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

Water Quality Study Design (Quality Assurance Project Plan)

April 2013

Publication No. 13-03-109

DEPARTMENT OF
ECOLOGY
State of Washington

Publication and Contact Information

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

The plan for this study is available on the Department of Ecology's website at https://fortress.wa.gov/ecy/publications/SummaryPages/1303109.html

Author: James Kardouni

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

Data for this project are available at Ecology's Environmental Information Management (EIM) website at www.ecy.wa.gov/eim/index.htm. Search User Study ID is jkar0004.

Activity Tracker Code (Environmental Assessment Program) is 13-012.

TMDL Study Code (Water Quality Program) is CLCR12MP.

Federal Clean Water Act 2004 303(d) Listings Addressed in this Study

Clover Creek LLID: 1225274471570 (PS92IZ) Listings 7553, 7549, 7548, 7547, 7545, 5847:
Temperature and Fecal coliform

North Fork Clover Creek LLID: 1224286471345 (FP21BP) Listings 7558, 5848:
Fecal coliform

Morey Creek LLID: 1224719471336 (FC86XG) Listing 7543:
Dissolved Oxygen

Cover photo: Clover Creek at 25th Avenue East, by Scott Groce

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

Water Quality Study Design (Quality Assurance Project Plan)

April 2013

Approved by:

Signature:	Date: April 2013
Cindy James, Client, Water Quality Program, SWRO	
Signature:	Date: April 2013
Kim McKee, Client's Unit Supervisor, Water Quality Program, SWRO	
Signature:	Date: April 2013
Bob Bergquist, Client's Section Manager, Water Quality Program, SWRO	
Signature:	Date: April 2013
James Kardouni, Author / Project Manager, Principal Investigator, EIM Data Engineer EAP	
Signature:	Date: April 2013
George Onwumere, Author's Unit Supervisor, EAP	
Signature:	Date: April 2013
Robert F. Cusimano, Author's Section Manager, EAP	
Signature:	Date: April 2013
Joel Bird, Director, Manchester Environmental Laboratory	
Signature:	Date: April 2013
Bill Kammin, Ecology Quality Assurance Officer	

Signatures are not available on the Internet version
EAP: Environmental Assessment Program
EIM: Environmental Information Management database
SWRO: Southwest Regional Office

Table of Contents

Page

List of Figures

Page

List of Tables

Abstract

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. Clover Creek and its tributaries were included on the Washington State 303(d) list of impaired water bodies because it does not meet water quality criteria for fecal coliform bacteria, dissolved oxygen, and temperature. The Clover Creek watershed is located in Pierce County, central western Washington, and flows through the City of Tacoma urban growth areas, the city of Lakewood, Joint Base Lewis-McChord, and empties into Steilacoom Lake. As a part of the TMDL for the Clover Creek watershed, this technical study will evaluate the relevant water quality parameters during the 2013 - 2014 study period. The goal of this TMDL is to determine the total maximum daily load of pollutants that will allow the water bodies to meet water quality criteria.

Data collected will form the basis for comparison to the State water quality criteria and development of contaminant load allocations. Using the results of this technical assessment, Ecology will work with local stakeholders to develop an implementation plan that describes what will be done to improve water quality in the Clover Creek watershed. The plan explains the roles and authorities of cleanup partners, along with the programs or other means through which these partners will address these water quality issues. The plan prioritizes specific actions to improve water quality and to achieve Washington State water quality standards.

What is a Total Maximum Daily Load (TMDL)?

Federal Clean Water Act requirements

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

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

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

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

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

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

Category 2 – Waters of concern.

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

Category 4 – Polluted waters that do not require a TMDL because they:

- 4a. – Have an approved TMDL being implemented.
- 4b. – Have a pollution-control program in place that should solve the problem.
- 4c. – Are impaired by a non-pollutant such as low water flow, dams, and 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) follows 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?

Organizations at the federal, state, and local level should participate in the TMDL process in order to ensure watershed restoration. Local citizens also play a key role in protecting and enhancing their watersheds. Actors with potential to improve the Clover Creek watershed include but are not limited to: EPA Region 10, the Department of Defense Joint Base Lewis-McChord (JBLM), Washington State Department of Transportation (WSDOT), Washington State Department of Ecology (Ecology), the U.S. Geological Survey (USGS), Pierce County, the cities of Tacoma and Lakewood, the urban growth areas of Spanaway and Parkland, and citizens.

The area under the Clover Creek dissolved oxygen, fecal coliform, and temperature study is shown in Figure 1.

