of Helsel and Hirsch (2002).

Usability of results from modeling or other analysis

The usability of the results from the QUAL2KW or WASP model will be assessed by the project manager and TMDL drafting committee by comparison of predicted model results to observed values, comparison of calibrated model parameters and rates to those from other studies, and other techniques.

External data usability

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

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

- Reference to a peer-reviewed and published Quality Assurance (QA) Project Plan
- Demonstration that the data collected yielded results of comparable quality to the study (based on data quality objectives and requirements in this QA Project Plan).

- Documentation that the objectives of the QA Project Plan or equivalent quality assurance procedures were met, and that the data are suitable for water quality-based actions. The assessment of the data must consider whether the data, in total, fairly characterize the quality of the water body at that location at time of sampling.
- Documentation of the planning, implementation, and assessment strategies used to collect the information, including:
    - Documentation of the original intended use of the information gathered (e.g., chemical/physical data for TMDL analyses)
    - Description of the limitations on use of the data (e.g., these measurements only represent storm-event conditions).
    - Datasets must be complete, that is, not censored to include only part of the data results from the project.

Project Organization

Table 17 lists the people and agencies involved in this project, as well as corresponding titles and responsibilities.

Table 17. Organization of project staff and responsibilities.

Staff (EAP staff unless noted otherwise)	Agency/ Organization	Title	Responsibilities
Cindy James Water Quality Program Southwest Regional Office Phone: 360-407-6556	Ecology	TMDL Lead; Client; TMDL drafting committee – Ecology Lead	Acts as point of contact between EAP staff and interested parties. Coordinates information exchange. Forms technical advisory team and organizes meetings. Reviews the QAPP and technical report. Prepares and implements TMDL report for submittal to EPA.
Laurie Mann Region 10 Watershed Unit Phone: 206-553-1583	EPA	TMDL drafting committee – EPA Lead; WA TMDL Program Manager	Assists with project planning, scope, and water quality management decisions. Reviews QAPP, interim modeling results, and final report.
Nancy Rapin MIT – Fisheries Division Phone: 253-876-3128	Muckleshoot Indian Tribe	TMDL drafting committee – MIT Lead	Assists with project planning, scope, and water quality management decisions. Reviews QAPP, interim modeling results, and final report.
Greg Pelletier Modeling and Information Support Unit - Statewide Coordination Section Phone: 360-407-6485	Ecology	Project Manager; Environmental Engineer	Co-authors the QAPP. Analyzes and interprets data. Co-authors the technical sections of the draft report and final TMDL report. Oversees model development, calibration, and application.
Ben Cope Region 10 Office of Environmental Assessment Phone: 206-553-1442	EPA	EPA technical modeling liaison; Environmental Engineer	Assists with design of study and analytical framework. Reviews model development, calibration, and application.
Dr. Joel Massmann Keta Waters Phone: 206-236-6225	Keta Waters	MIT technical modeling liaison; Professional Engineer	Assists with design of study and analytical framework. Reviews model development, calibration, and application.
Nuri Mathieu Directed Studies Unit - Western Operations Section Phone: 360-407-7359	Ecology	Principal Investigator	Co-authors the QAPP. Coordinates field surveys, oversees field sampling and transportation of samples to the laboratory. Conducts QC review of data, analyzes and interprets data, and enters data into EIM. Co-authors the technical sections of the draft report and final TMDL report. Assists with model development, calibration, and application.
Kirk Sinclair Groundwater Forests and Fish Unit – Statewide Coordination Section Phone: 360-407-6557	Ecology	Hydrogeologist	Provides hydrogeologic assistance with study design including interpretation of historical geology and groundwater data in the basin, groundwater data collection, and data QC review.
Kim McKee Water Quality Program Southwest Regional Office Phone: 360-407-6407	Ecology	Unit Supervisor of TMDL Lead / Client	Approves TMDL report for submittal to EPA.

