Lacamas Creek Fecal Coliform, Temperature, Dissolved Oxygen, and pH Total Maximum Daily Load

Water Quality Study Design (Quality Assurance Project Plan)

DEPARTMENT OF
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State of Washington

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Author: Trevor Swanson. Phone 360-407-6685.
Communication Consultant: Phone 360-407-6834.

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

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

Study Codes

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

Water body: Lacamas Creek	
Parameter	Listing ID
Fecal Coliform	7913, 22016
Dissolved Oxygen	7912, 7921, 7924, 7929, 7897, 7908, 7901, 7946, 7862, 7868, 7894
Temperature	7917, 7923, 7930, 7900, 7907, 7945, 7865, 7869
pH	7947

Water body Numbers:
Lacamas Creek, WA-28-2020; Fifth Plain Creek, WA-28-2024; Shanghai Creek, WA-28-2025; Matney Creek, WA-28-2026; China Ditch, WA-28-2023

Cover photo: Lacamas Creek at Goodwin Road, June 2010. Photo by Stephanie Brock.

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Approved by:

Signature:	Date: February 2011
Kim McKee, Client and Unit Supervisor, Water Quality Program, SWRO	
Signature:	Date: February 2011
Steve Eberl, Client's Acting Section Manager, Water Quality Program, SWRO	
Signature:	Date: February 2011
Trevor Swanson, QAPP Author, Project Manager, Principal Investigator, and EIM Data Engineer, EAP	
Signature:	Date: February 2011
Kirk Sinclair, Groundwater Support, EAP	
Signature:	Date: February 2011
Martha Maggi, Groundwater/Forest and Fish Unit Supervisor, EAP	
Signature:	Date: February 2011
George Onwumere, Author's Unit Supervisor, EAP	
Signature:	Date: February 2011
Robert F. Cusimano, Author's Section Manager, EAP	
Signature:	Date: February 2011
Stuart Magoon, Director, Manchester Environmental Laboratory, EAP	
Signature:	Date: February 2011
Bill Kammin, Ecology Quality Assurance Officer, EAP	

Signatures are not available on the Internet version.
SWRO: Southwest Regional Office.
QAPP: Quality Assurance Project Plan.
EAP: Environmental Assessment Program.
EIM: Environmental Information Management database.

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Abstract

Lacamas Creek and four of its tributaries were included on the Washington State 2008 303(d) list of impaired water bodies for fecal coliform bacteria, temperature, dissolved oxygen, and pH violations of water quality standards. Lacamas Creek is located within Water Resource Inventory Area (WRIA) 28, fully within Clark County in southwestern Washington. The lower portion of the stream, including Lacamas and Round Lakes, flows through the City of Camas.

The Washington State Department of Ecology (Ecology) is required under Section 303(d) of the federal Clean Water Act to develop and implement total maximum daily loads (TMDLs) for impaired waters of the state. As a part of the TMDL for Lacamas Creek, this technical study will evaluate 303(d) listed parameters in the watershed by

- Sampling surface water for fecal coliform twice monthly from December 2010 to December 2011.
- Conducting two critical-period (summer 2011) dissolved oxygen, pH, and nutrient synoptic surface-water and groundwater surveys.
- Installing and recording surface-water and groundwater thermistors from spring to fall, 2011.
- Conducting riparian habitat and channel geometry surveys.
- Conducting time-of-travel surveys.
- Storm sampling during the dry and wet seasons.

Fecal coliform will be analyzed using the rollback method and DO, pH, and temperature will be modeled using the QUAL2Kw model (Chapra and Pelletier, 2003; Ecology, 2003b). Data collected will form the basis for allocating contaminant loads to pollutant sources.

Each study conducted by Ecology requires an approved Quality Assurance Project Plan. The plan describes the objectives of the study and the procedures to be followed to achieve those objectives.

The goal of this TMDL project is to ensure that Lacamas Creek and its tributaries above Lacamas Lake attain water quality standards for fecal coliform, stream temperature, dissolved oxygen, and pH. The study area does not include Lacamas Lake, Round Lake, or Lacamas Creek below these lakes. After completion of the 2010-2011 study, a final report describing the results will be posted to the Internet.

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 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 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 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 – Meets standards for parameter(s) for which it has 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, or 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 a numerical value representing the highest pollutant load a surface water body can receive and still meet water quality standards. Any amount of pollution over the TMDL level needs to be reduced or eliminated to achieve clean water.

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. Ecology, with the assistance of local governments, tribes, agencies, and the community, then develops a strategy to control and reduce pollution sources and a monitoring plan to assess effectiveness of the water quality improvement activities. Together, the study and implementation strategy comprise the *Water Quality Improvement Report* (WQIR).

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 of pollutants addressed in this TMDL in the watershed must use the appropriate best management practices to reduce impacts to water quality. The area that will be subject to the TMDL is shown in Figure 1.

Similarly, all point source dischargers who release pollutants addressed in this TMDL in the watershed must also comply with the TMDL.

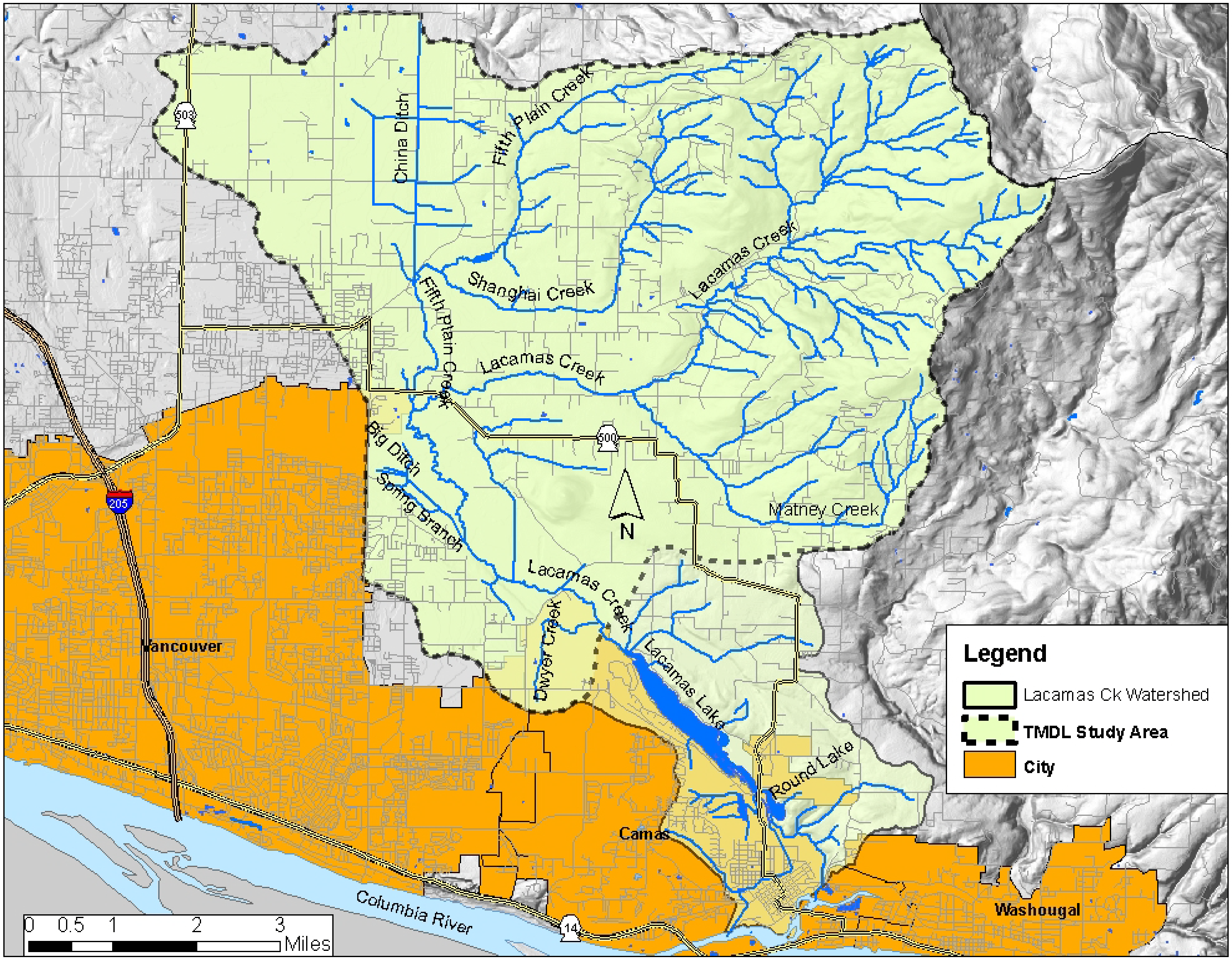

Figure 1. Study area for the Lacamas Creek multiparameter Total Maximum Daily Load study.

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

Ecology is conducting a multiple parameter TMDL study on Lacamas Creek because there are several stream reaches that do not meet water quality criteria. The parameters addressed in this study are fecal coliform bacteria (FC), temperature, dissolved oxygen (DO), and pH.

There is a high level of interest in water quality issues in the watershed, especially in Lacamas Lake, demonstrated by cooperative sampling efforts, watershed management, and concerned citizens. Ecology hopes to build on previous data collection and watershed clean-up efforts. Ecology will work with Clark County and any other contributing entities to better understand the water quality problems within the Lacamas Creek watershed.

Ecology will organize and conduct field work from December 2010 to December 2011. The data collected will be used to establish loading capacity as well as load and wasteload allocations for FC, temperature, DO, and pH.

Study area

Lacamas Creek is located within Water Resource Inventory Area (WRIA) 28, fully within Clark County in southwestern Washington. The lower portion of the stream, including Lacamas and Round Lakes, flow through the City of Camas (Figure 1). The TMDL study area lies within the Lacamas Creek watershed and includes Lacamas Creek and its major tributaries and stormwater inputs above Lacamas Lake (Figure 1).

Ecology is not including Lacamas Lake, Round Lake, or Lacamas Creek below Round Lake in this study. Ecology is well aware that the lakes have water quality problems of their own (Table 2). However, because lake systems are much more complicated than stream systems, they require a more expensive and extensive monitoring and modeling effort than Ecology can afford at this time. Focusing on the watershed upstream of Lacamas Lake first will give Ecology insight into the sources of pollution affecting the lakes and lower creek. Previous studies (see Historical Data Review) and the fact that Lacamas Creek is the only major input of surface water to Lacamas and Round Lakes lead Ecology to believe that the major sources of nutrients and other pollutants to the lake come from upstream in Lacamas Creek and its tributaries, not directly to the lakes themselves. Therefore, cleanup efforts above Lacamas Lake may contribute to water quality improvements in the lakes and lower Lacamas Creek.

Impairments addressed by this TMDL

The main beneficial uses to be protected by this TMDL include:

- *Aquatic Life Use* for salmonid spawning, rearing, and migration.
- *Primary Contact Recreation.*
- *Water Supply Uses* for domestic consumption, industrial production, and agriculture or hobby farm livestock.
- *Miscellaneous Uses* for wildlife habitat, harvesting, commerce/navigation, boating, and aesthetics (WAC 173-201A-600).

Washington Administrative Code (WAC) 173-201A-600 also states that all lakes and all feeder streams to lakes that have not had individual use designation determinations (173-201A-602) are also to be protected for the designated uses of:

- *Core Summer Salmonid Habitat.*
- *Extraordinary Primary Contact Recreation.*

Because Lacamas Creek and its tributaries flow into Lacamas Lake, this higher level of beneficial use protection is required everywhere in the watershed above the outlet of Round Lake.

Washington State has established water quality standards to protect these beneficial uses. Table 1 lists the water bodies within the study area that violate FC, DO, temperature, and pH criteria established by the water quality standards. These impairments are addressed in this TMDL.

To meet standards for the parameters in Table 1, loading of the following pollutants will need to be decreased:

- FC
- Biochemical Oxygen Demand (BOD)
- Nutrients
- Thermal heat loading

This study will be looking at this watershed more thoroughly and may find other impaired water bodies.

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

Water Body	Parameter	Listing ID	Township	Range	Section
Lacamas Creek	Fecal Coliform	7913	02N	03E	51
	Dissolved Oxygen	7912 7921 7924	02N 02N 02N	03E 03E 03E	51 07 10
	Temperature	7917 7923	02N 02N	03E 03E	51 10
Matney Creek	Fecal Coliform	22016	02N	03E	09
	Dissolved Oxygen	7929	02N	03E	09
	Temperature	7930	02N	03E	09
Fifth Plain Creek	Dissolved Oxygen	7897 7908 7901	02N 02N 03N	03E 03E 03E	07 06 32
	Temperature	7900 7907	03N 02N	03E 03E	32 06
Shanghai Creek	Dissolved Oxygen	7946	02N	03E	05
	Temperature	7945	02N	03E	05
	pH	7947	02N	03E	05
China Ditch	Dissolved Oxygen	7862	02N	03E	06
	Temperature	7865	02N	03E	06
China Lateral (tributary of China Ditch)	Dissolved Oxygen	7868	03N	02E	36
	Temperature	7869	03N	02E	36
Dwyer Creek	Dissolved Oxygen	7894	02N	03E	50

There are other Section 303(d) listed segments in the watershed, but this report does not address them directly (Table 2).

Table 2. Section 303(d) listed segments not addressed in the Lacamas Creek TMDL study.