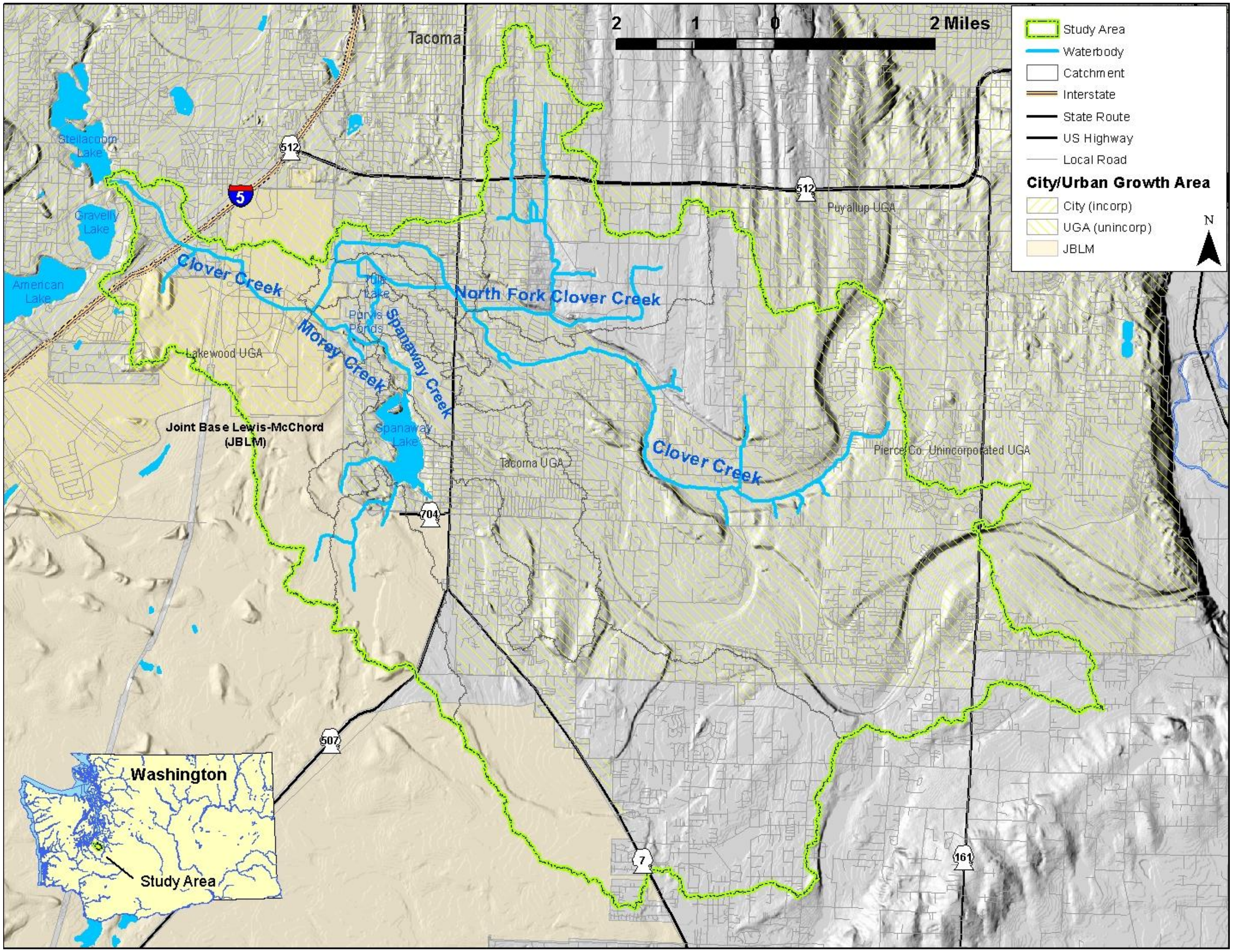

Figure 1. Clover Creek TMDL study area.

Nonpoint source pollutant load targets will likely be set in this TMDL. Because nonpoint pollution comes from diffuse sources, all upstream watershed areas have potential to affect downstream water quality. Therefore, all potential nonpoint sources in the watershed must use the appropriate best management practices (BMPs) to reduce impacts to water quality. Urban areas that collect stormwater runoff in municipal separate storm sewers (MS4s) and discharge it to surface waters are required to have a permit under the federal Clean Water Act. This TMDL will also set recommended targets for such permit holders.

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.

Surrogate Measures

To provide more meaningful and measurable pollutant loading targets, this TMDL may also incorporate *surrogate measures* other than daily loads. EPA regulations [40 CFR 130.2(i)] allow other appropriate measures in a TMDL. See the Glossary section of this document for more information.

Potential surrogate measures for use in this TMDL are discussed below. The ultimate need for, and the selection of, a surrogate measure for use in setting allocations depends on how well the proposed surrogate measure matches the selected implementation strategy.

Shade will be used as a surrogate to thermal load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR § 130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Other factors influencing the distribution of the solar heat load include increases in streamflow and groundwater interactions; however, these factors will not be used as a surrogate to thermal loads.

Why is Ecology Conducting a TMDL Study in This Watershed?

Background

Ecology is conducting the Clover Creek TMDL study because water quality data show that portions of the watershed do not meet the State criteria for dissolved oxygen (DO), fecal coliform (FC), and temperature. From 1991 to 1992, USGS data showed three out of five DO samples fell below criteria on Morey Creek. From 1991 to 1992, USGS data showed three excursions beyond the temperature criteria on Clover Creek at Gravelly Lake Drive. Furthermore, from 1993 to 2001, Ecology data showed four additional temperature excursions. Multiple FC excursions occurred throughout the watershed. Table 1 under the "Impairments Addressed by this TMDL" section of this Project Plan describes these results in detail as part of the EPA's approved water quality assessment for the state of Washington.

Ecology is initiating this TMDL for a number of reasons:

1. Stream segments in the Clover Creek basin do not meet water quality criteria.
2. Since it flows through the urban areas of Pierce County, the city of Tacoma's urban growth areas, and through JBLM, there is much support from local agencies and citizens to improve water quality in Clover Creek.
3. In 2002, the Clover Creek Basin Plan recommended a TMDL for Clover Creek based on programs in place to address water quality impacts in the creek (Pierce County, 2005).
4. Pierce County currently monitors the water quality of Clover Creek, providing necessary information to identify sources and land use practices that cause water quality problems. As a result, on-going efforts are made to reduce detrimental impacts and improve water quality.
5. Pierce County supports Washington's 2020 Clean Water Plan to identify and recommend improvements to the State's approach of assessing and cleaning up polluted water bodies (Britsch and Ratcliff, 2012).
6. Clover Creek is a tributary to Steilacoom Lake; therefore, information gained and restoration activities implemented through this TMDL will benefit the lake.
7. Local governments and citizens are already implementing actions to address water quality, so this study will assist with such efforts.

Study area

The study area for this TMDL consists of Clover Creek and its tributaries including North Fork Clover Creek, Morey Creek, and Spanaway Creek (Figure 2). The headwaters are located 6 miles east of Spanaway. Clover Creek flows 13.8 miles through residential and commercial areas, and empties into Steilacoom Lake. Other lakes in its 74-square-mile watershed include Spanaway Lake and Tule Lake (Pierce County, 2005).