Staff (EAP staff unless noted otherwise)	Agency/ Organization	Title	Responsibilities
Karol Erickson Modeling and Information Support Unit- Statewide Coordination Section Phone: 360-407-6694	Ecology	Unit Supervisor of Project Manager	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the TMDL report.
Will Kendra Statewide Coordination Section Phone: 360-407-6694	Ecology	Section Manager of Project Manager	Approves the QAPP and technical sections of the TMDL report.
George Onwumere Directed Studies Unit - Western Operations Section Phone: 360-407-6730	Ecology	Unit Supervisor of Principal Investigator	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the TMDL report.
Robert F. Cusimano Western Operations Section Phone: 360-407-6596	Ecology	Section Manager of Principal Investigator	Approves the QAPP and technical sections of the TMDL report.
Dean Momohara Manchester Environmental Laboratory Phone: 360- 871-8801	Ecology	Acting Director	Provides laboratory staff and resources, sample processing, analytical results, laboratory contract services, and quality assurance/quality control (QA/QC) data. Approves the QAPP.
William R. Kammin Phone: 360-407-6964	Ecology	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

EAP: Environmental Assessment Program
MIT: Muckleshoot Indian Tribe
EIM: Environmental Information Management system
QAPP: Quality Assurance Project Plan

Project Schedule

Table 18. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Field and laboratory work	Due date	Lead/support staff
Field work completed	December 2012	Nuri Mathieu
Laboratory analyses completed	January 2013	
Environmental Information System (EIM) database		
EIM user study ID	GPEL0010	
Product	Due date	Lead staff
EIM data loaded	December 2013	Nuri Mathieu
EIM quality assurance	January 2014	TBD
EIM complete	February 2014	Nuri Mathieu
Quarterly reports		
Author lead/support staff	Nuri Mathieu/Greg Pelletier	
Schedule		
1st quarterly report	December 2012 – Data collection summary	
2nd quarterly report	April 2013 – Data results/QA review summary	
3rd quarterly report	July 2013 – Modeling progress report #1	
4th quarterly report	October 2013 – Modeling progress report #2	
5th quarterly report	January 2014 – Modeling progress report #3	
Final TMDL (WQIR) report		
EAP Author lead/support staff	Nuri Mathieu/Greg Pelletier	
Schedule*		
Draft WQIR due to TMDL drafting committee	September 2014	
Draft WQIR due to technical/policy peer reviewers	November 2014	
Draft WQIR due to external reviewer(s)	November 2014	
Draft WQIR due to Joan (all reviews and author revisions complete)	January 2015	
Final TMDL (WQIR) report		
Joan transmits WQIR to WQP; report marked as complete in Project Tracker	February 2015	
Public 30 Day Notice	March 2015	
Final WQIR posted on web by WQP	May 2015	

*Schedule may be delayed by several months if additional modeling of 2000-01 data is performed.
WQIR: Water Quality Improvement Report.

Laboratory Budget

Table 19. Tentative lab budget.

This budget assumes 25 tributary/spring sites and 20 stormwater sites per synoptic; actual number of sites sampled could be more or less.

Parameter/analysis	Sites	Surveys	Field Dupes	Field blanks	Total Samples	$/sample	Subtotal
Summer Synoptic Surveys							
Turbidity	16	4	7	4	75	$ 11.92	$894
TSS + TNVSS	61	4	25	4	273	$ 26.02	$7,103
TSS + TNVSS - Light Extinction	4	10	4	1	45	$ 11.92	$537
Turbidity- Light Extinction	4	10	4	1	45	$ 26.02	$1,171
Alkalinity	77	4	31	4	343	$ 18.43	$6,320
BOD5	7	4	3	0	31	$ 59.61	$1,848
Chloride	61	4	25	4	273	$ 14.09	$3,847
Chlorophyll *a* - water (lab filter)	16	4	7	4	75	$ 59.61	$4,471
Total Persulfate Nitrogen (TPN)	77	4	31	4	343	$ 18.43	$6,320
Ammonia	77	4	31	4	343	$ 14.09	$4,833
Nitrite/Nitrate NO2/NO3	77	4	31	4	343	$ 14.09	$4,833
Orthophosphate (SRP)	77	4	31	4	343	$ 16.26	$5,577
Total Phosphorus (TP)	77	4	31	4	343	$ 19.50	$6,689
Dissolved Organic Carbon	32	4	18	4	195	$ 38.98	$7,602
Total Organic Carbon	32	4	18	4	195	$ 35.77	$6,975
						Subtotal =	**$69,019**
Groundwater Sampling							
Alkalinity	12	2	3	2	29	$ 18.43	$534
Chloride	12	2	3	2	29	$ 14.09	$409
Total Persulfate Nitrogen (TPN)	12	2	3	2	29	$ 18.43	$534
Ammonia	12	2	3	2	29	$ 14.09	$409
Nitrite/Nitrate NO2/NO3	12	2	3	2	29	$ 14.09	$409
Orthophosphate (SRP)	12	2	3	2	29	$ 16.26	$471
Total Phosphorus (TP)	12	2	3	2	29	$ 19.50	$566
Dissolved Organic Carbon	12	2	3	2	29	$ 38.98	$1,131
						Subtotal =	**$4,462**
Periphyton Surveys							
Identification (contract)	3		0	n/a	3	$ 300.00	$900
Periphyton Biomass Only (Chl a + AFDW)	3	4	1	0	14	$ 84.54	$1,184
Periphyton Biomass + Nutrients (Chl a, AFDW, Total C/N/P)	3	3	2	0	11	$ 241.95	$2,661
						Subtotal =	**$4,745**
						Total =	**$78,226**