Water Body	Parameter	Medium	Listing ID	Township	Range	Section
Lacamas Lake	PCB	Tissue	43465	02N	03E	34
	Total Phosphorus	Water	6346	02N	03E	34
Round Lake	pH	Water	7935	01N	03E	02
	Dissolved Oxygen	Water	7936	01N	03E	02
Lacamas Creek (below Round Lake)	Temperature	Water	7914	01N	03E	47
	Dissolved Oxygen	Water	7915	01N	03E	47
	pH	Water	7916	01N	03E	47

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 pollution problem and then recommending practices to reduce pollution, and by establishing limits for facilities that have permits. Since the study may also identify the main sources or source areas of pollution, Ecology and local partners will use these results to figure out where to focus water quality improvement activities. Study results may also be used to suggest areas for follow-up sampling to further pinpoint sources for cleanup.

Water Quality Standards and Numeric Targets

The Washington State water quality standards, set forth in Chapter 173-201A of the WAC, include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state. This section provides Washington State surface water quality information and those criteria applicable to this study in the Lacamas Creek watershed.

In July 2003, Ecology made significant revisions to the state's surface water quality standards (Chapter 173-201A WAC). These changes included eliminating the classification system the state used for decades to designate uses for protection by water quality criteria (e.g., temperature, DO, turbidity, bacteria). Ecology also revised the numeric temperature criteria assigned to waters to protect specific types of aquatic life uses (e.g., native char, trout and salmon spawning and rearing, and warm water fish habitat).

Ecology submitted the revised water quality standards regulation to EPA for federal approval in July 2003. These standards were approved by EPA on February 11, 2008. The revisions to the existing standards are online at Ecology's water quality standards website: www.ecy.wa.gov/programs/wq/swqs.

The Lacamas Creek watershed is listed on the 2008 303(d) list as impaired for FC, DO, temperature, and pH. Table 3 shows the applicable water quality criteria for these parameters.

Table 3. Washington State water quality criteria for impaired parameters in the Lacamas Creek Watershed.

Water Quality Parameter	2008 Use Classification	2008 Criteria
Temperature	Core summer salmonid habitat, spawning, rearing, and migration	16°C 7-DADMax[1]
Dissolved Oxygen		9.5 mg/L 1-DMin[2]
pH		6.5 to 8.5 units[3]
Fecal Coliform Bacteria	Extraordinary primary contact recreation	Geometric mean: 50 cfu/100 mL
		10% not to exceed: 100 cfu/100 mL

1. 7-DADMax means the highest annual running 7-day average of daily maximum temperatures.
2. 1-DMin means the lowest annual daily minimum oxygen concentration occurring in the water body.
3. A human-caused variation within the above range of less than 0.2 units is acceptable.

Fecal coliform bacteria

Bacteria criteria are set to prevent waterborne illnesses in people who work and play in and on the water. Washington State water quality standards use FC as an “indicator bacteria” for the state’s freshwaters (e.g., lakes and streams). FC in water “indicates” the presence of waste from humans and other warm-blooded animals. Warm-blooded animals’ waste is more likely than cold-blooded animals’ waste to contain pathogens that will cause illness in humans. The FC criteria are set at levels shown to minimize rates of serious intestinal illness (gastroenteritis) in people.

The *Extraordinary Primary Contact* use classification is intended for waters capable of “providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.” To protect this use category, FC organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10% of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100 colonies/100 mL” [WAC 173-201A-200(2)(b), 2003 edition].

Compliance is based on meeting both the geometric mean criterion and the 10% of samples (or single sample if less than ten total samples) limit. These two measures used in combination ensure that bacterial pollution in a water body will be maintained at levels that will not cause a greater risk to human health than intended. While some discretion exists for selecting sampling averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal data sets.

The criteria for FC are based on allowing no more than the pre-determined illnesses to humans that work or recreate in a water body. The criteria used in the state standards are designed to allow seven or fewer illnesses out of every 1,000 people engaged in primary contact activities. Once the concentration of FC in the water reaches the numeric criterion, human activities that would increase the concentration above the criteria are not allowed. If the criterion is exceeded, the state will require that human activities be conducted in a manner that will bring FC concentrations back into compliance with the standard.

Humans are not allowed to contribute any FC bacteria if criteria are already being exceeded due to natural causes. While the specific level of illness rates caused by animal versus human sources has not been quantitatively determined, warm-blooded animals (particularly those that are managed by humans and thus exposed to human-derived pathogens as well as those of animal origin) are a common source of serious waterborne illness for humans.

Dissolved oxygen

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

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

In the state water quality standards, freshwater aquatic life use categories are described using key species (salmonid versus warm-water species) and life-stage conditions (spawning versus rearing). Minimum concentrations of DO are used as criteria to protect different categories of aquatic communities [WAC 173-201A-200; 2003 edition].

In this TMDL the designated aquatic life use to be protected is *Core Summer Salmonid Habitat.* The lowest 1-day minimum oxygen level must not fall below 9.5 mg/L more than once every ten years on average.

The criteria described above are used to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying above the fully protective DO criterion. When a water body is naturally lower in oxygen than the criterion, the state provides an additional allowance for further depression of oxygen conditions due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.2 mg/L decrease below that naturally lower (inferior) oxygen condition. Whether or not the water body is naturally low in oxygen is determined by using a model. The model roughly approximates natural conditions and is appropriate for determining the implementation of the DO criterion.

The water quality standards contain a default that would allow the numeric criteria to be modified to reflect the natural condition, if the natural condition is a lower DO concentration than the numeric criteria.

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

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 CO_2 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 also to protect waters for domestic water supplies. Water supplies that have 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 (i.e., 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].

In this TMDL, the designated aquatic life use to be protected is *Core Summer Salmonid Habitat*. To protect this designated aquatic life use, 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.

Temperature

Temperature affects the physiology and behavior of fish and other aquatic life. Temperature may be the most influential factor limiting the distribution and health of aquatic life and can be greatly influenced by human activities.

Temperature levels fluctuate over the day and night in response to changes in climatic conditions and river flows. Since the health of aquatic species is tied predominantly to the pattern of maximum temperatures, the criteria are expressed as the highest 7-day average of the daily maximum temperatures (7-DADMax) occurring in a water body.

In the state water quality standards, aquatic life use categories are described using key species (salmon versus warm-water species) and life-stage conditions (spawning versus rearing) [WAC 173-201A-200; 2003 edition].

In this TMDL, the designated aquatic life use to be protected is *Core Summer Salmonid Habitat.* The highest 7-DADMax temperature must not exceed 16°C (60.8°F) more than once every ten years on average.

Washington State uses the criteria described above to ensure that where a water body is naturally capable of providing full support for its designated aquatic life uses, that condition will be maintained. The standards recognize, however, that not all waters are naturally capable of staying below the fully protective temperature criterion. When a water body is naturally warmer than the above-described criterion, the state provides a small allowance for additional warming due to human activities. In this case, the combined effects of all human activities must not cause more than a 0.3°C (0.54°F) increase above the naturally higher temperature condition. Whether or not the water body is naturally high in temperature is determined using a model. The model roughly approximates natural conditions, and is appropriate for determining the implementation of the temperature criterion. This model results in what is called the "system thermal potential" or "system potential" of the water body.

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 associated with global climate change may require further modifications to human-source allocations at some future time.

Watershed Description

The Lacamas Creek watershed is about 67 square miles of forest, farm, residential, commercial, and industrial land. Located in southeastern Clark County, the watershed extends from Hockinson in the north to Camas in the south. Roads such as State Route 503 and NE 162nd Avenue follow its western boundary, and the Elkhorn and Livingston Mountains lie on its eastern boundary. Most of the watershed is in unincorporated Clark County. A significant area southwest of Lacamas Lake is within the City of Camas. The eastern edge of Vancouver also extends into the watershed.

Lacamas Creek has five major tributaries: Matney Creek, Shanghai Creek, Fifth Plain Creek, China Ditch, and Dwyer Creek. There are also many smaller streams within the watershed.

Lacamas Creek flows about 18 miles from relatively undisturbed forest headwaters through rural, agricultural, and residential areas into Lacamas and Round Lakes. Below the lakes, Lacamas Creek drops through a series of scenic waterfalls, and finally into the lower Washougal River. Lacamas and Round Lakes are used for boating, water skiing, fishing, canoeing, and swimming. The 3.5-mile Heritage Trail brings access to the entire southwestern shore of Lacamas Lake. Lacamas Park is a 312- acre county park that surrounds Round Lake and offers an extensive system of trails, scenic views, picnic spots, and access to the lake and Lower Lacamas Creek waterfalls (Clark County, 2004).

Beginning in the 1890s, several man-made channels were built in the Brush Prairie area to drain wetlands for farmland and to increase the volume of water available to Camas mills. This area includes almost all the channels in the China Ditch system. Although considered an improvement when built, these channels have unintended consequences. With significantly fewer wetland areas to store runoff from rainstorms, higher volumes of stormwater now funnel more quickly into streams, eroding stream banks and causing increased flooding in low-lying lands (Clark County, 2004).

Geographic setting

Streamflow

Like most lowland perennial streams in the Lower Columbia River Basin, Lacamas Creek is heavily dependent on natural groundwater discharge to sustain it during the dry summer months when precipitation is scarce. During the wet season peak flows are dominated by rainfall events.

Flow gaging

Clark County currently collects continuous flow data from two gages on Lacamas Creek. The gage at Goodwin Road, just before Lacamas Creek enters the lake, and another on NE 217th Avenue, about 7 miles upstream from Goodwin Road, have been in operation since 2003. Table 4 summarizes streamflow statistics at the two gages.

Table 4. Summary streamflow statistics for Clark County stations located on Lacamas Creek.

Clark County Station	Water Years	Flow (cfs)		
		Maximum	Minimum	Mean
Lacamas Ck at Goodwin Road	2004-2009*	1,375	7.5	119
Lacamas Ck at NE 217th Avenue	2003-2009	705	3.0	56

* 1999-2004 data are available from Clark County, but not on their website.

For more detailed flow data, see Clark County's flow monitoring website at www.clark.wa.gov/water-resources/monitoring/flow.html.

Several crest-stage gages are located throughout the watershed. The crest-stage gage is a standard U.S. Geological Survey (USGS) type with a graduated wooden staff and ground cork in a 2-inch galvanized pipe. This gage is a device for obtaining the elevation of the flood crest of streams. The gage is simple, economical, reliable, and easily installed. Crest-stage gages may be referenced in the case of a flood event.

Geology

The bedrock exposed in the Lacamas Creek watershed consists mostly of basalt. In the western part of the watershed, bedrock is buried beneath sediments consisting mostly of detritus carried by the ancestral Columbia River. In middle Pleistocene time, basalt and basaltic andesite erupted from three small volcanoes in the southern half of the watershed. In late Pleistocene time, the Missoula floods deposited poorly sorted gravels in the southwestern part of the Lacamas Creek watershed that grade northward into finer grained sediments. Because of extensive dense vegetation, natural outcrops in the watershed are generally limited to steep cliff faces, landslide scarps, and streambeds (Evarts, 2006).

Climate

Lacamas Creek is located in the West Coast Marine Climate Region that includes the Pacific coast from southeastern Alaska to northern California (City of Vancouver, 2002). The Columbia River and Pacific Ocean moderate temperatures lending to a maritime climate. As a result, the area experiences mild, cool, wet winters and relatively dry, warm summers. The Willapa Range to the west and the relatively taller Cascade Range to the east influence the climate as well. In Vancouver, the average maximum monthly air temperatures range from 44°F in January to near 80°F in August. Severe temperature extremes are infrequent. The foothills in the upper Lacamas Creek watershed receive slightly more rainfall than the lowlands in Camas and Vancouver. Average annual rainfall for Vancouver is just over 40 inches, falling mainly in the winter months.

Wildlife

Historically, the watershed supported native cutthroat trout; however, these fish are almost completely absent today due to changes in water quality. Lacamas and Round Lakes are now stocked annually with about 25,000 brown and rainbow trout from the Vancouver Trout Hatchery. These stocked fish make up the primary species in the lakes, along with introduced warm-water species such as yellow perch, largescale sucker, and largemouth bass. The watershed probably supports other species such as sculpin, shiners, sticklebacks, dace, and lamprey larvae.

There is evidence that salmon use lower Lacamas Creek for spawning and rearing but cannot access the watershed above Round Lake because of natural waterfalls and man-made dams (Schnabel, 2010).

The Lacamas Creek watershed provides habitat for many animal species, particularly along the riparian corridor and wetlands. Both resident and migratory birds rely on the area for food and raising their young. Many types of mammals, amphibians, and reptiles are abundant in the watershed.

Vegetation

Historically, the watershed was forested with some wetland prairies. Tree species such as alder, cottonwood, maple, willow, western hemlock, spruce, Douglas fir, and western red cedar dominated the canopy along most of the riparian corridor. Understory species included vine maple, huckleberry, salal, ferns, and devil’s club.

Humans have altered the vegetation dramatically along portions of Lacamas Creek and its tributaries by introducing exotic and invasive plant species and deforesting riparian habitat. China Ditch, Big Ditch, and Spring Branch were dug to drain wetlands and provide dry land for agriculture. These areas now contain many exotic plant species, such as blackberries and reed canary grass.

Hydromodifications

Historically, natural wetlands covered much of the western part of the study area. This area has since been drained for agriculture by a series of ditches that empty into Lacamas Creek. Significant areas of pasture/grassland remain. Drainage Improvement District No. 5 is located in the China Ditch area and is responsible for the maintenance of drainage and diking improvements there (Figure 2). Drainage District No. 7 in the Spring Branch/Big Ditch area is no longer functional.

The largest of the man-made drainages include China Ditch, Spring Branch, and Big Ditch. The Big Ditch and Spring Branch area still floods during the wet season, but eventually drains to Lacamas Creek and infiltrates into the ground in time for spring and summer agriculture.