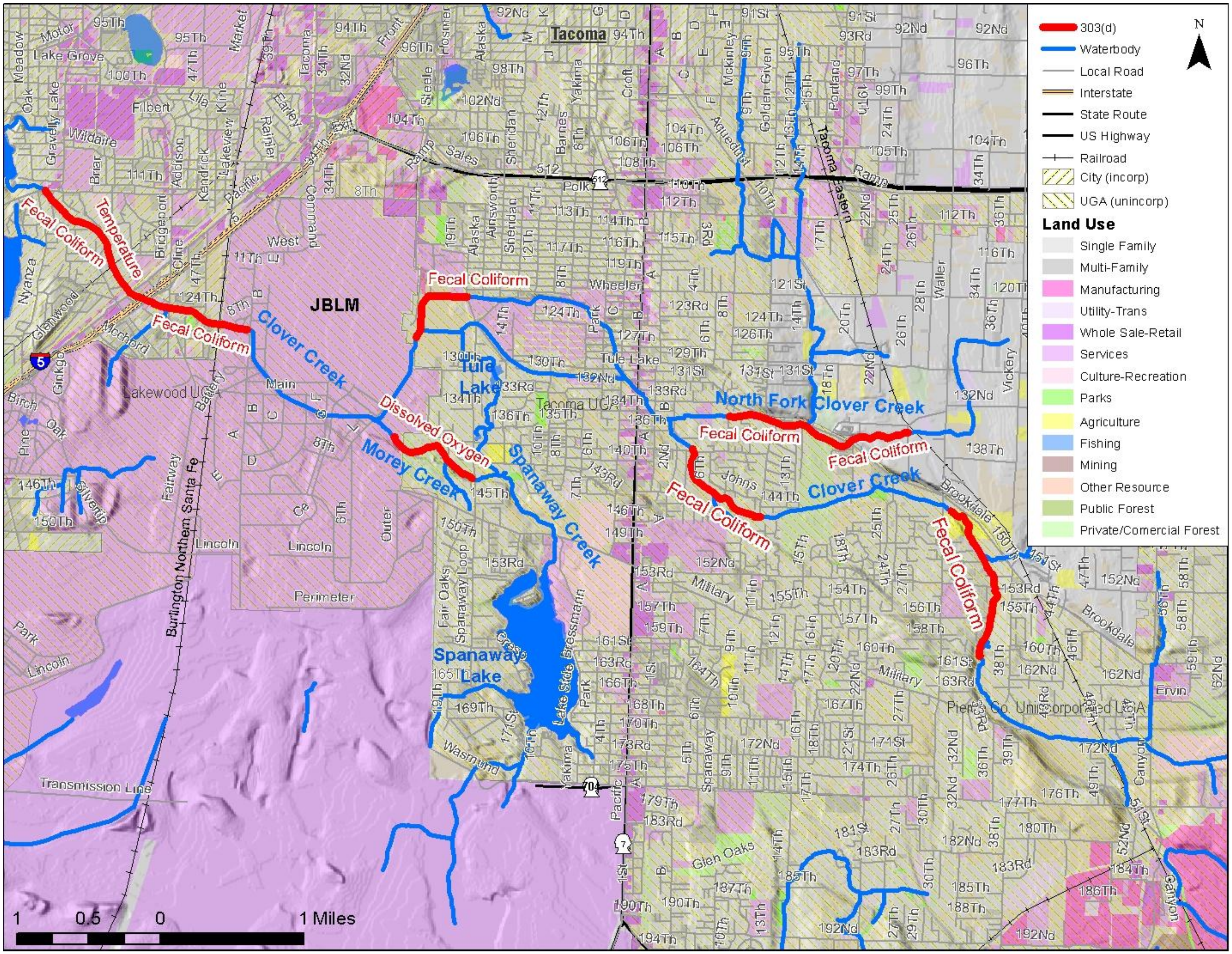

Figure 2. Clover Creek water quality impairments and land use.

Water Resource Inventory Area (WRIA) and 8-digit Hydrologic Unit Code (HUC) numbers for the study area

The study area is within the Chambers-Clover Creek Water Resource Inventory Area (WRIA) 12. The eight-digit Hydrologic Unit Code (HUC) is 17110019, known as the Puget Sound unit.

Impairments addressed by this TMDL

Table 1 shows 303(d) listed (Category 5) water bodies to be addressed. The listing ID is also provided in the table as an Internet link.

Table 1. 2008 303(d) listed reaches addressed in this study.

Water body	Parameter	Listing ID	Township - Range - Section
Clover Creek	Temperature	7553	19N - 2E - 11
Clover Creek	Fecal Coliform	7549	19N - 2E - 11
Clover Creek	Fecal Coliform	7548	19N - 2E - 48
Clover Creek	Fecal Coliform	7547	19N - 3E - 42
Clover Creek	Fecal Coliform	7545	19N - 3E - 47
Clover Creek	Fecal Coliform	5847	19N - 3E - 23
North Fork Clover Creek	Fecal Coliform	7558	19N - 3E - 15
North Fork Clover Creek	Fecal Coliform	5848	19N - 3E - 48
Morey Creek	Dissolved Oxygen	7543	19N - 3E - 45

Spanaway Lake has a 303(d) listing for FC, but this study will not address it. The scope is limited to flowing waterways; therefore, lakes or impoundments will not be directly addressed as part of this study.

Table 2 shows existing waters of concern (Category 2) in the Clover Creek watershed for FC, DO, and temperature. There are several reasons why a water body would be placed in this category:

- Pollution levels not quite high enough to violate the water quality criteria.
- Not enough violations to categorize as impaired (Category 5 – 303(d)) according to Ecology's listing policy (Water Quality Policy 1-11).
- Data showing water quality violations not collected using appropriate scientific methods or under an approved QAPP.

In all of these situations, these waters need further investigation.

Table 2. Category 2 waters of concern in the Clover Creek watershed.