[1] Lab filtered
[2] Colorimetric method – SM 4500- P F
[3] Contract laboratory

References

Adams, K., 2010. Quality Assurance Monitoring Plan: Ambient Biological Monitoring in Rivers and Streams: Benthic Macroinvertebrates and Periphyton. Washington State Department of Ecology, Olympia, WA. Publication No. 10-03-109. www.ecy.wa.gov/biblio/1003109.html

Ambrose, R.B., C. Knightes, and T.A. Wool, 2010. WASP7 pH-Alkalinity - Model Theory and User's Guide Supplement to Water Quality Analysis Simulation Program (WASP) User Documentation. U.S. Environmental Protection Agency. Office of Research and Development National Exposure Research Laboratory. Ecosystems Research Division. Athens, GA.

APHA, AWWA, and WEF, 2005. Standard Methods for the Examination of Water and Wastewater; 21st Edition; American Public Health Association, Washington, D.C.

Bilhimer, D. and A. Stohr, 2009. Standard Operating Procedures for continuous temperature monitoring of fresh water rivers and streams conducted in a Total Maximum Daily Load (TMDL) project for stream temperature, Version 2.3. Washington State Department of Ecology, Olympia, WA. SOP Number EAP044. www.ecy.wa.gov/programs/eap/quality.html

Cascade Water Alliance (CWA), Muckleshoot Indian Tribe, and Puyallup Tribe of Indians, 2008. White River Management Agreement. Dated 8/6/2008. Cascade Water Alliance Website: http://cascadewater.org/lake_tapps_tribal_agreements.php

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

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

Chapra, S.C., G.J. Pelletier, and H. Tao, 2008. QUAL2K: A Modeling Framework for Simulating River and Stream Water Quality, Version 2.11: Documentation and Users Manual. Civil and Environmental Engineering Dept., Tufts University, Medford, MA.,

Cusimano, B., 1994. Technical guidance for assessing the quality of aquatic environments. Washington State Department of Ecology, Olympia, WA. Publication No. 91-78. www.ecy.wa.gov/biblio/9178.html

CWA, 2010. Lake Tapps Reservoir Water Rights and Supply Project: Draft Environmental Impact Statement. Cascade Water Alliance. July 29, 2010.

Czuba, J.A., C.R. Czuba, C.S. Magirl, and F.D. Voss, 2010. Channel-Conveyance Capacity, Channel Change, and Sediment Transport in the Lower Puyallup, White, and Carbon Rivers, Western Washington. U.S. Geological Survey Scientific Investigations Report 2010–5240, Tacoma, WA, 104 p.

Dinicola, R.S., 1990. Characterization and simulation of rainfall-runoff relations for headwater basins in western King and Snohomish Counties, Washington: U.S. Geological Survey Water-Resources Investigations Report 89-4052, 52 p.

Ebbert, J.C., 2003. Water Temperature, Specific Conductance, pH, and Dissolved-Oxygen Concentrations in the Lower White River and the Puyallup River Estuary, Washington, August-October 2002. U.S. Geological Survey, Water-Resources Investigations Report 03-4177, Tacoma, WA.