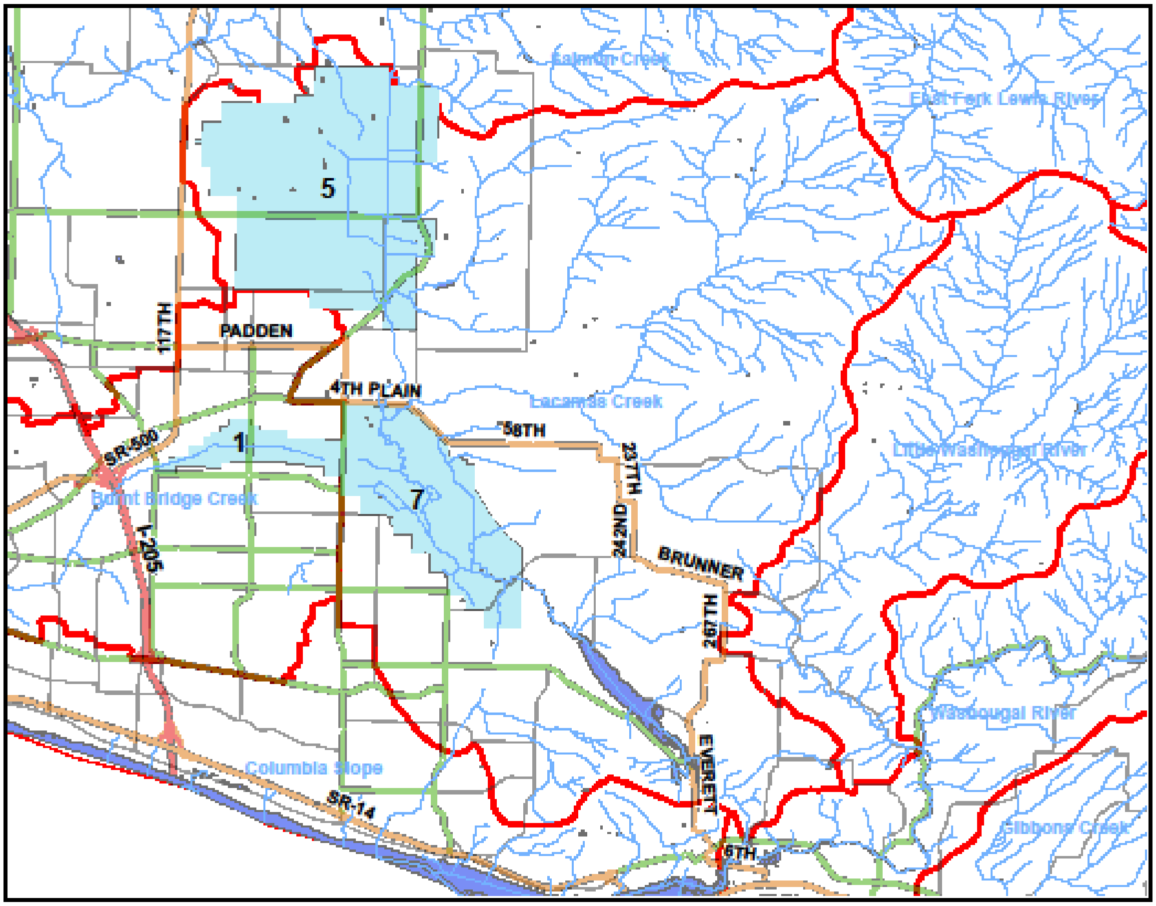

Figure 2. Map of Lacamas Creek watershed showing the locations of Drainage Districts 5 and 7 (blue shaded areas) (Schnabel, 2010).

Potential sources of contamination

Point sources

Three dairies in the study area operate under a Concentrated Animal Feeding Operations (CAFO) General Permit. Ecology administers the general permit to cover CAFO operations. As of July 1, 2003, the jurisdiction was transferred to the Washington State Department of Agriculture (WSDA) under the Livestock Nutrient Management Program. However, until EPA delegates permit authority to WSDA, Ecology will continue to administer the permit, with inspections performed by WSDA. The current general permit does not cover specific provisions relating to a TMDL, but facilities cannot discharge process waters to surface water bodies except under catastrophic conditions. Facilities must be "… designed, constructed, and operated to treat all process generated wastewater plus the runoff from a 25-year 24-hour rainfall event…."

Clark County has an NPDES Phase I Municipal Stormwater Permit and the City of Vancouver has a Phase II Municipal Stormwater Permit (see Stormwater section below). The cities of Camas and Vancouver currently release wastewater into the Columbia River.

There are no other permitted point sources affecting water quality in the study area, although there may be unknown, illicit discharges in the watershed.

Stormwater

During significant rain events, rainwater can wash the surface of the landscape, pavement, rooftops, and other impervious surfaces. This stormwater runoff can accumulate and transport pollutants and contaminants via stormwater drains to receiving waters and can degrade water quality.

Clark County

Ecology issued an NPDES Phase I Municipal Stormwater Permit to Clark County and other western Washington jurisdictions in January 2007 and revised it in June 2009. Phase I permittees are cities and counties that operate large and medium municipal separate storm sewer systems (MS4s). Governmental bodies, such as state highway departments and drainage districts, are also required to meet permit requirements within their boundaries. State highways in the Lacamas watershed include SR 500 and SR 503. The permit regulates stormwater discharges to waters of Washington State from the permittees' MS4s in compliance with Washington Water Pollution Control Law (Chapter 90.48 RCW) and the federal Clean Water Act (Title 33 USC, Section 1251 et seq.).

Clark County has a new Stormwater Management Plan (2010) that outlines the county's responsibilities to protect water through stormwater management. The Plan can be found at www.clark.wa.gov/water-resources/SWMP/stormwater_plan.html.

More information on Phase I permits and Clark County can be found at www.ecy.wa.gov/programs/wq/stormwater/municipal/Phase1equivalentstormwatermanualsWestern.html

City of Vancouver

The City of Vancouver encompasses a very small portion in the western part of the watershed near the confluence of Fifth Plain and Lacamas Creeks (Figure 1).

Ecology issued the Western Washington Phase II Municipal Stormwater Permit in January 2007. Under the Phase II permit, the City of Vancouver must follow the prescribed guidelines to manage stormwater before it discharges to surface water. Permit requirements fall under five basic categories: public education and outreach, public involvement and participation, illicit discharge detection and elimination, the control of runoff from development, and pollution prevention. General information on the Phase II permit is available at www.ecy.wa.gov/programs/wq/stormwater/municipal/phaseIIww/wwphiipermit.html.

In 1996, the City of Vancouver established a city-wide Surface Water Utility. The utility manages the city's stormwater flowing into Lacamas Creek. The city is currently mapping all stormwater drainages and lines, and inspecting the lines using a submersible camera (Kardouni, 2010).

At this time the Surface Water Utility is well established with an existing surface water utility rate structure, and the City of Vancouver has implemented the required NPDES Phase II Permit program elements. As part of the Phase II Permit, the city has developed a Stormwater Management Program. Documentation of the program and the annual report summarizing how the city is complying with each section of the Phase II Permit are available on the city website. Outside of the city, Clark County must follow Phase I of the NPDES municipal stormwater guidelines to manage stormwater before it discharges to surface water.

Ecology's five-volume Stormwater Management Manual is available on the internet at www.ecy.wa.gov/programs/wq/stormwater/manual.html.

Nonpoint sources

Nonpoint pollution sources are dispersed and thus not controlled through discharge permits. Potential nonpoint sources within the Lacamas Creek watershed include:

- Residential properties adjacent to the creek
- Riparian residential development
- Agricultural land
- Golf courses
- Wildlife waste
- Pet waste
- Human waste
- Failing onsite septic systems

Nonpoint sources are important to understand due to their impacts on stream water quality, and also as a major component of stormwater runoff.

The water quality standards use FC as indicators of pathogenic organisms associated with fecal contamination. FC are produced in the guts of warm-blooded animals and are present in high concentrations in fecal material. Potential sources of FC include humans, domestic animals, and wildlife. Fecal contamination of water poses a human public health threat when humans ingest FC while recreating in the water or when they drink the water.

Fecal coliform bacteria

FC from nonpoint sources are transported to the creeks by direct and indirect means. For example, manure that is spread over fields during certain times of the year can enter streams via surface runoff or fluctuating water levels. Livestock often have direct access to water. Manure is deposited in the riparian area of the access points where fluctuating water levels, surface runoff, or constant trampling can transport the manure into the water. The Big Ditch and Spring Branch area often floods during the winter, which can lead to overland flow of fecal material.

Some residences may have wastewater illegally piped to waterways or may have malfunctioning on-site septic systems where effluent seeps to nearby waterways. Pet waste concentrated in public parks, on creek-side trails, or private residences can be a source of contamination, particularly in urban areas. Swales, subsurface drains, and flooding through pastures and near homes can carry FC, nutrients, and other pollutants from sources to waterways. Even illegal campsites can be a source of human waste, carrying bacteria and nutrients to streams.

Dissolved oxygen and pH

Nonpoint sources may also contribute to DO or pH impairments. Depressed DO may result from increased nutrient loads that stimulate algae and plant growth, referred to as productivity. The decomposition of dead algae and other organic matter consumes DO. Productivity may be limited by a specific nutrient (usually phosphorus in streams and lakes), by light to fuel photosynthesis, or by retention time in a water body.

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

- Septic systems.
- Stormwater runoff from paved and pervious lands.
- Improper manure storage or disposal from commercial and non-commercial agriculture.
- Vegetation removal without erosion control from construction areas or forest harvest.
- Channel bank erosion or bed scour due to high flows or constrained reaches.
- Poor fertilizer and irrigation water management.
- Removal of riparian zone vegetation (riparian trees and other vegetation naturally filter nutrients and other pollutants and also reduce solar radiation reaching the stream surface, which may limit algal growth).

The diel cycle of algal growth adds DO during the daylight hours as the plants photosynthesize, but reduces DO levels to a minimum around daybreak as respiration occurs. Increased nutrient loading from anthropogenic sources can enhance algal growth and increase the diel DO fluctuation. This can result in lower levels of DO than would have resulted under conditions where humans were absent.

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

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

Wetlands can affect pH. The high residence time and high organic matter loading in wetlands, for example, produce low DO and pH levels. Some wetland complexes exist within the Lacamas Creek system and may contribute to the low levels recorded in the mainstem and the tributaries.

Groundwater inputs can also affect stream DO and pH, as well as temperature. Groundwater can warm a stream in winter and cool a stream in the summer, and the amount of DO is often lower in groundwater. In the adjacent watershed (Burnt Bridge Creek), groundwater pH values ranged from 6.3 to 7.2 (Sinclair, 2010).

Anthropogenic activities can lower pH as well. For example, decomposing organic material, such as that found in logging slash, and even acid deposition can lower pH below the state criterion.

Some streams have a naturally low buffering capacity, which makes them more susceptible to pH changes. These streams can have both low and high pH in the same stretch, though often during different times of the year.

Wildlife and background sources

A variety of wildlife lives within the Lacamas Creek watershed. Wildlife presents a potential source of FC, BOD, and nutrients. Open fields, riparian areas, and wetlands provide feeding and roosting grounds for some birds whose presence can increase FC counts, BOD, and nutrients in runoff.

Usually these sources are dispersed and may not elevate FC counts or affect DO and pH in streams significantly enough to violate state surface water quality criteria. Sometimes animal populations become concentrated and can cause water quality violations. Concentrated wildlife (for example, nutria, raccoons, beaver, deer, and birds) in the watershed will be noted during sampling surveys.

Historical Data Review

Ecology ambient monitoring

Ecology established an ambient monitoring station (28I120) on Lacamas Creek at Goodwin Road in October 2006 and sampled there once per month until October 2007. Table 5 shows data collected during the one year sampling effort. The data show routinely elevated FC concentrations, and also indicate periods with depressed DO levels and elevated temperatures. Details and results can also be found at www.ecy.wa.gov/apps/watersheds/riv/station.asp?sta=28I120.

Table 5. Ecology's ambient monitoring data for Lacamas Creek at Goodwin Road, October 2006 to October 2007.

Date	Time	Cond.	FC		Flow	Ammonia		Nitrate + Nitrite	Sol. Reactive Phos.	Oxygen	pH		Susp. Solids	Temp	Total Phos.	Total Persulfate Nitrogen	Turb.
		(umhos/ cm)	(#/ 100 ml)		(cfs)	(mg/L)		(mg/L)	(mg/L)	(mg/L)	(s.u.)		(mg/L)	(deg C)	(mg/L)	(mg/L)	(NTU)
10/16/06	15:30	122	480		29.5	0.01*	U	2.42*	0.025	9.9	7.2		5	12	0.033	1.92*	5
11/13/06	14:25	63	-		461	0.07		1.24	0.113	8.1	6.6		2	9.6	0.095	1.55	7.9
12/18/06	14:00	60	3		326	0.01	U	1.25	0.025	12.3	-		3	3.7	0.032	1.35	5.7
1/22/07	14:20	76	23		147	0.02		1.24	0.015	11.8	7.2		2	5.8	0.026	1.26	6.5
2/12/07	14:20	93	160	J	83.1	0.22		1.21	0.0348	11	7		6	8	0.069	1.47	12
3/19/07	12:35	81	74		92.2	0.03		1.15	0.016	10.22	7.2		6	10.6	0.031	1.26	6.1
4/23/07	12:40	82	47		93.8	0.04		1.02	0.015	10.82	7.1		2	11.2	0.038	1.12	6.2
5/21/07	12:40	106	510		45.8	0.03		1.2	0.021	10	7.3	J	4	11.9	0.033	1.34	5
6/11/07	13:00	113	77		22.7	0.01		1.4	0.024	10.95	7.6		3	14.7	0.035	1.6	5.5
7/16/07	15:10	152	110		12.5	0.01	U	2.61	0.0324	10.39	7.8		5	19.2	0.036	3.06	6
8/20/07	14:03	153	430		10.2	0.01	U	2.52	0.0367	9.4	7.4		5	16.2	0.037	3.51	7.5
9/24/07	13:50	149	180		7.76	0.01	U	2.64	0.0301	10.3	7.6		3	13.4	0.036	2.36	4.1

Common data qualifiers: U: not detected at the reported level; J: estimated value
Asterisk * indicates possible quality problem for the result.
Sol: Soluble; Phos: Phosphorus; Susp: Suspended; Turb: Turbidity

Clark County Public Works

Recent studies, data, and focus sheets can be found on Clark County's Water Resources and Clean Water Program website at www.clark.wa.gov/water-resources/index.html.