Water body	Parameter (Category 2)	Listing ID	Township - Range - Section
Clover Creek	Bacteria	7535	19N - 3E - 25
Clover Creek	Dissolved Oxygen	7537	19N - 3E - 25
Clover Creek	Temperature	7538	19N - 3E - 48
Clover Creek	Dissolved Oxygen	7539	19N - 3E - 48
Clover Creek	Dissolved Oxygen	7540	19N - 2E - 48
Clover Creek	Dissolved Oxygen	7541	19N - 2E - 11
Clover Creek	Temperature	7551	19N - 3E - 47
Clover Creek	Temperature	7552	19N - 2E - 48
Clover Creek	Temperature	7554	19N - 3E - 42
Spanaway Creek	Temperature	7557	19N - 3E - 49

Beneficial Use

The Washington State water quality standards, set forth in Chapter 173-201A of the Washington Administrative Code (WAC), include designated beneficial uses, water body classifications, and numeric and narrative water quality criteria for surface waters of the state.

Beneficial uses in the Clover Creek watershed to be protected by this TMDL include extraordinary primary contact and primary contact recreation; that is, people coming into contact with bacteria-contaminated water through boating, fishing, wading, swimming, and other water-related activities.

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 watershed and then recommending BMPs 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 use these results to figure out where to focus water quality improvement activities. Sometimes the study suggests areas for follow-up sampling to further pinpoint sources for cleanup known as source identification (ID).

Water Quality Criteria and Numeric Targets

Specific water quality criteria for temperature, DO, and FC in the Clover Creek watershed are listed in Table 3. The units for each parameter are as follows:

- Temperature (°C)
- Dissolved oxygen (mg/L)
- Fecal coliform bacteria (colonies(cfu)/100mL)

Table 3. Water quality criteria and beneficial uses in the Clover Creek watershed.

Parameter	Condition
Clover Creek and **Spanaway Creek** Salmonid Spawning, Rearing and Migration Habitat, Primary Contact Recreation	
Temperature	Highest 7-DADMax (7 day average of the daily maximum temperatures) 17.5º C
Dissolved Oxygen	Lowest 1 day minimum 8 mg/L
Bacteria	Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies/100mL, with not more than 10% of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean value > 200 colonies/100 mg/L.
Morey Creek and **North Fork Clover Creek** Core Summer Salmonid Habitat, Extraordinary Primary Contact Recreation	
Temperature	Highest 7-DADMax (7 day average of the daily maximum temperatures) 16.0º C
Dissolved Oxygen	Lowest 1 day minimum 9.5 mg/L
Bacteria	Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100mL, with not more than 10% of all samples (or any single sample when less than 10 sample points exist) obtained for calculating the geometric mean value > 100 colonies/100 mg/L.

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; 2006 edition].

1. To protect the designated aquatic life uses of “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.
2. To protect the designated aquatic life uses of “Salmonid Spawning, Rearing, and Migration, and Salmonid Rearing and Migration Only” the highest 7-DADMax temperature must not exceed 17.5°C (63.5°F) more than once every ten years on average.

Washington State uses the criteria described above and in Table 3 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 criteria. When a water body is naturally warmer than the above-described criteria, the state provides an 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 (inferior) temperature condition.

In addition to the maximum criteria noted above, compliance must also be assessed against criteria that limit the incremental amount of warming of otherwise cool waters due to human activities. When water is cooler than the criteria noted above, the allowable rate of warming up to, but not exceeding, the numeric criteria from human actions is restricted to:

1. Incremental temperature increases resulting from individual point source activities must not, at any time, exceed 28/T+7 as measured at the edge of a mixing zone boundary (where “T” represents the background temperature as measured at a point or points unaffected by the discharge).
2. Incremental temperature increases resulting from the combined effect of all nonpoint source activities in the water body must not at any time exceed 2.8°C (5.04°F).

Dissolved oxygen

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

Low DO can release toxic metals and phosphorus from sediments, and cause increased availability of toxic substances like ammonia and hydrogen sulfide. These problems may contaminate the habitat of aquatic organisms reducing the overall health of the water body (EPA, 2000).

Oxygen levels can fluctuate over the day and night (diurnal fluctuation) in response to changes in climatic 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.

Nutrient enrichment may lead to low DO levels and increase the occurrence of excessive primary productivity leading to harmful algal blooms and macrophyte growth. Large biomass of primary producers may be associated with severe diurnal swings in DO concentrations (EPA, 2000).

Water quality criteria described in Table 3 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 criteria recognize, however, that not all waters are naturally capable of staying above the fully protective DO criteria. When a water body is naturally lower in oxygen than the criteria, 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 DO condition.

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, focusing sampling on surface areas within a uniquely turbulent area would provide data that are erroneous for comparing to the criteria.

Fecal coliform bacteria

Bacteria criteria are set to protect people who work and play in and on the water from waterborne illnesses. In the Washington State, the Department of Ecology's (Ecology) 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. Waste from warm-blooded animals is more likely to contain pathogens that will cause illness in humans than waste from cold-blooded animals. The FC criteria are set at levels that are shown to maintain low rates of serious intestinal illness (gastroenteritis) in people.

Other indicators, such as Escherichia (E.) coli and enterococci, have been evaluated as alternative or additional surrogates for pathogens under the triennial review of Washington State water quality standards. However, at the time of publication, FC bacteria remain the designated indicator.

During sufficient precipitation events, rainwater washes the surface of the landscape and the impervious surfaces, saturates soils, and raises water tables. Runoff from the stormwater can accumulate and transport fecal matter. This stormwater loaded with fecal matter may often drain to receiving water bodies and potentially degrade water quality.

The criteria for FC outlined in Table 3 and described below are based on allowing no more than the pre-determined risk of illness to humans that work or recreate in a water body. 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 all known and reasonable technologies and targeted BMPs be implemented to reduce human impacts and bring FC concentrations into compliance with the standard.

1. The *Extraordinary Primary Contact* use 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: Fecal coliform organism levels must not exceed a geometric mean value of 50 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 100/colonies mL" [WAC 173-201A-200(2)(b), 2003 edition].