Ecology, 2011a. Permits – Point Source Pollution. Water Quality Program, Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/wq/permits/index.html

Ecology, 2011b. River and Stream Water Quality Monitoring. Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/fw_riv/rv_main.html

EPA, 2009. Water Quality Analysis Simulation Program (WASP). Version 7.4 Release Notes. Watershed and Water Quality Modeling Technical Support Center. U.S. Environmental Protection Agency. Athens, Georgia. www.epa.gov/athens/wwqtsc/html/wasp.html

Erickson, K., 1999. Review Draft: Assimilative Capacity Study for Nutrient Loading in the Lower White River. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-001. www.ecy.wa.gov/biblio/0003001.html

Hallock, D., 2009. Quality Assurance Monitoring Plan: Continuous Monitoring for Oxygen, Temperature, pH, and Conductivity in Statewide Rivers and Streams. Washington State Department of Ecology, Olympia, WA. Publication No. 10-03-040. www.ecy.wa.gov/biblio/0903122.html

Helsel, D.R. and R.M. Hirsch, 2002. Statistical Methods in Water Resources. Techniques of Water-Resources Investigations of the United States Geological Survey. Book 4, Hydrologic Analysis and Interpretation. U.S. Geological Survey.

James, C. and N. Mathieu, 2011. Puyallup River Watershed Fecal Coliform Total Maximum Daily Load - Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Olympia, WA. Publication No. 11-10-040. www.ecy.wa.gov/biblio/1110040.html

Johnston, G., N. Ackerman, and B. Gerke, 2005. Kalama, Washougal and Lewis River Habitat Assessments, Chapter 4: East Fork Lewis River Basin - Habitat Assessment. Lower Columbia Fish Recovery Board.

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

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

Marti, P., 2009. Standard Operating Procedure for Manual Well-Depth and Depth-to-Water Measurements. Version 1.0. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_052ManualWellDepth&DepthtoWaterMeasures_v_1_0.pdf

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

Mathieu, N., 2010. Lower White River Nutrients and pH Study: Data Summary Report. Washington State Department of Ecology, Olympia, WA. Publication No. 10-03-040. www.ecy.wa.gov/biblio/1003040.html

MEL, 2006. Manchester Environmental Laboratory Quality Assurance Manual. Washington State Department of Ecology, Manchester, WA.

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

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

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

Muckleshoot Indian Tribe, Washington State Department of Ecology, EPA, 2001. Memorandum of Agreement Relating to the Development of a TMDL for the Lower White River.

National Oceanic and Atmospheric Administration (NOAA), 2012. Snow – Station Information for Morse Lake Snotel Station (MRSW1). Accessed on 4/30/2012. www.nwrfc.noaa.gov/snow/

Pacific Groundwater Group (PGG), 1999. 1999 Hydrogeologic Characterization Report, City of Auburn. Prepared for the City of Auburn, Department of Public Works Water Utility Engineering, Auburn, WA.

Pelletier, G., 1993. Puyallup River Total Maximum Daily Load for Biochemical Oxygen Demand, Ammonia, and Residual Chlorine. Washington Department of Ecology, Olympia, WA. Publication No. 96-326. www.ecy.wa.gov/biblio/96326.html

Puget Sound Energy and Cascade Water Alliance, 2008. Lake Tapps Asset Purchase Agreement. Dated 4/23/2008. Cascade Water Alliance website: http://cascadewater.org/lake_tapps_agreements.php

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

Schuett-Hames, D., A. Pleus, E. Rashin, and J. Matthews, 1999. TFW Monitoring Program Method Manual for the Stream Temperature Survey. Prepared for the Washington State Department of Natural Resources Under the Timber, Fish, and Wildlife Agreement. TFW-AM9-99-005. DNR # 107. Ecology Publication No. 99-e01. www.ecy.wa.gov/biblio/99e01.html

Shedd, J.R. Springer, C. and C.J. Clishe, 2008. Standard Operating Procedure for Operation of the Teledyne RD Instruments Stream-Pro Acoustic Doppler Current Profiler, Version 1.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP055. www.ecy.wa.gov/programs/eap/quality.html

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

Stohr, A., 2008. Standard Operating Procedures for the computer analysis of hemispherical digital images collected as part of a temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit technical study. Version 2.0. Washington State Department of Ecology, Olympia, WA. SOP Number EAP046. www.ecy.wa.gov/programs/eap/quality.html

Stuart, D., 2002. A study of periphyton induced pH spikes on the White River, Washington. Master’s thesis. Department of Civil and Environmental Engineering, University of Washington, Seattle.