Some reports include:

- *2001 Matney Creek and Dwyer Creek Subwatershed Survey: Habitat and Benthic Macroinvertebrates* by Jeff Schnabel, March 2002.
- *Long-Term Index Site Monitoring Project: 2002 Physical Habitat Characterization* by Jeff Schnabel, December 2003.

- *Lacamas Lake: Nutrient Loading and In-lake Conditions* by Jeff Schnabel and Bob Hutton, April 2004.
- *Clark County Stormwater Management Plan* by Clark County Environmental Services, Clean Water Program, 2010.
- *Clark County 2010 Stream Health Report* by Clark County Environmental Services, Clean Water Program, 2010.

Historical and recent streamflow data can be accessed at www.clark.wa.gov/water-resources/monitoring/flow.html.

Lacamas Lake eutrophication studies

Many water quality studies have taken place in the Lacamas Creek watershed since the early 1980s. While most of them focused directly on Lacamas Lake and its eutrophication problems, a few have focused on Lacamas Creek and its tributaries as a source of pollution to Lacamas Lake. Data from past studies suggest that Lacamas Creek is the major source of nutrient loading to Lacamas Lake. Some of the more relevant studies are described below.

The 1983-1984 Lacamas Lake Diagnostic and Restoration Analysis (BCI, 1985) measured phosphorous loading to the lake and estimated target loading levels. In the 1984 water year, the lake received 15,046 kg of total phosphorous: 95.6% from Lacamas Creek, 4.0% from Dwyer Creek, and 0.4% from precipitation. The study recommended reducing the lake's phosphorous external loading 84% to reduce its trophic status with 90% certainty, which corresponds to an overall target lake concentration of 0.012 mg/L and a target concentration of 0.015 mg/L for Lacamas Creek.

Water quality monitoring by Clark County Water Quality Division in 1991 and 1992 found that Lacamas and Round Lakes continued to exhibit eutrophic conditions. Overall water quality in the lakes did not improve between 1984 and 1992. Decreases in tributary phosphorus levels were evident, but limited data and the influence of substantial differences in precipitation and streamflow made validation of any trends statistically impossible. The report highlighted the need for long-term water quality data to verify water quality trends and take into account variability associated with weather, land use, and the effects of restoration efforts.

In March 2002, Clark County Water Resources Section summarized results from nutrient loading investigations and in-lake monitoring during water year 2000 and water year 2001. Clark County also discussed current lake conditions, assessed trends in nutrient loading from 1983 to 2001, and compared current conditions to original program goals. Phosphorus loading and in-lake phosphorus concentrations had decreased by approximately 50% since 1983. The program goal was to achieve an 84% reduction in phosphorus. Despite the significant decrease in phosphorus, in-lake conditions had not improved and all applicable indicators suggested that the lake remained eutrophic.

Other studies

In 1987 Southwest Washington Health District evaluated septic system function for 52.8% of the approximately 2,061 homes in the Lacamas basin. Based on the survey results, the report concluded that septic tank systems contribute less than 2.5% of the annual phosphorus load to Lacamas Lake and have little impact on water quality in the lake.

Also in 1987, Clark County Intergovernmental Resource Center inventoried 1,087 agricultural parcels (29,000 acres) and identified 42 different best management practices (BMPs) that were needed to address problems on 437 individual agricultural operations in the basin. Farms were prioritized according to a problem severity ranking process. Total cost of cleanup was estimated at $3,170,000. Assuming full BMP implementation on the worst 122 operations, it was estimated that a 50-75% reduction in phosphorus loading to Lacamas Lake could potentially be realized.

In 1995 the United States Department of Agriculture's Natural Resources Conservation Service summarized implemented BMPs to date. At that time, 42 landowners had installed 35 waste management and 66 riparian BMPs, for a total of 101 BMP installations. Inspections of the installed BMPs during 1995 indicated that 88 of these 101 BMPs were completely fulfilling their conservation objectives.

Ecology's TMDL evaluation (1996)

In 1996, Ecology published the Lacamas Creek Watershed TMDL Evaluation (www.ecy.wa.gov/biblio/96307.html). The evaluation showed that Lacamas Creek violated state water quality criteria for temperature, DO, pH, and FC and was therefore included on the 303(d) list requiring formulation of a TMDL. The report evaluated whether past assessment and control activities in the watershed were sufficient to meet EPA requirements for a TMDL. The evaluation was accomplished by an examination of each element of a TMDL in terms of EPA requirements, work completed in the basin, and an evaluation of completeness. TMDL requirements were not fully achieved by the current program. An outline of additional actions needed for a complete TMDL submittal was provided.

Goals and Objectives

Project goal

The goal of the proposed TMDL study is to ensure that Lacamas Creek and its tributaries above Lacamas Lake attain Washington State water quality standards for pH, DO, FC, and temperature. Lacamas Lake, Round Lake, and Lacamas Creek below Round Lake will not be included in this study.

Study objectives

Objectives of the TMDL study are as follows:

- Collect high quality data during field surveys from December 2010 to December 2011.
- Characterize FC concentrations and loads from all major tributaries, point sources, and drainages into Lacamas Creek under various seasonal and hydrological conditions.
- Calculate percent reductions and establish FC load and wasteload allocations.
- Identify relative contributions of FC loading to Lacamas Creek based on source areas so clean-up activities can focus on the largest sources.
- Characterize processes governing DO and pH in Lacamas Creek above Lacamas Lake, including the influence of tributaries, nonpoint sources, and groundwater.
- Develop a model to simulate biochemical processes and productivity in Lacamas Creek above Lacamas Lake. Using critical conditions in the model, determine the capacity to assimilate biochemical oxygen demand and nutrients.
- Characterize stream temperatures and processes governing the thermal regime in Lacamas Creek above Lacamas Lake. This includes the influence of tributaries and groundwater/surface water interactions on the heat budget.
- Develop a predictive temperature model for Lacamas Creek above Lacamas Lake. Using critical conditions in the model, determine the creek's capacity to assimilate heat. Evaluate the system potential temperature (approximate natural temperature conditions) for Lacamas Creek.
- Establish load allocations for nonpoint sources to meet temperature and DO water quality standards and protect beneficial uses.
- Use the calibrated model to evaluate future water quality management decisions for the Lacamas Creek watershed.

Study Design

Overview

TMDL study objectives will be supported by data collected by Ecology during field monitoring surveys from 2010-2011. The study may also be supported with pertinent existing data collected by Clark County, Ecology, and others.

DO, pH, temperature, and associated conventional parameters will be monitored at a fixed network of sampling sites during the summer critical season. These sites include locations at the mouths of all tributaries, significant drainage/discharges, and key locations along Lacamas Creek.

FC sampling will occur twice monthly for one year at the same locations as the other parameters, but also upstream in tributaries and where sources may be present.

Streamflow will be measured or calculated at all sites at the time of sampling.

The water quality models will be calibrated to field data. The calibrated models will then be used to evaluate the water quality in Lacamas Creek in response to various alternative scenarios of pollutant loading. Only the loading capacity of Lacamas Creek above Lacamas Lake will be evaluated. In addition, load allocations for nonpoint sources will be evaluated. The models will be used to determine (1) how much nutrients and biochemical oxygen demand need to be reduced to meet DO and pH water quality criteria and (2) how much effective shade is necessary to bring stream temperature into compliance with water quality criteria. Components and descriptions of the models are summarized in the following section.

FC TMDL allocations will be set based on applying a statistical method to measured data (the numeric water quality model will not be used). The statistical roll-back method, described in the following section, will be used to determine how much (in terms of percent) FC concentrations need to be reduced at each sampling site.

Modeling and analysis framework

The QUAL2Kw model (Chapra and Pelletier, 2003; Ecology, 2003b**)** or similar modeling framework will be developed to simulate both observed and critical conditions. The specific modeling framework will depend on a review of available frameworks at the time when modeling tasks are conducted. Critical conditions for temperature and DO are characterized by a period of low flows and high water and air temperatures. 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 relative percent difference (RPD). This statistic provides a relative estimate of whether a model consistently predicts values higher or lower than the measured value.

> RPD = (| Pi – Oi | *2) / (Oi + Pi), where
> Pi = ith prediction
> Oi = ith observation

QUAL2Kw graphically represents 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.

Means, maximums, minimums, and 90th percentiles will be determined from the data collected at each monitoring location. For temperature, the maximum, minimum, and daily average will be determined. Estimates of groundwater inflow will be calculated by constructing a water mass balance from continuous and instantaneous streamflow data and piezometer studies.

Temperature

The QUAL2Kw model (Chapra and Pelletier, 2003; Ecology, 2003b**)** or similar modeling framework will be used to evaluate the system potential temperature in the river. The model will be used to evaluate various heat budget scenarios for future water quality management decisions in the Lacamas Creek basin.

GIS coverage of riparian vegetation in the Lacamas Creek study area will be created from information collected during the 2011 temperature field study as well as from 2007 and 2009 Clark County digital aerial orthophotographs. Riparian vegetation coverage will be created by qualifying four attributes: vegetation height, general species type or combinations of species, percent vegetation overhang, and average canopy density of the riparian vegetation.

Data collected during this TMDL effort will allow the development of a temperature simulation methodology that is both spatially continuous and spans full-day lengths. The model will be calibrated to observed (2011) conditions measured by this study design. The GIS and modeling analysis will be conducted using specialized software tools:

- Ecology's Ttools extension for ArcView will be used to sample and process GIS data for input to the shade and temperature models.
- Ecology's shade calculator (Ecology, 2003a) will be used to estimate effective shade along Lacamas Creek. Effective shade will be calculated at 50- to 100-meter intervals along the streams, and then averaged over 500- to 1000-meter intervals for input to the temperature model.

- The QUAL2Kw model (Chapra and Pelletier, 2003; Ecology, 2003b) will be used to calculate the components of the heat budget and simulate water temperatures. The temperature model simulates diurnal variations in stream temperature using the kinetic formulations for the components of the surface water heat budget that are described in Chapra (1997).

QUAL2Kw will be applied by assuming that flow remains constant (i.e., steady flows) for a given condition such as a 7-day or 1-day period (using daily average flows), but key variables other than flow will be allowed to vary with time over the course of a day. For QUAL2Kw temperature simulation, the solar radiation, air temperature, relative humidity, headwater temperature, and tributary water temperatures are specified or simulated as diurnally varying functions.

Dissolved oxygen and pH

Water quality modeling for DO and pH will also be conducted using QUAL2Kw (Chapra and Pelletier, 2003; Ecology, 2003b) or with a similar biogeochemical modeling framework. The water quality model will use kinetic formulations for simulating DO and pH in the water column. The model will be calibrated and corroborated using data collected during the synoptic surveys and historical data to the extent possible.

Fecal coliform

Data analysis will include evaluation of data distribution characteristics and, if necessary, appropriate distribution of transformed data. Streamflow data will be frequently reviewed during the field data survey season to check longitudinal water balances. FC mass balance calculations will be performed on a reach basis. Estimation of univariate statistical parameters and graphical presentation of the data (box plots, time series, and regressions) will be made using WQHYDRO (Aroner, 2003) and Excel® (Microsoft, 2001) software.

The statistical rollback method (Ott, 1995) will be applied to determine the necessary reduction for both the geometric mean value (GMV) and 90_{th} percentile bacteria concentration (Joy, 2000) to meet water quality criteria. Ideally, at least 20 data are needed from a broad range of hydrologic conditions to determine an annual FC distribution. If sources of FC vary by season and create distinct critical conditions, seasonal targets may be required. Fewer data will provide less confidence in FC reduction targets, but the rollback method is robust enough to provide general targets for planning implementation measures. Compliance with the most restrictive of the dual FC criteria determines the bacteria reduction needed.

The rollback method uses the statistical characteristics of a known data set to predict the statistical characteristics of a data set that would be collected after pollution controls have been implemented and maintained. In applying the rollback method, the target FC GMV and the target 90_{th} percentile are set to the corresponding water quality criteria.

The rollback factor, $f_{rollback}$, is

$f_{rollback}$ = minimum { (50/sample GMV), (100/sample 90_{th} percentile) }.

The percent reduction ($f_{reduction}$) needed is

$f_{reduction} = (1 – f_{rollback}) \times 100\%$,

which is the percent reduction that allows both GMV and 90th percentile target values to be met. The result is a revised target value for either the GMV or the 90th percentile. In most cases, a reduction of the 90th percentile is needed, and application of this reduction factor to the study GMV yields a target GMV that is usually more restrictive than the water quality criterion. The 90th percentile is used as an equivalent expression to the "no more than 10%" criterion found in the second part of the water quality standards for FC.

Details

Fixed-network sampling

The following describes the study design for each Section 303(d)-listed parameter covered by this TMDL. Streamflow, time-of-travel, and groundwater sampling will also be discussed.

Figure 3 and Table 6 show the fixed-network of sampling locations. Table 7 shows the proposed survey schedule. Stations were selected based on 303(d) listings, historical site locations, spatial resolution, and location of tributaries. One reference station, outside the study area, will be sampled below Round Lake at 3rd Avenue, but data will not be used in the TMDL evaluation. See Table 6. Data from this site may be useful for comparison purposes and for future studies in the watershed.