2. The *Primary Contact* use is intended for waters "where a person would have direct contact with water to the point of complete submergence including, but not limited to, skin diving, swimming, and waterskiing." More to the point, however, the use is designated to any waters where human exposure is likely to include exposure of the eyes, ears, nose, throat, and urogenital system. Since children are also the most sensitive group for many of the waterborne pathogens of concern, even shallow waters may warrant primary contact protection. To protect this use category: "Fecal coliform organism levels must not exceed a geometric mean value of 100 colonies/100 mL, with not more than 10 percent of all samples (or any single sample when less than ten sample points exist) obtained for calculating the geometric mean value exceeding 200/colonies 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 sample averaging periods, compliance will be evaluated for both monthly (if five or more samples exist) and seasonal (dry season versus wet season) data sets.

The criteria for fecal coliform are based on allowing no more than the pre-determined risk of illness 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 fecal coliform 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 fecal coliform concentrations back into compliance with the standard.

If natural levels of fecal coliform (from wildlife) cause criteria to be exceeded, no allowance exists for human sources to measurably increase bacterial pollution. 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.

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 indicating summer temperature increases at least two times higher than winter increases. Summer streamflows are also predicted to decrease as a consequence of global climate change (Hamlet and Lettenmaier, 1999).

The expected changes coming to our region's climate highlight the importance of protecting and restoring the mechanisms that help keep stream temperatures cool. Stream temperature improvements obtained by growing mature riparian vegetation corridors along stream banks, reducing channel widths, and enhancing summer baseflow may all help offset the changes expected from global climate change – keeping conditions from getting worse. It will take considerable time, however, to reverse those human actions that contribute to excess stream warming. The sooner such restoration actions begin and the more complete they are, the more effective we will be in offsetting some of the detrimental effects on our stream resources.

These 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. As global climate change progresses, the thermal regime of the stream itself will change due to reduced summer streamflows and increased air temperatures.

The state is writing this TMDL to meet Washington State's water quality standards based on current and historic patterns of climate. Changes in stream temperature associated with global climate change may require further modifications to the human-source allocations at some time in the future. However, the best way to preserve our aquatic resources and to minimize future disturbance to human industry would be to begin now to protect as much of the thermal health of our streams as possible.

Watershed Description

Geographic setting

The Clover Creek watershed, in western Washington, is in the Puget Sound lowlands south of Tacoma (Figures 1 and 2). The study area consists of Clover Creek and its tributaries including North Fork Clover Creek, Morey Creek, and Spanaway Creek. The headwaters originate from springs and groundwater discharge located 6 miles east of Spanaway. Clover Creek flows 13.8 miles through residential and commercial areas, and empties into Steilacoom Lake. Other lakes in its 74-square-mile watershed include Spanaway Lake and Tule Lake (Pierce County, 2005).

Clover Creek drops approximately 150 feet in elevation over its length. The basin lies in an upland plain of moderate relief ranging in elevation from 200 to 600 feet above sea level containing numerous sub parallel elongate hills or drumlins (Sinclair, 1986). Many small lakes in the basin are associated with underlying slow-draining substrates and gentle topography where wetlands tend to form. Seepage from lakes, wetlands, and springs contribute to the Clover Creek system and sustain baseflow during the summer months (Runge et al., 2003).

North Fork Clover Creek begins as seasonal surface runoff and flows approximately 3.2 miles before joining Clover Creek at river mile (RM) 12.25 (Figures 1 and 2). The North Fork branches to the north and to the east at RM 1.0. Both branches are just over 2 miles in length. Due to urbanization, the North Fork Clover Creek basin became a series of interconnected roadside ditches, culverts, and stormwater retention ponds.

Spanaway Creek originates from springs and wetlands upstream of Spanaway Lake in JBLM (Figures 1 and 2). These upper reaches are locally referred to as Coffee Creek (Runge et al., 2003). Spanaway Creek drains the lake flowing north through a wooded county park known as Bresemann Forest. Approximately 2,200 feet downstream of the Spanaway Lake is a 6-foot-high dam (Bresemann Dam), historically creating a fish habitat barrier and pond (Runge et al., 2003). However, in 2007, 260 feet of stream channel were restored, allowing bypass of the dam. As a result the former habitat barrier has been bypassed, giving fish uninterrupted access upstream to Spanaway Lake and its tributaries. Approximately 1,800 feet downstream of the restored channel, Spanaway Creek forks, providing flow for Morey Creek. It then continues through Tule Lake before joining Clover Creek at RM 9.85.

Morey Creek originates from a branch of Spanaway Creek, flows for approximately 1 RM, and enters Clover Creek at RM 9.15 (Figures 1 and 2). Morey Creeks flows through associated wetlands and relatively undeveloped land with few houses and one small sub-division. Over 2,000 feet of Morey Creek has been dredged to a depth of 12 feet and a total of 4 miles have been dredged to varying depths. A culvert allows water to flow into JBLM. A nine-foot-high concrete dam (Morey Creek Dam) exists 115 feet upstream from the mouth of the creek containing Morey Pond (Runge et al., 2003). In 2009 a new stream channel was constructed around the dam. This allowed continuous fish access upstream of the former barrier, opening approximately 6 miles of habitat.

Land use

Land use in the Clover Creek study area is primarily urban comprising approximately 66% of the study area including Tacoma, Lakewood, Parkland, and Spanaway. Land use in the watershed includes single- and multi-family residence, commercial, parks and recreation, golfing, rural and military reserves, and agriculture (Figure 2).

JBLM is recognized as the largest military installation on the West Coast. The most recent population estimate for the base was 95,000 people, including military personnel, military dependants residing on base, civilian employees, and visitors. The base area covers 142 square miles (EPA, 2013).

Creek alterations

Historically Clover Creek drained several wetland networks. Since 1930 it has gradually evolved from a perennial creek to a creek which is dry throughout its central reach for much of the summer (Sinclair, 1986). Many stream reaches have been extensively modified by channelization, flood control structures, impoundments, bank armoring, and concrete slabs lining the streambed.

In 1853 a dam was built impounding the low-lying wetlands of Clover Creek to power a sawmill operation. This formed present day Steilacoom Lake. Steilacoom Lake is downstream of the study area and will not be assessed in this study.