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

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

Tooley, J., 1997. Assessment of pH Response to Nutrient Loading in the Lower White River – Nutrient Loading from Groundwater. Appendix B of “Review Draft: Assimilative Capacity Study for Nutrient Loading in the Lower White River.” State Department of Ecology, Olympia, WA. Publication No. 00-03-001. www.ecy.wa.gov/biblio/0003001.html

USACE, 2012. Mud Mountain Dam Intake Works Improvements. U.S. Army Corps of Engineers – Seattle District. www.nws.usace.army.mil/

USGS, 2011. USGS Real-Time Water Data for Washington: Water Quality. Puyallup River Basin Stations: 12098700,12100490, 12101100. National Water Information System: Web Interface. United States Geological Survey. http://waterdata.usgs.gov/wa/nwis/current/?type=quality

WAC 173-201A. Water Quality Standards for Surface Waters in the State of Washington Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/biblio/wac173201a.html

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

Ward, W., 2007. Standard Operation Procedures for the Collection, Processing, and Analysis of Stream Samples. Version 1.3. Washington State Department of Ecology, Olympia, WA. SOP Number EAP034. www.ecy.wa.gov/programs/eap/quality.html

Ward, W.J. and N. Mathieu, 2011. Standard Operating Procedures for the Collection and Analysis of Dissolved Oxygen (Winkler Method), Version 2.1. Washington State Department of Ecology, Olympia, WA. SOP Number EAP023. www.ecy.wa.gov/programs/eap/quality.html

Welch, E.B., 1992. Ecological Effects of Waste Water: Applied Limnology and Pollutant Effects, Second Edition, Routledge Press, 1992.

Western Regional Climate Center (WRCC), 2011. Data summary for Buckley, Washington COOP site #450945. Period of Record 1/ 1/1913 to 12/31/2010. www.wrcc.dri.edu/summary/Climsmwa.html

Appendices

Appendix A. Previously Established 7Q10 Flows and MIT Reserve Allocations

7Q10 Flows

The natural 7Q10 flow for the White River above the diversion dam is 260 cfs based on data collected from 1977 to 2003 and is 302 cfs based on data collected from 1928 to 2003. These 7Q10 values are also shown in Table A-1.

The 7Q10 and 30Q10 flow statistics were calculated using data from the White River near Buckley USGS gauge (Gauge 12098500). The White River near Buckley gauge is located above the White River diversion canal and the flows at this gauge were not affected by historic diversions into Lake Tapps. Flow data are available at the White River near Buckley gauge for the period from October 1, 1928 to September 30, 2003.

Data analyses completed by the USGS suggest that hydrometeorological conditions in the Pacific Northwest have likely shifted in recent decades because of changes in atmospheric-circulation patterns and sea-surface temperatures. This shift has resulted in less precipitation and streamflow at most locations, based on a comparison of data collected after 1976 versus before 1976 (Vaccaro, 2002).

Table A-1. Flow statistics based on observations at the USGS gauge near Buckley (RM 27.9, gauge #12098500).

Record	Assumed growing season					
	9/20 through 11/30		9/1 through 12/30		Full year	
	7Q10	30Q10	7Q10	30Q10	7Q10	30Q10
1977-2003	260	335	260	335	260	297
1928-2003	302	377	302	377	250	298

Reserve Allocation for MIT Reservation Tribal Waters

This TMDL will also include a reserve allocation for future municipal, industrial, and stormwater discharges related to the Muckleshoot Indian Tribe. A reserve allocation, to be determined, in pounds per day of total phosphorus will be established for that portion of the White River that flows through the reservation to allow for growth that may occur on the reservation in the next 5 to 20 years.

The Reserve allocation for the tribal waters will be calculated by estimating loads for hypothetical examples of point sources that are similar to existing point sources of nearby municipalities within the TMDL reach. The size of the reserve allocation will be the summation of these representative discharges. These representative loads serve only to establish the reserve allocation quantity and do not reflect current facility plans.