Sites may be added or removed from the sampling plan depending on access and new information provided during the field observation and preliminary data analysis.

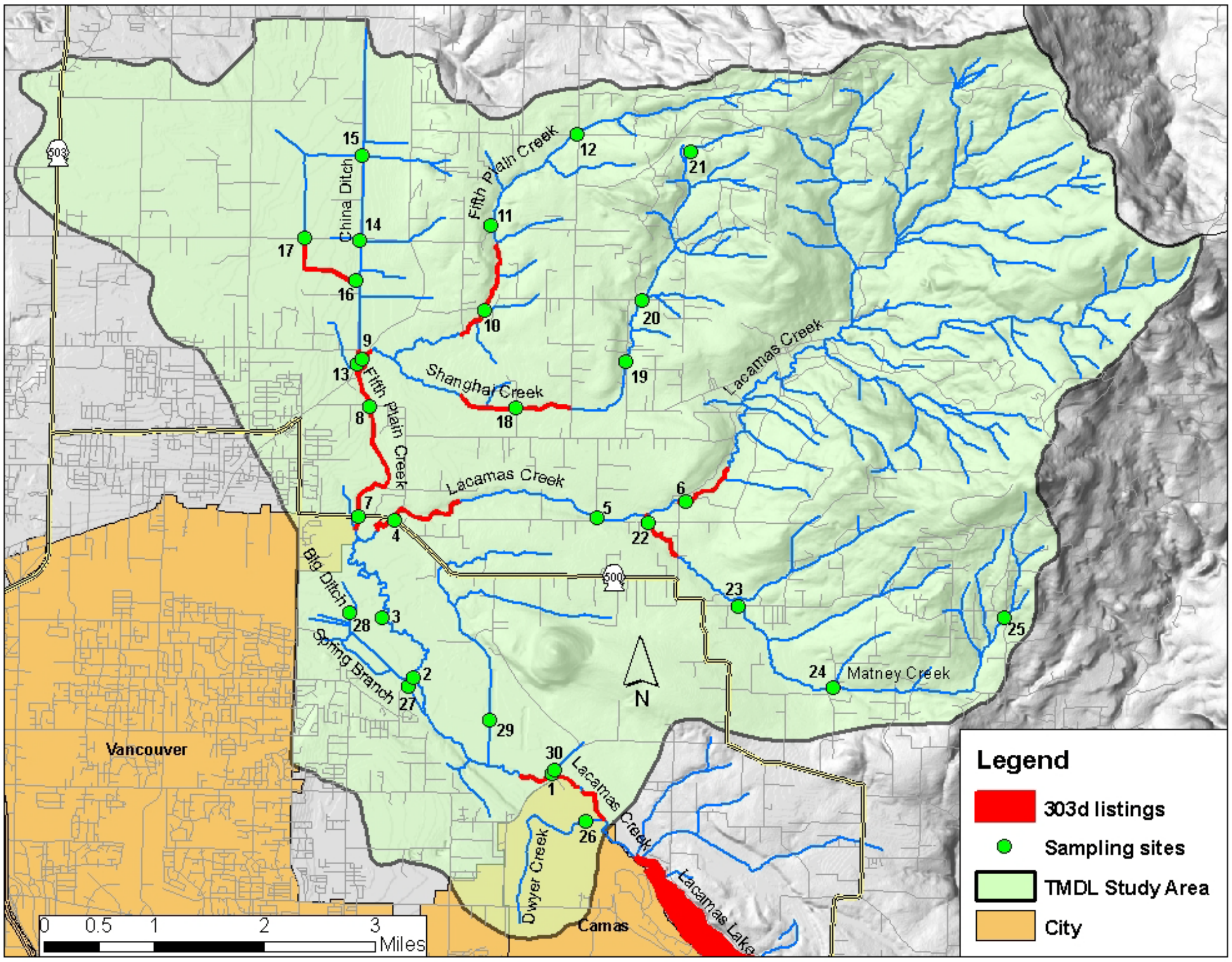

Figure 3. Fixed-network sampling locations in the Lacamas Creek watershed.

Table 6. Ecology's proposed sampling locations in the Lacamas Creek watershed.

Site ID	Map #	Bacteria	Synoptic survey [1]	H20 Thermometer	Air Thermometer	Continuous diel monitoring [2]	Relative humidity probe	Piezometer [3]	County flow gage	Ecology flow gage	Description	NAD 83 Latitude	NAD 83 Longitude
28-LAC-0.2	-	X	X	X	X						Lacamas Ck at NE 3rd Ave (below lake and study area)	45.58897	-122.39078
28-LAC-5.6	1	X	X	X	X	X	X		X		Lacamas Ck at Goodw in Rd	45.63878	-122.45697
28-LAC-7.5	2	X	X	X	X	X	X	X			Lacamas Ck upstream of Spring Branch off 182nd and 38th	45.65105	-122.48349
28-LAC-9.1	3	X	X	X	X	X	X	X			Lacamas Ck near Big Ditch	45.65872	-122.48950
28-LAC-11.1	4	X	X	X	X	X	X	X			Lacamas Ck at 4th Plain NE (SR 500)	45.67170	-122.48783
28-LAC-13.3	5	X	X	X	X	X			X		Lacamas Ck at NE 217th Ave	45.67262	-122.44988
28-LAC-14.8	6	X	X	X	X	X	X	X			Lacamas Ck just upstream of Camp Bonneville border	45.67503	-122.43331
28-FIF-0.2	7	X	X	X	X	X				X	5th Plain Ck at 4th Plain NE (SR 500)	45.67198	-122.49457
28-FIF-1.4	8	X									5th plain Ck at 88th St	45.68657	-122.49293
28-FIF-1.9	9	X	X	X		X					5th Plain Ck at NE Ward Rd and 172nd Ave intersection	45.69280	-122.49449
28-FIF-3.4	10	X	X	X	X	X		X			5th Plain Ck at NE Davis Rd	45.69956	-122.47187
28-FIF-4.3	11	X									5th Plain Ck at Sliderberg Rd and 122nd Circle	45.71074	-122.47104
28-FIF-5.5	12	X									5th Plain Ck at NE 212th Ave near intersection w ith NE 139th St	45.72300	-122.45527
28-CHI-0.0	13	X	X	X	X	X	X	X		X	China Ditch at NE Ward Rd and 172nd Ave intersection	45.69203	-122.49551
28-CHI-1.2	14	X	X	X	X			X			China Ditch at intersection of NE 172nd Ave and NE 119th St	45.70839	-122.49560
28-CHI-1.9	15	X									China Ditch north of 131st St on NE 172nd Ave	45.71945	-122.49564
28-CHB-0.0	16	X	X	X	X						China Ditch trib branch at Hockinson Meadow s Park	45.70299	-122.49603
28-CHB-0.8	17	X									China Ditch trib branch at NE corner of Hockinson Meadow s Park	45.70848	-122.50595
28-SHA-1.3	18	X	X	X	X	X	X				Shanghai Ck at NE 202nd Ave	45.68687	-122.46555
28-SHA-2.7	19	X		X	X			X			Shanghai Ck at NE 222nd Ave	45.69327	-122.44520
28-SHA-3.4	20	X									Shanghai Ck at NE 109th St	45.70130	-122.44241
28-SHA-5.0	21	X									Shanghai Ck at 39th Loop at end of NE 139th St	45.72103	-122.43393
28-MAT-0.1	22	X	X	X	X	X				X	Matney Ck at NE 68th St	45.67218	-122.44010
28-MAT-1.4	23	X									Matney Ck at NE 53rd St	45.66142	-122.42297
28-MAT-2.8	24	X									Matney Ck at NE 261st Ave	45.65106	-122.40480
28-MAT-4.9	25	X									Matney Ck at Livingston Rd	45.66085	-122.37292
28-DWY-0.1	26	X	X	X	X	X					Dw yer Ck at golf course maintenance shop	45.63267	-122.45051
28-SPR-0.3	27	X	X	X	X	X		X			Spring Branch Ck at 182nd Ave and 38th Way	45.64985	-122.48429
28-BIG-0.2	28	X		X				X			Big Ditch near Lacamas Ck	45.65913	-122.49566
28-TUG-0.0	29	X	X	X	X						Unnamed tributary to Lacamas Ck below Tug Lake	45.64564	-122.46890
28-GOL-0.0	30	X	X	X							Unnamed trib to Lacamas Ck entering at Goodw in Rd (left bank)	45.63886	-122.45695
Total		31	19	21	18	14	7	10					

[1] Includes sampling all parameters in Table 10 and periphyton. Groundwater will be sampled at piezometer sites for parameters in Table 9.
[2] Flux chambers will also be deployed where possible. Parameters monitored include dissolved oxygen, pH, conductivity, and temperature.
[3] Monitored parameters for groundwater are shown in Table 9.

Table 7. Proposed survey schedule for the Lacamas Creek TMDL study.

Survey type and frequency	Dec (2010)	Jan (2011)	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
FC bacteria sampling	2	2	2	2	2	2	2	2	2	2	2	2
Piezometer water level measurements and thermistor downloads	1*	1*	1*	1*	1*	1	1	1	1	1	1	1*
Air and surface water thermistor downloads						1	1	1	1	1	1	
Stormwater+					1	1	1	1	1	1	1	1
Dissolved oxygen, pH, and nutrient synoptic surface water and groundwater sampling^								1		1		
Time-of-travel (dye) study								1		1		
Habitat and channel geometry								1	1			
Periphyton sampling										1		

* If possible. Water levels may be too high to access some piezometers.

\+ Weather permitting. The goal is to sample one summer storm for nutrients and FC and three fall through spring storms for FC.

^ Includes Hydrolab and benthic flux chamber deployment

Fecal coliform bacteria

The fixed-network sites will be sampled twice monthly from December 2010 to December 2011.

Data from the fixed-network will provide FC data sets to meet the following needs:

- Provide an estimate of the annual and seasonal geometric mean and 90th percentile statistics FC counts. The schedule should provide 24 samples per site to develop the annual statistics. This will include 10 samples per site during the dry season (June - October), and 14 samples per site during the wet season (November - May).
- Provide reach-specific FC load and concentration comparisons to define areas of FC loading increases (e.g., malfunctioning on-site septic systems, livestock, wildlife, or manure spreading) or decreases (e.g., settling with sediment, die-off, or dilution). With accurate streamflow monitoring, tributary and source loads also can be estimated.

Sites may be added if land access permissions are granted, better or more access to streams are found during sampling, or data from investigatory surveys show areas of concern or areas that need further bracketing. Conversely, sampling at some sites may be discontinued if data isn't useful to the TMDL analysis or the site does not help bracket pollution sources.

Dissolved oxygen and synoptic surveys

DO and associated conventional parameter data will be collected synoptically[1] from the fixed-network of stations (Figure 3 and Table 6). In early morning and late afternoon, field teams will record in-situ parameters (temperature, DO, pH, and conductivity) and will collect representative grab samples for laboratory analysis. Synoptic surveys will be conducted at least 2 times during the course of the project to provide model calibration and corroboration data sets.

The fixed-network synoptic sampling will occur during the summer low-flow months (June to September) to capture critical conditions. Synoptic sampling will include grab samples of DO[2], chloride, total suspended solids, total non-volatile suspended solids, turbidity, ammonia, nitrite/nitrate, orthophosphate, total phosphorous, total persulfate nitrogen, dissolved and total organic carbon, alkalinity, chlorophyll-*a*, and streamflow.

Continuous diel monitoring for pH, DO, conductivity, and temperature will be conducted at several of the fixed-network sites with Hydrolab DataSondes® or MiniSondes® following standard operating procedures (Swanson, 2010). Sediment oxygen demand may be characterized by installing sediment flux chambers in up to 4 representative reaches along the creek or tributaries during the synoptic surveys if resources allow (Roberts, 2007). The benthic chambers will remain in place for at least 24 hours. Once deployed, Winkler DO grab samples will be taken at dawn and dusk. Periphyton sampling will occur at each fixed-network sampling site to determine biomass and chlorophyll-*a* levels.

Temperature

Continuous temperature dataloggers (thermistors) will be deployed at several fixed-network sites (Figure 3 and Table 6). Each site will have at least two thermistors: one to measure water temperature and another to measure air temperature. The thermistors will measure temperature at 30-minute intervals. Instream thermistors are deployed in the thalweg of a stream, suspended off the stream bottom and in a well-mixed area, typically in riffles or swift glides. Some sites may also have a datalogger measuring air relative humidity (Table 6).

The temperature assessment of Lacamas Creek will use effective shade as a surrogate measure of heat flux. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Human activities increase water temperature when the removal of riparian vegetation reduces effective shade.

Heat loads to the stream will be calculated using a heat budget that accounts for surface heat flux and mass transfer processes. Heat loads are of limited value in guiding management activities needed to solve identified water quality problems. Shade will be used as a surrogate to heat load as allowed under EPA regulations (defined as “other appropriate measure” in 40 CFR § 130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and heat load upon the affected stream section. Other factors influencing the

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[1] All stations sampled over a short period of time.
[2] Winkler dissolved oxygen samples for lab check of field measurements.

effect of the solar heat load on stream temperatures will also be assessed, including human-caused changes in stream morphology, streamflow, and groundwater interactions.

Groundwater and synoptic surveys

Groundwater and surface-water interactions will be assessed via a combination of field techniques. Instream piezometers were installed in September 2010 at 10 of the fixed-network sites (Figure 3 and Table 6) in accordance with standard EA Program methodology (Sinclair and Pitz, 2010). Most of these sites are in the mid to lower watershed where soft sedimentary deposits make installation possible. Piezometer installation will be difficult or impossible in the upper watershed due to the presence of near-surface bedrock or consolidated sediments. Where piezometers cannot be installed, natural seeps will be targeted and sampled where possible. The piezometers will be used at discrete points along the creek to monitor surface-water and groundwater head relationships, streambed water temperatures, and groundwater quality.