Anthropogenic stream alterations and re-routing continued over the years. For example, in the early 1900s a canal approximately 0.5 miles long was built between Old Military Road and 38th Avenue East, adjacent to Clover Creek (Figure 2). This canal was intended to provide the City of Tacoma with drinking water but was never used for such purposes. The canal has a gravel bottom and carries around half of Clover Creek's discharge at that location (Runge et al., 2003).

Interviews with residents who have historical knowledge of the creek revealed that there was plenty of water in the creek during the summer and fall months. Around 1940 the Works Progress Administration (WPA) projects, designed to prevent flooding by dredging and bulldozer work, disturbed the streambed. The dredging occurred from east of Pacific Avenue upstream to around 138th St S. through the Pacific Lutheran University (PLU) campus (Tobiason, 2003) (Figure 2). Since then the creek tends to dry up through its middle reaches and in other places. It has been postulated that the dredging disturbed the streambed's natural seal (confining geologic layer) built up from decaying organic matter (from vegetation) and fine sedimentation. As a result, in some reaches, surface water is now allowed to percolate toward the groundwater at a greater rate than historical conditions allowed.

Approximately one mile of Clover Creek between Golden Given Road East and 138th Street East was rechanneled into two irrigation canals (Runge et al., 2003) (Figure 2). The water is no longer used for irrigation and is currently a restoration project known as the Clover Creek Reserve. The Clover Creek Reserve project is designed to remove invasive plants, and reestablish native plants as well as the historical stream channel. Project outcomes include improvements to wildlife habitat, improvements to water quality, and restoration of stream hydrology including less frequent flooding and increased baseflow.

In the early 1940s, Clover Creek was extensively dredged, channelized, and diked on present day JBLM. Two 12-foot-diameter culverts allow the creek to flow under the aircraft runway for a reach of 0.6 miles (Runge et al., 2003) (Figure 2). The creek also flows through a large culvert under Interstate 5 downstream of JBLM.

In the late 1960s, the creek was rerouted into a new channel between Pacific Avenue South and Spanaway Loop Road South. This canal was lined with asphalt to reduce surface water loss to groundwater under baseflow conditions (Runge et al., 2003) (Figure 2).

There are several constructed creek-fed ponds in the eastern region of Clover Creek. Few of these ponds were permitted or have established water rights. The impacts on water quality and water quantity from these impoundments are not known (Runge et al., 2003).

Climate

The study area has a temperate marine climate with warm, dry summers, and cool, wet winters. Annual precipitation in the Chambers-Clover Creek watershed (WRIA 12) ranges from 40 to 60 inches per year. Mean annual average precipitation in nearby Tacoma is 39.7 inches. Maximum average air temperature is 22.4 °C (72.4 °F) from May through September, and 12 °C (53.6 °F) from October through April. Weather data are provided by Western Regional Climate Center (1982-2012) from the Tacoma station 458278 that is 8 miles northwest of Clover Creek.

Hydrogeology

Continental glaciers during the Pleistocene epoch of the Quaternary Period left behind approximately 2,000 ft of unconsolidated deposits in and around the study area. Glacier intervals and interglacial periods created the hydrogeological units of today (Johnson et al., 2011). The hydrogeology consists of both unconfined and confined layers in the system affecting groundwater movement and storage.

The land surface geology in the Clover Creek watershed is mostly unconfined with some local confined deposits. Aquifers primarily comprise coarse-grained materials and confining units comprise fine-grained materials. With the exception of the North Fork drainage, the Clover Creek basin is underlain by 10- to 60-foot-thick deposits of highly permeable Steilacoom gravel. Possibly where the creek bed is undisturbed, a natural seal of silt and organic debris (confining layers) inhibits water loss due to percolation. In some areas when the creek bed is disturbed by dredging or rechanneling and this seal is broken, water loss may result. The central portion of Clover Creek and the entire North Fork are intermittent, becoming dry during the summer months (Sinclair, 1986).

Unconfined conditions allow the water table to rise and decline in response to changes in groundwater discharge and recharge. Confined conditions allow little groundwater permeability and often contribute to lateral movement along the layer or, in some cases, upward movement under certain pressure gradients (Savoca et al., 2010). Confined conditions may contribute to the formation of springs and seeps. When compared to surface water, groundwater typically has lower concentrations of DO, lower temperatures and, if uncontaminated by a local source, lower nutrients and little to no fecal coliform bacteria.

Physical characteristics vary greatly within the glacier deposits; therefore, hydraulic conductivity is highly variable. Estimated horizontal hydraulic conductivity values (feet per day) in the alluvial valley aquifer are as follows: minimum – 36, median – 328, and maximum – 3,779 (Savoca et al., 2010). Although these estimates may be biased high, they agree with similar studies and show that the immediate underlying hydrogeology of the study has a high rate of hydraulic conductivity. The potential for vertical groundwater movement between underlying aquifers is difficult to determine due to variable distribution of hydrogeological units and limited sampling points (Johnson et al., 2011).

Precipitation is the dominant source of aquifer recharge in the watershed. However, reduced permeability from urban land-cover inhibits the rate of recharge (Savoca et al., 2010). Undeveloped open areas, forested areas, and stormwater retention ponds in the watershed increase the potential for groundwater recharge. Recharge also occurs through return flows of septic systems, irrigation, and public utility water lines (Johnson et al., 2011).

Natural impervious cover includes soil types such as exposed bedrock or thick clay layers. Accessing local knowledge on sub-watershed soils is helpful to assign the degree of imperviousness for each land use category. For example, in western Washington a common Puget Sound basin soil is called glacial till. This soil type is well drained in an undisturbed area; however, upon residential development, glacial till is easily compacted to the point of 100% imperviousness (same as pavement).

Streamflow

The watershed experiences both extreme flooding and low to non-existent (intermittent) streamflows, depending on location and time of year. The chances of flooding increase during the wet season. Flooding tends to occur in the eastern and central reaches of Clover Creek from precipitation that causes surface water runoff and groundwater flooding (Figure 2). North Fork Clover Creek flooding occurs from roadside waterways and culverts being overwhelmed by precipitation. Flooding also occurs along Spanaway Creek (Runge et al., 2003).