The load for a future MIT fish facility will be based on hypothetical load for a facility of this type. This load will be based on an assumed flow of 0.11 cubic meters per second (cms), and an assumed total phosphorus net discharge concentration of 100 ug/L (Table A-2). Phosphorus limits in NPDES permits for hatcheries are expressed in total phosphorus and range 40 – 100 ug/L (Fromme, 2005). Data for the range of total phosphorus concentrations in hatchery effluents have been provided in a report by the Washington Department of Ecology (Kendra 1989). Kendra (1989) reports a range of 0 – 340 ug/L total phosphorus for effluents of 16 hatcheries monitored in Washington State.

A stormwater runoff value of 0.14 cms for future build-out on the MIT reservation has been developed using the Western Washington Hydrology Model Version 3.0 (WWHM3). This assumes development of the 5.40 square mile portion of the reservation that lies within the White River watershed, and includes the amphitheater property.

Table A-2. Flows and concentrations that will be used to develop loads for the stormwater and fish facility portions of the MIT reserve allocation.

Name	Flow (m^3/s)	Soluble Reactive P (ug/L)
Future MIT stormwater	0.140	Equal to concentration used for allocations assigned to cities.
Future MIT Fish Facility	0.110	100.0

The reserve allocation for the tribal waters will be a reserve for the river and will be managed by EPA and the Muckleshoot Indian Tribe with review and concurrence from Ecology. Accessing a portion of the reserve allocation for a specific point source will be done through an adjustment of this TMDL. This process will be initiated with a letter from the Tribe to Ecology and EPA that acknowledges a new discharge and provides information on the proposed point source discharge including treatment levels and anticipated effluent pollutant levels; or through submittal of an NPDES permit application to EPA and notification to Ecology. WLA for any other future point source discharge will be developed by EPA using technology-based effluent limitations or water quality based limits, as appropriate. In all cases, public comment will be solicited by EPA as part of the NPDES permit public notice process. Once a public notification process is complete and comments have been adequately addressed, Ecology will formally request that EPA revise allocations in the approved pH TMDL to acknowledge this new tribal discharge to the White River.

Appendix B. Glossary, Acronyms, and Abbreviations

Glossary

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

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

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

Diatom: A major group of algae that possess a rigid siliceous cell wall.

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

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

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

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

Fecal coliform (FC): That portion of the coliform group of bacteria which is present in intestinal tracts and feces of warm-blooded animals as detected by the product of acid or gas from lactose in a suitable culture medium within 24 hours at 44.5 plus or minus 0.2 degrees Celsius. Fecal coliform bacteria are "indicator" organisms that suggest the possible presence of disease-causing organisms. Concentrations are measured in colony forming units per 100 milliliters of water (cfu/100 mL).

Glide: A shallow stream reach without surface turbulence, often found in the transitional area between a pool and a run. Typically, a glide has a maximum depth that is 5% or less of the average stream width and a water velocity less than 0.65 ft/sec.

Irradiameter: A meter used to measure the intensity of incoming solar radiation on the surface being measured.

Lahar: A landslide or mudflow of volcanic fragments on the flanks of a volcano.

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

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

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

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

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

Parameter: Water quality constituent being measured (analyte).

Periphyton: A complex mixture of algae, cyanobacteria, heterotrophic microbes, and detritus that is attached to submerged surfaces.

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

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

Riffle: A **s**hallow stream reach, with visible surface turbulence, where water flows swiftly over rough streambed substrates.

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

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

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

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

Thalweg: The path of a stream that follows the deepest part of the channel.

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

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

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

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

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

Acronyms and Abbreviations

Ecology	Washington State Department of Ecology
EPA	U.S. Environmental Protection Agency
MEL	Manchester Environmental Laboratory
NPDES	(See Glossary above)
RM	River mile
SRP	Soluble reactive phosphorus
TMDL	(See Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WWTP	Wastewater treatment plant
%RSD	Percent relative standard deviation

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
kg	kilograms, a unit of mass equal to 1,000 grams.
kg/d	kilograms per day
m	meter
mm	milliliter
mg	milligrams
mgd	million gallons per day
mg/L	milligrams per liter (parts per million)
mL	milliliters
NTU	nephelometric turbidity units
s.u.	standard units
ug/L	micrograms per liter (parts per billion)
uS/cm	microsiemens per centimeter, a unit of conductivity