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 4). 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 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).

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 EA Program methodology (Sinclair and Pitz, 2010). The water level (head) difference between the piezometer and the creek provides an indication of the vertical hydraulic gradient and the direction of flow between the creek and groundwater. When the piezometer head exceeds the creek stage, groundwater discharge into the creek can be inferred. Similarly, when the creek stage exceeds the head in the piezometer, loss of water from the creek to groundwater storage can be inferred.

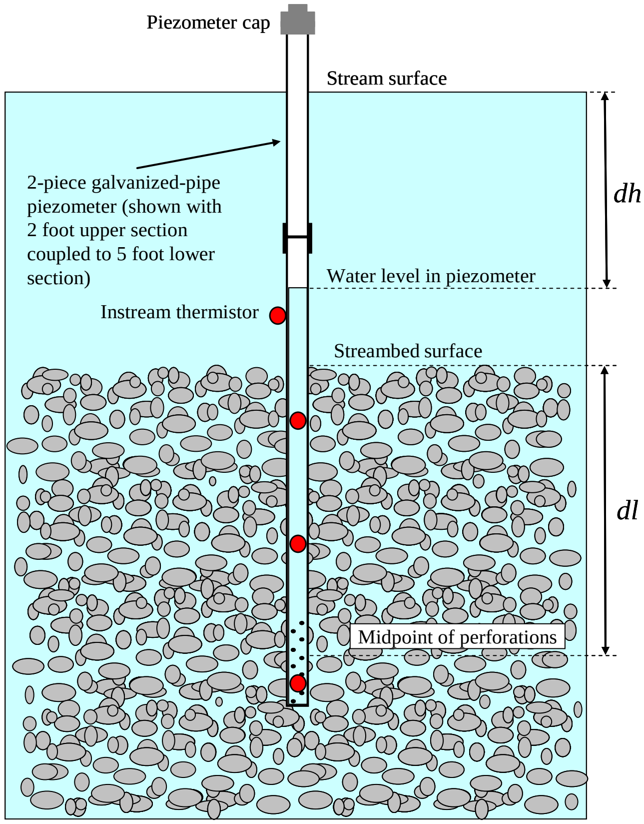

Figure 4. Instream piezometer conceptual diagram (diagram not to scale).

Two groundwater quality sampling events (scheduled to coincide with synoptic surface-water sampling events) will be conducted to assess the quality of groundwater discharging to the creek. During the synoptic surveys, groundwater samples will be collected from piezometers in gaining stream reaches or seeps if necessary. The samples will be submitted to the laboratory for analysis of FC, alkalinity, chloride, orthophosphate, total phosphorus, nitrate/nitrite, ammonia, total persulfate nitrogen, dissolved organic carbon, and iron concentration analysis. Temperature, water level, conductivity, pH, and DO will also be measured in the piezometers during the surveys.

To confirm the instream piezometer dataset, Ecology will (where necessary) also attempt to arrange access to shallow off-stream domestic wells to monitor local groundwater levels, temperatures, and groundwater quality. When selecting wells, preference will be given to shallow, properly documented wells in close proximity to Lacamas Creek. Wells selected for monitoring will be visited monthly during the 2010-2011 study period to measure groundwater levels. Where owner's permission is granted and site conditions allow, logging thermistors may also be deployed in the wells. Ecology also hopes to collect water quality samples from a subset of the off-stream wells during each of the two instream piezometer sampling events described above.

Time of travel to determine average stream velocities

Travel times will be estimated within several reaches of Lacamas Creek 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. These studies will take place at different streamflow regimes during summer and fall. Dye studies will coincide with the synoptic surveys.

Ecology will notify Clark County Environmental Services and other 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).

Establishing a continuously recording stream gage network to measure streamflows

Ecology's Freshwater Monitoring Unit plans to install and maintain three continuous streamflow gages for this project. These gages will help quantify streamflows in Lacamas Creek or its tributaries. Proposed sites are Matney Creek at 68th St., Fifth Plain Creek at Fourth Plain Rd. (SR 500), and China Ditch near Ward Rd.

Continuously recorded streamflow data, instantaneous streamflow measurements conducted during baseflow conditions, piezometer vertical hydraulic gradient measurements, and the resulting flow mass balance will be used to determine surface-water and groundwater interactions. The major surface-water inputs to Lacamas Creek, including tributaries and point discharges, will be measured during each field visit, if possible.

Riparian habitat and channel geometry surveys

Effective shade inputs to the water quality model (QUAL2Kw) require an estimate of the aerial density of vegetation shading the stream. Ground truthing is necessary, so a hemispherical lens and digital camera will be used to take 360° pictures of the sky to calculate the shade provided by vegetation and topography at the center of the stream. These photographs will be taken at each fixed-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).

Ecology will also use Solar Pathfinder™ equipment to collect effective shade data at each site. The Solar Pathfinder™ uses a polished, transparent, convex plastic dome. A panoramic view of the area is reflected in the dome. Trees, hills, bridges, or other obstacles to sunshine are plainly visible as reflections on the polished surface of the dome. Since the dome is transparent, the user can also look through the dome to a sun chart within the Solar Pathfinder™. This chart shows the Sun's path through the sky for all months of the year. The chart is also calibrated by the hours of the day. The dome has slots in its sides and the user traces the outline of the horizon's reflection of the dome onto the sun chart. The traced line shows exactly at what hours of the day, and months of the year an obstacle will shade the stream.

Ecology will follow Timber-Fish-Wildlife stream temperature survey methods for the collection of data during thermal reach surveys (Schuett-Hames et al., 1999). The surveys will be conducted during the summer of 2011 at the fixed-network sites. Depending on stream access, field 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 habitat field data collection includes 150 feet on both banks of Lacamas Creek (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.

Stormwater monitoring

Stormwater will be evaluated as part of the TMDL. The Ecology project team will attempt to capture up to three storm events during the fall/winter season and one during the summer low-flow season to characterize the impact of these events. Winter storms will be sampled for bacteria only. The summer storm will include grab samples for nutrients, sediment, bacteria, and carbon.

The purpose of storm monitoring is to better characterize potential sources of contaminant loading to Lacamas Creek. During rain events, greater than average loading may occur when surface-water flushes into the creeks. For this TMDL, a storm event is defined as a minimum of 0.2 inches of rainfall in a 24-hour period, with an antecedent dry period of 24 hours in winter, 72 hours in summer. Daily rainfall data will be obtained from local sources.

During the wet season, Ecology will try to sample all fixed-network sites twice during each storm event. This may not be possible if resources are scarce. When grab samples are collected, streamflow will be measured with a flow meter, estimated using stage and rating curves, compared with other monitoring locations and calculated using regression analysis, or calculated or estimated using other measures as appropriate. Local weather forecasts and predictive models will allow anticipation of significant storm events suitable for sampling.

Ecology will attempt to sample one summer storm event. During this storm event, sites and representative outfalls will be monitored for bacteria, total organic carbon (TOC), dissolved organic carbon (DOC), total suspended solids (TSS), and nutrients (ammonia, nitrite-nitrate, total persulfate nitrogen, orthophosphate, and total phosphorus).

The stormwater sampling sites will include all fixed-network sites plus up to 10 outfalls, ditches, small creeks, or drains representing runoff from the different major land uses in the watershed. Ecology will search the watershed further and work with regional staff during the project to find suitable sampling sites. Urban, farm, and roadside ditches or outfalls will likely be targeted.

Practical constraints and logistical problems

Seasonal conditions may affect access to some sampling locations. For example, sites in the Big Ditch/Spring Branch area may not be accessible in the winter because of flooding.

Inclement weather, such as heavy rainfall resulting in temporary flooding or heavy snowfall, may also limit access to some sites.

Although rare, logistical problems such as scheduling conflicts, sample bottle delivery errors, vehicle or equipment problems, or the limited availability of personnel or equipment may interfere with sampling as well.

Sampling Procedures

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

Grab samples will be collected directly into pre-cleaned containers supplied by Ecology's Manchester Environmental Laboratory (MEL) and described in their *Lab Users Manual* (MEL, 2008). Samples will be collected according to the standard operating procedures (SOPs) for surface water and bacteria sampling (Joy, 2006; Mathieu, 2006). DO sampling (Winkler method) will follow the SOP for measuring DO in surface waters (Mathieu, 2007). Sample parameters, containers, volumes, preservation requirements, and holding times are listed in Table 8. All samples for laboratory analysis will be labeled, stored on ice, and delivered to MEL within 24 hours of collection via FedEx and Ecology courier.

A minimum of 10% of the samples (20% of FC samples) will be field duplicates used to assess total (field and lab) variability. Samples will be collected in the thalweg and just under the water's surface.

Periphyton field sampling protocols are adapted from the USGS protocols (Porter et al., 1993)

Temperature monitoring stations and piezometers will be checked monthly to obtain field measurements and to clear accumulated debris away from the thermistors. Documentation of the temperature monitoring stations will include:

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

Table 8. Containers, preservation requirements, and holding times for surface water samples (MEL, 2008).

Parameter	Sample Matrix	Container	Preservative	Holding Time
Fecal Coliform	Surface water, groundwater, & runoff	250 or 500 mL glass/poly autoclaved	Cool to 4ºC	24 hours
Dissolved Oxygen	Surface water	300 mL BOD bottle & stopper	2 mL manganous sulfate reagent + 2 mL alkaline-azide reagent	4 days
Chloride	Surface water, groundwater, & runoff	500 mL poly	Cool to 4ºC	28 days
Total Suspended Solids; TNVSS[1]	Surface water & runoff	1000 mL poly	Cool to 4ºC	7 days
Turbidity	Surface water & runoff	500 mL poly	Cool to 4ºC	48 hours
Alkalinity	Surface water, groundwater, & runoff	500 mL poly – No Headspace	Cool to 4°C; Fill bottle *completely*; Don't agitate sample	14 days
Ammonia	Surface water, groundwater, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Dissolved Organic Carbon	Surface water, groundwater, & runoff	60 mL poly with: Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; 1:1 HCl to pH<2; Cool to 4°C	28 days
Nitrate/Nitrite	Surface water, groundwater, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Total Persulfate Nitrogen	Surface water, groundwater, & runoff	125 mL clear poly	H_2SO_4 to pH<2; Cool to 4ºC	28 days
Orthophosphate	Surface water, groundwater, & runoff	125 mL amber poly w/ Whatman Puradisc™ 25PP 0.45um pore size filters	Filter in field with 0.45um pore size filter; Cool to 4°C	48 hours
Total Phosphorous	Surface water, groundwater, & runoff	60 mL clear poly	1:1 HCl to pH<2; Cool to 4°C	28 days
Total Organic Carbon	Surface water & runoff	60 mL clear poly	1:1 HCl to pH<2; Cool to 4°C	28 days
Dissolved Iron	Groundwater	500 mL HDPE[2] bottle	Filter; Then HNO3 to pH<2 3; Cool to 4°C	6 months
Chlorophyll a	Surface water & periphyton	1000 mL amber poly	Cool to 4°C; If filtered in the field, freeze filters in acetone at -20°C	24 hrs to filtration; 28 days after filtration

TNVSS[1]: Total Nonvolatile Suspended Solids.
HDPE[2:] High-density polyethylene.

Two groundwater sampling events will be conducted in summer 2011 to assess the quality of groundwater discharging to the creek along gaining stream reaches. The samples will be evaluated for the parameters shown in Table 9.

Table 9. 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	Sentix® 41-3 probe[2]	0.1°C
Specific Conductance	Tetracon® 325 probe[2]	1 uS/cm
pH	Sentix® 41-3 probe[2]	0.1 s.u.
Dissolved Oxygen	Cellox® 325 probe[2]	0.1 mg/L
Laboratory Analyses		
Coliform, fecal (MF)	SM 9222D	1 CFU/100 mL
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
Iron[1]	EPA 200.7	0.05 mg/L

[1] Dissolved fraction.
[2] Probe used with a WTW multiline P4 meter.
MF: Membrane filter method.
s.u.: Standard units.

Measurement Procedures

Field measurements will include conductivity, temperature, pH, and DO using a calibrated Hydrolab DataSonde® or MiniSonde® (Swanson, 2010). DO will also be collected and analyzed using the Winkler titration method (Mathieu, 2007).

Measurement of relative head conditions between the piezometer and the creek will be accomplished by direct comparison measurements using standard procedures for calibrated electric well probes (Marti, 2009; Sinclair and Pitz, 2010). Temperature dataloggers will also be downloaded monthly or bi-monthly using SOP protocols (Bilhimer and Stohr, 2009).

Instantaneous flow measurements will follow the EA Program protocol (Sullivan, 2007).

Continuous flow volumes at Ecology gages will be calculated from stage height records and rating curves developed during the project at three locations in the watershed. Proposed sites are Matney Creek at 68th St., China Ditch near Ward Road, and Fifth Plain Creek at Fourth Plain Road (SR 500). Stage height will be measured by pressure transducer and recorded by a datalogger every 15 minutes. All dataloggers will be downloaded monthly or bi-monthly to reduce potential data loss due to vandalism, theft, or equipment malfunction. Staff gages or tape-down measurements may be established at other selected sites. During the field surveys, staff gage/tape-down readings will be recorded at all stations, and streamflow will be measured when possible. A flow rating curve will be developed for sites with a staff gage or tape-down reference point so gage readings can be converted to a discharge value.

All continuously recording dataloggers will be synchronized to official U.S. time. The official time can be found at: www.time.gov/timezone.cgi?Pacific/d/-8/java. This information is available through (1) the National Institute of Standards and Technology (NIST), a Department of Commerce agency, and (2) the U.S. Naval Observatory (military counterpart of NIST). All date and time stamps will be recorded in Pacific Daylight Savings Time.