Intermittent streamflow commonly occurs during the dry season particularly on the north fork and on the middle reaches of Clover Creek from Spanaway Loop Road just west of JBLM and 138th Street (Sinclair, 1986) (Figure 2). At times the creek has also been dry east of JBLM all the way to Steilacoom Lake despite the contributing discharge from Spanaway Creek (Runge et al., 2003).

There are two USGS gage stations in the watershed, providing continuous stream discharge data. One is located on Clover Creek on Pacific Highway SW (station ID 12090500). The other is located on North Fork Clover Creek at Golden Given Road E (station ID 12090400). The mean annual discharge of Clover Creek and the North Fork is 39.7 ft^3/s and 7.6 ft^3/s respectively, according to recorded data at these gaged locations. Figures 3 and 4 are streamflow summaries from these gage stations from 1990 through 2011.

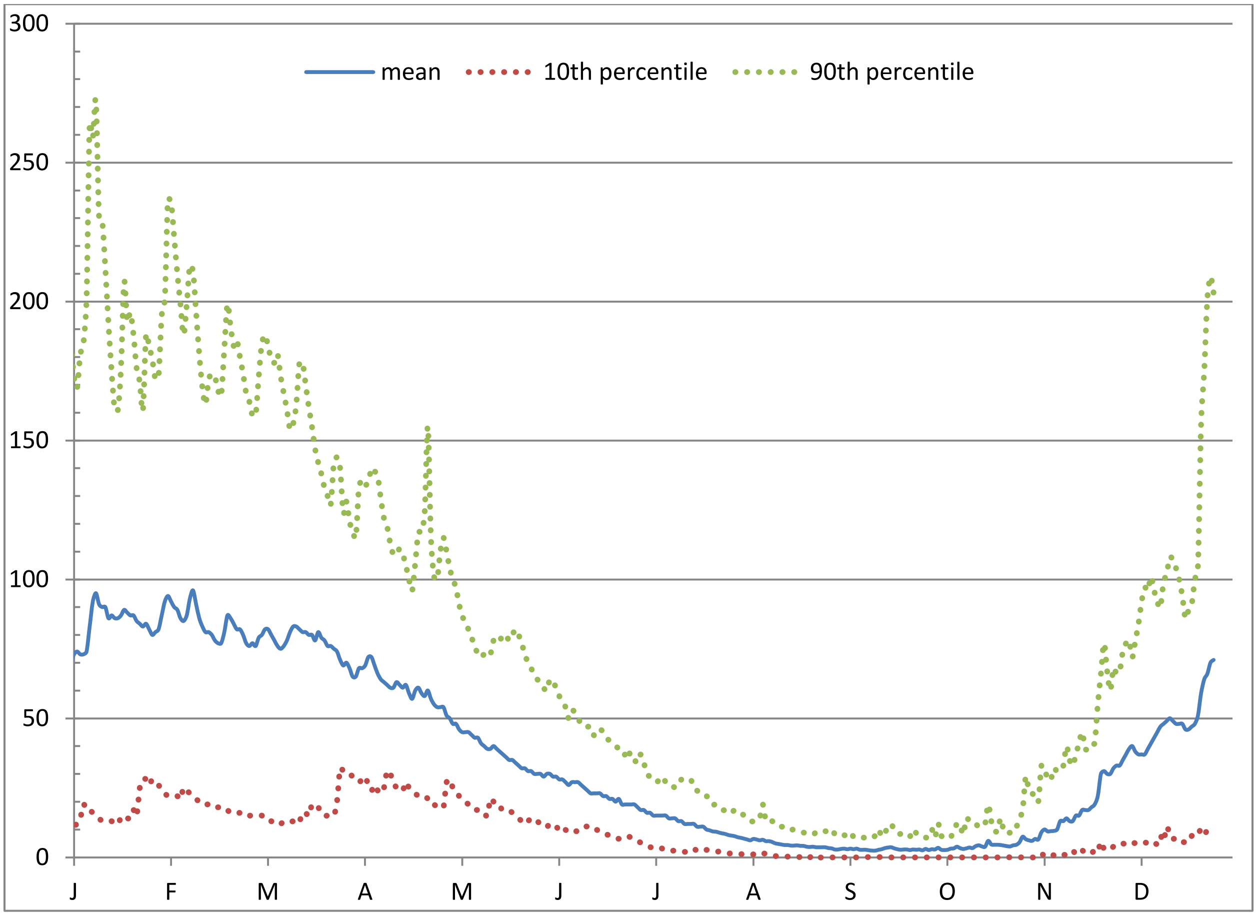

Figure 3. Summary of USGS streamflow data for Clover Creek from 1990-2011.