Data Quality Objectives

Field sampling procedures and laboratory analyses inherently have associated uncertainty which results in data variability. Measurement quality objectives state the desired data variability for a project. *Precision* and *bias* are data quality criteria used to indicate conformance with measurement quality objectives. The term *accuracy* refers to the combined effects of precision and bias.

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

Bias is defined as the difference between the population mean and true value of the parameter being measured. Bias will be minimized by strictly following sampling and handling protocols. Field equipment will be pre-calibrated and post-checked and compared in a side by side manner with other calibrated instruments. Relative percent difference (RPD) will be used as a measure of bias where appropriate.

Field sampling precision and bias will be addressed by submitting field blanks and replicate samples. Manchester Laboratory will assess precision and bias in the laboratory through the use of check standards, duplicates, spikes, and blanks.

Field equipment and laboratory analytical methods, precision and bias objectives, method reporting limits and resolution, and estimated range for field and laboratory measurements are shown in Table 10. The targets for analytical precision of laboratory analyses are based on historical performance by MEL for environmental samples taken around the state by the EA Program (Mathieu, 2006). The laboratory's measurement quality objectives and quality control procedures are documented in the MEL *Lab Users Manual* (MEL, 2008).

A WTW 340i multi-meter will be used to measure water conductivity and temperature of groundwater in piezometers. A Hydrolab DataSonde® or MiniSonde® will be used to measure DO, temperature, pH, and conductivity of surface waters.

Table 10. Measurement quality objectives for measurement systems.

Analysis	Equipment Type and Method	Precision (Percent Relative Standard Deviation, %RSD)	Bias (Relative Percent Difference, RPD)	Method Lower Reporting Limit and/or Resolution	Estimated Range
Field Measurements					
Stream Velocity	Marsh McBirney Flo-Mate Model 2000	10%	NA	0.01 ft/s	0.01 – 10 ft/s
Water Temperature[1]	Hydrolab MiniSonde®	+/- 0.2° C	NA	0.01° C	0 – 30° C
Specific Conductivity	Hydrolab MiniSonde®	5%	10%	0.1 umhos/cm	20 – 1000 umhos/cm
pH[1]	Hydrolab MiniSonde®	+/- 0.05 s.u.	NA	0.01 s.u.	1 – 14 s.u.
Dissolved Oxygen[1]	Hydrolab MiniSonde®	+/- 0.2 mg/L	NA	0.1 mg/L	0 – 15 mg/L
Dissolved Oxygen[1]	Winkler Titration	+/- 0.2 mg/L	NA	0.1 mg/L	0 – 15 mg/L
Laboratory Analyses					
Fecal Coliform – MF	SM 9222D	50% of replicate pairs < 20% RSD; 90% of replicate pairs <50%[2]	40%	1 cfu/100 mL	1 – >5000 cfu/100 mL
Chloride	EPA 300.0	5%[3]	If sample is >5 times reporting limit, then 20% RPD	0.1 mg/L	0.1 – 250 mg/L
Total Suspended Solids	SM 2540D	15%[3]	See above	1 mg/L	1 – 5000 mg/L
Total Non-Volatile Suspended Solids	SM 2540 D, E	15%[3]	See above	1 mg/L	1 – 5000 mg/L
Turbidity	SM 2130	10%[3]	See above	1 NTU	1-100 NTU
Alkalinity	SM 2320B	10%[3]	See above	5 mg/L	5 – > 100 mg/L
Ammonia	SM 4500-NH_3^-H	10%[3]	See above	0.01 mg/L	0.01 – 20 mg/L
Dissolved Organic Carbon	EPA 415.1	10%[3]	See above	1 mg/L	1 – 20 mg/L
Nitrate/Nitrite	SM 4500-NO_3^- I	10%[3]	See above	0.01 mg/L	0.01 – 10 mg/L
Total Persulfate Nitrogen	SM 4500 NO_3^-B	10%[3]	See above	0.025 mg/L	0.025 – 20 mg/L
Orthophosphate	SM 4500-PG	10%[3]	See above	0.003 mg/L	0.003 – 1 mg/L
Total Phosphorous	SM 4500-PF	10%[3]	See above	0.005 mg/L	0.005 – 10 mg/L
Total Organic Carbon	EPA 415.1	10%[3]	See above	1 mg/L	1 – 20 mg/L
Chlorophyll-*a*	SM 10200H(3)	20%[3]	See above	0.05 ug/L	1 – 100 ug/L

[1] as units of measurement, not percentages.
[2] replicate results with a mean of less than or equal to 20 cfu/100 mL will be evaluated separately.
[3] replicate results with a mean of less than or equal to 5X the reporting limit will be evaluated separately.

SM: Standard Methods for the Examination of Water and Wastewater, 20th Edition (APHA, 1998).
EPA: EPA Method Code.

Table 11 summarizes the manufacturer's stated accuracy (precision and bias) and resolution of the equipment used in groundwater and temperature surveys. Certain instruments are used exclusively for water temperature and others for air as noted in the table.

Table 11. Accuracy (precision and bias) and resolution of field equipment used for temperature and groundwater surveys.

Measurement/ Instrument Type	MQO* and Manufacturer's Stated Accuracy	Required Resolution
Continuous temperature/ Hobo Water Temp Pro v2	±0.2°C at 0 to 50°C (± 0.36°F at 32° to 122°F)	0.2°C for water temperature
Continuous temperature/ StowAway Tidbits -5°C to +37°C model	±0.4°F (±0.2°C) at +70°F	0.2°C for water temperature
Continuous temperature / StowAway Tidbits -20°C to +50°C model	±0.8°F (±0.4°C) at +70°F	0.4°C for air temperature
Hobo Pro Relative Humidity	±3% RH	n/a
Instantaneous conductivity and temp./ TetraCon 325C probe and WTW 340i multi-meter	±1% of value (conductivity) 0.2°C (temperature)	0.2°C for temperature

*Measurement Quality Objective

Representative sampling

The study is designed to have enough sampling sites and sufficient sampling frequency to meet study objectives. Some parameter values, especially FC, are known to be highly variable over time and space. Sampling variability can be somewhat controlled by strictly following standard procedures and collecting quality control samples, but natural spatial and temporal variability can contribute greatly to the overall variability in the parameter value. Resources limit the number of samples that can be taken at one site spatially or over various intervals of time. Laboratory and field errors are further expanded by estimate errors in seasonal loading calculations.

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 the Lacamas Creek TMDL is to correctly collect and analyze 100% of the samples for each of the 31 sites, and 100% of the storm event samples and groundwater samples. However, problems occasionally arise during sample collection that cannot be controlled; this can interfere with the goal. Example problems are flooding, inadequate rain for storm sampling, site access problems, or sample container shortages. A lower limit of five samples per season per site will be required for comparison to Washington State criteria. This should easily be met with the current sampling design. For bacteria, WAC 173-201A states:

"When averaging bacteria sample data for comparison to the geometric mean criteria, it is preferable to average by season and include five or more data collection events within each period….and [the period of averaging] should have sample collection dates well distributed throughout the reporting period."

Investigatory samples may be collected at sites not included in this QA Project Plan, or, if necessary, a site may be added to further characterize problems in an area. Such sampling that does not meet the lower limit criteria of five samples per season (wet or dry) per site will still be useful for source location identification, recommendations, or other analyses. But such sampling will not be used to set load or wasteload allocations.

Quality Control

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

Laboratory

MEL will analyze all samples. The laboratory's measurement quality objectives and QC procedures are documented in the MEL *Lab Users Manual* (MEL, 2008). Field sampling and measurements will follow QC protocols described in Ecology (1993). If any of these QC procedures are not met, the associated results may be qualified by MEL or the project manager and used with caution, or not used at all.

Bacteria samples tend to have a high relative standard deviation (RSD) between replicates compared to other water quality parameters. Bacteria sample precision will be assessed by collecting replicates for approximately 20% of samples in each survey.

Standard Methods (APHA, 1998) recommends a maximum holding time of eight hours for microbiological samples (six hours transit and two hours laboratory processing) for non-potable water tested for compliance purposes. MEL has a maximum holding time for microbiological samples of 24 hours (MEL, 2008). Standard Methods (APHA, 1998) recommends a holding time of less than 30 hours for drinking water samples and less than 24 hours for other types of water tested when compliance is not an issue. Microbiological samples analyzed beyond the 24-hour holding time are qualified as estimates with a *J* qualifier code. MEL accepts samples Monday through Friday, which means Ecology can sample Sunday through Thursday.

To identify any problems with holding times, two comparison studies were conducted during the Yakima Area Creeks TMDL (Mathieu, 2005). A total of 20 FC samples were collected in 500-mL bottles and each split into two 250-mL bottles. The samples were driven to MEL within 6 hours. One set of the split samples was analyzed upon delivery. The other set was stored overnight and analyzed the next day. Both sets were analyzed using the membrane filter (MF) method.

The combined precision results between the different holding times yielded a mean RSD of 19%. This is comparable to the 23% mean RSD between field replicates for 12 EA Program TMDL studies using the MF method, suggesting that a longer, 24-hour holding time has little effect on FC results processed by MEL. Samples with longer holding times did not show a significant bias towards higher or lower FC counts compared to the samples analyzed within 6-8 hours.

Field

Three instantaneous streamflow measurements will be replicated during each summer synoptic survey to check precision. Multiple flow meters may be compared to check for instrument bias or error. If a significant difference is found between flow meters (>5%), the instruments will be recalibrated or not used. Instantaneous flows may also be compared to Ecology or Clark County continuous stream gage results as an additional QA/QC measure.

QA/QC for field measurements begins with a calibration check of dataloggers. The Onset StowAway Tidbits© and the Hobo Water Temp Pro© thermistors will have a calibration check both pre- and post-study in accordance with Ecology Temperature Monitoring Protocols (Stohr, 2009). This check is done to document instrument accuracy at representative temperatures. A NIST-certified reference thermometer will be used for the calibration check. The calibration check may show that the temperature datalogger differs from the NIST-certified thermometer by more than the manufacturer-stated accuracy of the instrument (range greater than ±0.2°C or ±0.4°C).

A datalogger that fails the pre-study calibration check (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 2011 study period. Air temperature data and instream temperature data for each site will be compared to determine if the instream thermistor was exposed to the air due to stream stage falling below the installed depth of the stream thermistor.

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

Hydrolab MiniSonde® and DataSonde® DO, pH, and conductivity sensors will be calibrated according to manufacturer's recommendations and the Hydrolab SOP (Swanson, 2010). Temperature is factory-calibrated. Hydrolabs will be calibrated before each sampling survey and checked afterward using certified standards and reference solutions. During regular, non-synoptic surveys, Winkler DO samples will be taken at one or two sites each day and compared to the Hydrolab's DO measurements. Hydrolab results will be accepted, qualified, rejected, or corrected, as appropriate.

Three or more Winkler samples will be taken at each Hydrolab location during long-term deployments (up to one week during summer synoptic surveys) for comparison purposes. Conductivity, pH, and temperature will also be checked with another calibrated Hydrolab at the same time. The two Hydrolab's measurements will be compared and results from the deployed Hydrolab will be accepted, qualified, rejected, or corrected, as appropriate.

Corrective actions

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

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

In addition, Hydrolab data may be corrected to a known standard or more accurate measurement. For example, if diel DO data from a Hydrolab is plotted on an Excel® chart and shows bias from the Winkler DO check values, the whole diel curve may be adjusted to “fit” or overlap the Winkler values. Winkler DO results are generally considered more accurate than Hydrolab DO results. Thus, correcting the Hydrolab results using the Winkler results will give us a more accurate representation of the true diel curve of DO throughout the course of the 24-hour period. If Ecology decides to correct any Hydrolab data (usually DO or pH) it will be noted. Raw data will still be included in the report. If any data is corrected, the correction methods will be explained in the final report.

Data Management Procedures

Field measurements will be entered into a water-resistant field book and then transferred into Excel® spreadsheets (Microsoft, 2001) as soon as practical after returning to the office. The spreadsheets will be used for preliminary analysis and to create a table to upload data into Ecology's Environmental Information Management database (EIM).

Sample result data received from MEL through 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.

All continuous data will be stored in a project database that includes station location information and data QA information. This database will facilitate summarization and graphical analysis of the temperature data and also create a temperature data table for uploading to the EIM geospatial database.

An EIM user study ID (TSWA0003) has been created for this TMDL. All monitoring data will be available via the internet once the project data have been validated. The URL address for this geospatial database is: http://apps.ecy.wa.gov/eimreporting/search.asp. After reviewing project data for quality and finalizing, the EIM data engineer will upload the data.

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

Any existing data or non-Ecology data used in the TMDL analysis must meet the same precision and bias criteria as data collected by Ecology during the study.

Audits and Reports

The project manager will submit quarterly progress reports and the final technical study report to Ecology's Water Quality Program client (TMDL coordinator) according to the project schedule (Table 13).

Data Verification

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

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 is complete. Data entry will be checked against the field notebook data for errors and omissions. Missing or unusual data will be brought to the attention of the project manager for consultation. Validated data will be moved to a separate file labeled "Final."

As soon as FC data are verified by MEL, the laboratory microbiologist will notify the field lead about results greater than 200 cfu/100 mL. The field lead will then notify the Southwest Regional Office client staff contact and the Water Quality Program section manager of these elevated counts in accordance with EA Program Policy 1-03. The TMDL coordinator will notify local authorities or permit managers as appropriate.

The field lead will check data received through LIMS for omissions against the Request for Analysis forms. Data can be in Excel® spreadsheets (Microsoft, 2001) or downloaded tables from EIM. These tables and spreadsheets will be located in a file labeled "Draft" until data verification and validation is completed. Field replicate sample results will be compared to quality objectives in Table 10. The project manager will review data requiring additional qualifiers.

Data for instream temperature monitoring stations will be verified against the corresponding air temperature station to ensure the stream temperature record represents water temperatures and not temperatures recorded during a time the instream thermistor was dewatered. Measurement accuracy of individual thermistors is verified using a NIST-certified reference thermometer and field measurements of stream temperature at each thermistor location several times during the study period.

After data verification and data entry tasks are completed, all field, laboratory, and flow data will be entered into a file labeled "Final" and then uploaded into EIM. Another EA Program field assistant will independently review 10% of the project data in EIM for errors. If significant data entry errors are discovered, a more intensive review will be undertaken.

Data Quality (Usability Assessment)

The field lead will determine if measurement and other data quality objectives have been met for each monitoring station and each survey. The field lead will determine this by examining the data and all of the associated QC information. Data that does not meet the project data quality criteria will either be qualified or rejected. The final data set or report will not include rejected data. The field lead will produce a station QA report that will include site descriptions, data QA notes, and graphs of all continuous data, for inclusion in the project report.

Project Organization

Table 12 shows the roles and responsibilities of Ecology staff.

Table 12. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
(To be declared - position currently vacant) WQP, SWRO Phone: (360) 690-4664	Overall Project 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 section of the joint TMDL report. Prepares and implements the joint TMDL report for submittal to EPA.
Kim McKee WQP, SWRO Phone: (360) 407-6407	Unit Supervisor of Project Lead	Approves TMDL report for submittal to EPA. Temporarily fills role of Project Lead while position is vacant.
Trevor Swanson DSU/WOS/EAP Phone: (360) 407-6498	QAPP Author, Project Manager/ Field Lead/ EIM Engineer	Defines project objectives, scope, and study design. Writes the QAPP. Develops TMDLs for temperature, bacteria, and DO, including writing the technical section of the joint TMDL report. Manages the data collection program. Coordinates and conducts field survey and data collection. Enters project data into the EIM system and conducts data quality review.
Stephanie Brock DSU/WOS/EAP Phone: (360) 407-6517	Modeler and Mentor	Provides mentorship for modeling temperature, pH, DO, and associated parameters and technical portion of joint TMDL report.
Kirk Sinclair GFFU/EAP Phone: (360) 407-6557	Hydrogeologist	Provides hydrogeologic assistance with study design including interpretation of historical geology and groundwater data in the basin, groundwater data collection, data analysis, and report writing.
Chuck Springer FMU/WOS/EAP Phone: (360) 407-6997	Hydrogeologist	Deploys and maintains continuous flow gages and staff gages. Produces records of streamflow data at sites selected for this study.
George Onwumere DSU/WOS/EAP Phone: (360) 407-6730	Unit Supervisor of Project Manager	Reviews and approves the QAPP, staffing plan, technical study budget, and the technical sections of the joint TMDL report.
Robert F. Cusimano WOS/EAP Phone: (360) 407-6596	Section Manager of Project Manager	Approves the QAPP and technical sections of the joint TMDL report.
Stuart Magoon MEL/EAP Phone: (360) 871-8801	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 EAP Phone: (360) 407-6964	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

DSU: Directed Studies Unit.
EAP: Environmental Assessment Program.
EIM: Environmental Information Management database.
FMU: Freshwater Monitoring Unit.
GFFU: Groundwater/Forest and Fish Unit.
MEL: Manchester Environmental Laboratory.
QAPP: Quality Assurance Project Plan.
SWRO: Southwest Regional Office.
WOS: Western Operations Section.
WQP: Water Quality Program.

Project Schedule

Table 13 shows the proposed project schedule for the Lacamas TMDL study.

Table 13. Proposed schedule and assignments for completing field work, laboratory work, report writing, and data entry into EIM.

Field and laboratory work	
Field work completed	December 2011
Laboratory analyses completed	January 2012
Environmental Information Management database (EIM)	
EIM data engineer	Trevor Swanson
EIM user study ID	TSWA0003
EIM study name	Lacamas Creek Fecal Coliform Bacteria, Temperature, Dissolved Oxygen, and pH TMDL
Data due in EIM	April 2012
Quarterly/annual reports	
Author lead	Trevor Swanson
Schedule	
1st quarterly/annual report	March 2011
2nd quarterly/annual report	June 2011
3rd quarterly/annual report	September 2011
4th quarterly/annual report	January 2012
Groundwater report	
Activity Tracker code	(Not assigned yet)
Author lead	Kirk Sinclair
Schedule (estimate)	
Draft due to supervisor	(Not assigned yet)
Draft due to client/peer reviewer	(Not assigned yet)
Draft due to external reviewer	(Not assigned yet)
Final report due on web	November 2012
Final report	
Author lead	Trevor Swanson
Schedule	
Draft due to supervisor	June 2013
Draft due to client/peer reviewer	July 2013
Draft due to external reviewer	September 2013
Final report due on web	March 2014

Laboratory Budget

Table 14 presents the estimated laboratory budget for this study. The budget and lab sample load are based on:

1. Sampling bacteria at each fixed-network site twice per month.
2. One periphyton assessment.
3. Two synoptic surface-water surveys.
4. Two groundwater quality surveys (corresponding with 3 above).
5. Two storm sampling events for bacteria.
6. One summer storm sampling event for bacteria, nutrients, TSS + TNVSS, TOC and DOC.

The greatest uncertainty in the laboratory workload and cost estimate is with the synoptic storm survey work since the storm sites have not yet been selected. However, efforts will be made to keep the submitted number of samples within the estimate provided here.

Table 14. Laboratory budget.

Parameter	Cost*/ Sample	# of Sites	Times Sampled per day	Number of Samples (including field QA)	Number of Surveys	Total Number of Samples	Total Cost
Turbidity	11.42	19	2	42	2	84	959
Total Suspended (TSS) + TNVSS**	36.34	19	2	42	2	84	3053
Alkalinity	17.65	19	2	42	2	84	1483
Chloride	13.50	19	2	42	2	84	1134
Chlorophyll-a (lab filtered)	57.10	19	2	42	2	84	4796
Ammonia (NH3)	13.50	19	2	42	2	84	1134
Nitrite-Nitrate (NO2/NO3)	13.50	19	2	42	2	84	1134
Total Persulfate Nitrogen (TPN)	17.65	19	2	42	2	84	1483
Orthophosphate (OP)	15.57	19	2	42	2	84	1308
Total Phosphorus (TP)	18.69	19	2	42	2	84	1570
Periphyton (biovolume, ID)	80.10	19	1	21	2	42	3364
Dissolved Organic Carbon	37.34	19	2	42	2	84	3137
Total Organic Carbon	34.26	19	2	42	2	84	2878
Fecal Coliform	23.88	31	1	37	24	888	21205
Two bacteria storm sampling events, plus one summer storm sampling event for all parameters							$8,745
Additional samples (e.g., for additional storm sampling or unknown sources)							$5,000
Groundwater sampling (including iron)							$5,557

*Costs include 50% discount for Manchester Laboratory. Total $67,939

References

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

Aroner, E.R., 2003. WQHYDRO: Water Quality/Hydrology Graphics/Analysis System. Portland, OR.

BCI (Beak Consultants and Scientific Resources Incorporated), 1985. Lacamas-Round Lake Diagnostic and Restoration Analysis Final Report and Appendices. Intergovernmental Resource Center, Vancouver, WA.

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.
www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_044Cont_Temp_Monit_TMDL.pdf

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 Companies, Inc., New York, NY.

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

City of Vancouver, 2002. Vancouver Urban Parks, Recreation, and Open Space Plan. Vancouver, WA.
www.cityofvancouver.us/parks-recreation/parks_trails/planning/pdfs/urban2001.pdf

Clark County, 2004. Clark County Stream Health: A comprehensive overview of the condition of Clark County's streams, rivers, and lakes. Clark County Public Works, Clean Water Program, Vancouver, WA.

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

Ecology, 2003a. Shade.xls - A Tool for Estimating Shade from Riparian Vegetation. Washington State Department of Ecology, Olympia, WA.
www.ecy.wa.gov/programs/eap/models/

Ecology, 2003b. QUAL2Kw.xls - A Diurnal Model of Water Quality for Steady Flow Conditions. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/models/

Evarts, R.C., 2006. Geologic Map of the Lacamas Creek Quadrangle, Clark County, Washington. U.S. Geological Survey Scientific Investigations Map 2924, 22 p. plus map.

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.

Joy, J. 2000. Lower Nooksack River Basin Bacteria Total Maximum Daily Load Evaluation. Washington State Department of Ecology, Olympia, WA. Publication No. 00-03-006. www.ecy.wa.gov/biblio/0003006.html

Joy, J. 2006. Standard Operating Procedure for Manually Obtaining Surface Water Samples, Version 1.0. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_015ManuallyObtainingSurfaceWaterSamples.pdf

Kardouni, J., 2010. Personal communication. Environmental Specialist, Washington State Department of Ecology, Olympia, WA.

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., 2005. Yakima Area Creeks Fecal Coliform TMDL Quarterly Progress Report #3 (July 2005 through September 2005). Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA.

Mathieu, N., 2006. Replicate Precision for 12 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., 2007. Standard Operating Procedure for Measuring Dissolved Oxygen in Surface Water, Version 1.1. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_035MeasuringDO_v1_1.pdf

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 pp.

NADP (National Atmospheric Deposition Program) (NRSP-3)/National Trends Network, 2004. NADP Program Office, Illinois State Water Survey, Champaign, Illinois. http://nadp.sws.uiuc.edu/NTN/maps.aspx

Ott, W., 1995. Environmental Statistics and Data Analysis. Lewis Publishers, New York, NY.

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

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

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

Schnabel, J., 2010. Personal communication. Natural Resources Specialist, Clark County Department of Environmental Services, Vancouver, WA.

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

Sinclair, K., 2010. Personal communication. Hydrogeologist, Environmental Assessment Program, Washington State Department of Ecology, Olympia, WA.

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. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_046Hemispherical_Photography_Computer_Analysis.pdf

Stohr, A., 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. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_044Cont_Temp_Monit_TMDL.pdf

Sullivan, L., 2007. Standard Operating Procedure for Estimating Streamflow, Version 1.0. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_024WQSUSstreamflow_v1_0.pdf

Swanson, T., 2010. Standard Operating Procedure (SOP) for Hydrolab® DataSonde® and MiniSonde® Multiprobes, Version 1.0. Washington State Department of Ecology, Olympia, WA. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_033Hydrolab.pdf

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

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. www.ecy.wa.gov/programs/eap/qa/docs/ECY_EAP_SOP_034CollectionandProcessingofStreamSamples.pdf

Appendix. Glossary, Acronyms, and Abbreviations

Glossary

Anthropogenic: Human-caused.

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

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

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

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

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.

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

Extraordinary primary contact: Waters providing extraordinary protection against waterborne disease or that serve as tributaries to extraordinary quality shellfish harvesting areas.

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).

Geometric mean: A mathematical expression of the central tendency (an average) of multiple sample values. A geometric mean, unlike an arithmetic mean, tends to dampen the effect of very high or low values, which might bias the mean if a straight average (arithmetic mean) were calculated. This is helpful when analyzing bacteria concentrations, because levels may vary anywhere from 10- to 10,000- fold over a given period. The calculation is performed by either:

(1) taking the nth root of a product of n factors, or (2) taking the antilogarithm of the arithmetic mean of the logarithms of the individual values.

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

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

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

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

National Pollutant Discharge Elimination System (NPDES): National program for issuing, modifying, revoking and reissuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements under the Clean Water Act. The NPDES program regulates discharges from wastewater treatment plants, municipal separate storm sewer systems, 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).

Pathogen: Disease-causing microorganisms such as bacteria, protozoa, viruses.

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

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

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

Point source: 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 five acres of land.

Pollution: Such contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state. This includes change in temperature, taste, color, turbidity, or odor of the waters. It also includes discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state. This definition assumes that these changes will, or 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.

Primary contact recreation: Activities where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and water skiing.

Reserve Capacity: A calculated amount of pollutant loading sometimes incorporated into the TMDL to allow for uncertainty and future growth.

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

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

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

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

System potential: The design condition used for TMDL analysis.

System potential temperature: An approximation of the temperatures that would occur under natural conditions. System potential is our best understanding of natural conditions that can be supported by available analytical methods. The simulation of the system potential condition uses best estimates of *mature riparian vegetation, system potential channel morphology, and system potential riparian microclimate* that would occur absent any human alteration.

Synoptic sampling: All site sampled in over a short period of time (usually one day).

Thalweg: The deepest moving portion of a stream’s channel.

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

Turbidity: A measure of the amount of suspended silt or organic matter in water. High levels of turbidity can have a negative impact on aquatic life.

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

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

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.

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

7Q10 flow: A critical low-flow condition. The 7Q10 is a statistical estimate of the lowest

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

90th percentile: A statistical number obtained from a distribution of a data set, above which 10% of the data exists and below which 90% of the data exists.

Acronyms and Abbreviations

BMP	Best management practices
DO	(See Glossary above)
EA	Environmental Assessment
Ecology	Washington State Department of Ecology
EIM	Environmental Information Management database
EPA	U.S. Environmental Protection Agency
FC	(See Glossary above)

MEL	Manchester Environmental Laboratory
NAD	North American Datum
NIST	National Institute of Standards and Technology
NPDES	(See Glossary above)
QA	Quality assurance
QC	Quality control
RPD	Relative percent difference
TMDL	(See Glossary above)
USGS	United States Geological Survey
WAC	Washington Administrative Code
WRIA	Water Resource Inventory Area

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
cfu	colony forming units
ft	feet
mg	milligrams
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)
umhos/cm	micromhos per centimeter
uS/cm	microsiemens per centimeter, a unit of conductivity