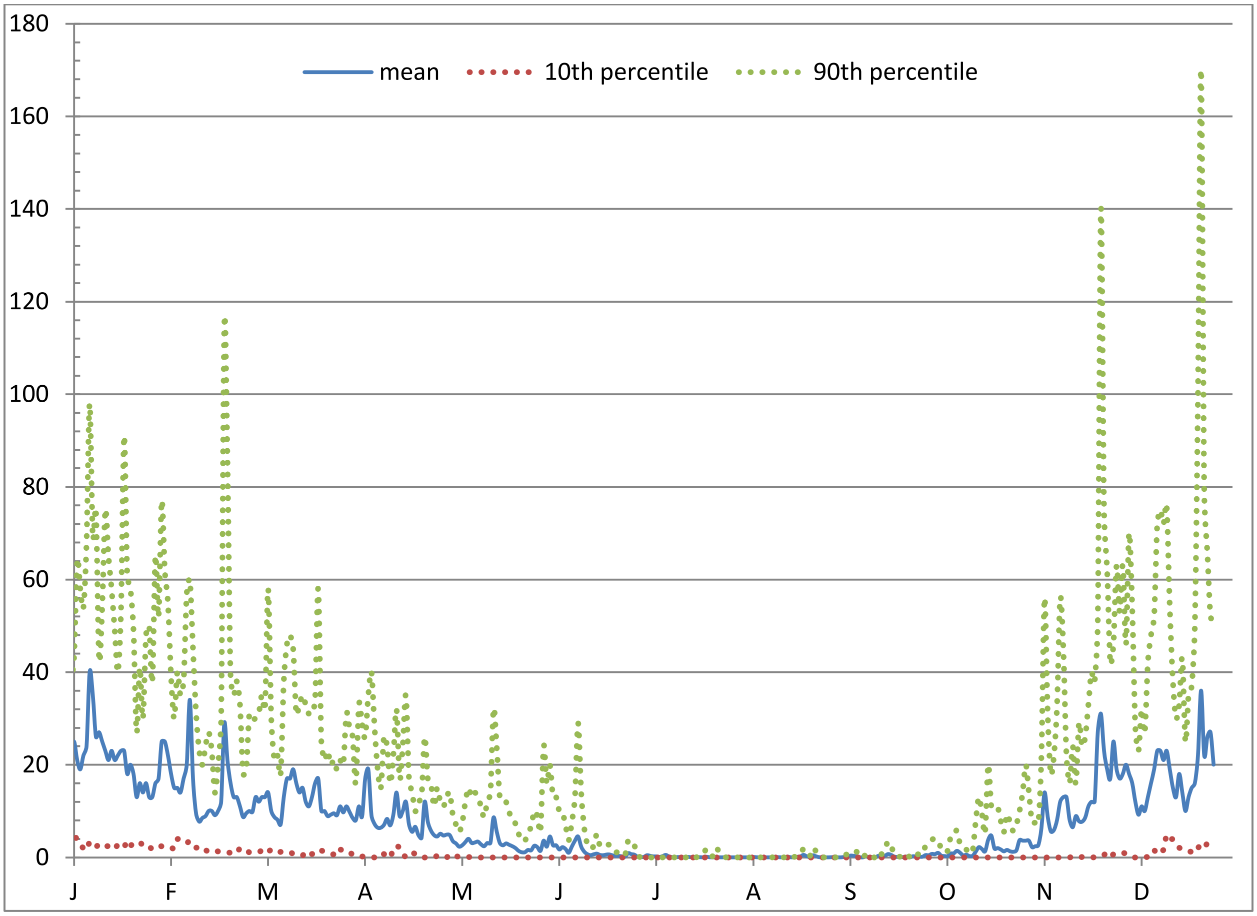

Figure 4. Summary of USGS streamflow data for North Fork Clover Creek from 1990-2011

During the summer, there is little rain, and naturally low streamflows (baseflow) are dependent on groundwater discharge (upwelling). WAC 173-512 is the stream resources protection program rule for the Chambers-Clover Creek watershed. This rule, adopted in 1979, closes the watershed to new appropriations that would reduce streamflow (Ecology, 2012). There are 44 active surface water rights in the watershed totaling 6 cfs. Of the 44 water rights, 20 are claims for which validity can only be confirmed through the judicial process. However, additional surface water rights have been closed. Furthermore, extremely low summer flows are inadequate to support existing rights, fish populations, and provide recreation along certain reaches of the creek.

Flooding from increased precipitation is common and often problematic in the Clover Creek watershed. Groundwater flooding also occurs after extended periods of rainfall, causing an increase in water-saturated soils. Groundwater flooding typically subsides at a very slow rate.

Permits

Urban areas that collect stormwater runoff in municipal separate storm sewers (MS4s) and discharge it to surface waters are required to have a National Pollutant Discharge Elimination System (NPDES) permit under the federal Clean Water Act. The Department of Ecology develops and administers NPDES municipal stormwater permits in Washington State.

The area along Clover Creek near I-5 is covered by a Phase 2 municipal stormwater permit (permit ID WAR045012). The remaining watershed is covered by a Phase 1 permit area (permit ID WAR009609).

There are at least 16 stormwater outfalls that directly discharge to the stream network of the Clover Creek watershed (Table 4) (Pierce County, 2005). Table 4 reflects current outfall information. As new information becomes available, such as Geographic Information System (GIS) files and on-the-ground observations, a better understanding of where stormwater enters the creek will allow for a more accurate characterization of the system.

Table 4. Stormwater outfalls to Clover Creek and tributaries

Stormwater outfall locations
Clover Creek at Gravelly Lake Drive SW
Clover Creek at Nyanza Road SW
Clover Creek at Pacific Highway S
Clover Creek at C Street S
Clover Creek a Pacific Avenue S
Clover Creek at Golden Given Road E
Clover Creek at 25th Avenue E
Clover Creek east of 25th Avenue E
Spanaway Creek at Military Road S
NF Clover Creek at B Street S
NF Clover Creek near 8th Avenue E
NF Clover Creek at Golden Given Road E
NF Clover Creek at Brookdale Road E
NF Clover Creek at 128th Street E
NF Clover Creek at 112th Street E
NF Clover Creek at 121st Street E

The Washington State Department of Transportation (WSDOT) has an NPDES permit for stormwater management with permit conditions similar to Ecology's Stormwater Management Manual. Ecology’s five-volume manual is available at www.ecy.wa.gov/programs/wq/stormwater/manual.html.

JBLM has a proposed MS4 stormwater permit under review by EPA and Ecology (EPA, 2013a).

There are two NPDES general permits for industrial stormwater that discharge surface water to the watershed. One general stormwater permit covers a material salvage and auto-wrecking facility, R.W. Rhine Inc. (permit ID WAR00563). The other stormwater permit covers a metal salvage facility, Pearson Metal Salvage Inc. (permit ID WAR044002). Stormwater from these facilities discharge to Pierce County Drainage District 19 waterways that comprise the North Fork Clover Creek sub-watershed. There are approximately 30 NPDES construction stormwater permits covering facilities and sites that discharge stormwater throughout the watershed.

Wildlife

The majority of anadromous fish use Chambers Creek, which is downstream of Steilacoom Lake (not in the study area of this project). The mouth of the lake has a concrete fish ladder which is only functional when sufficient discharge is available from the lake. Discharge is controlled by the outlet weir operated by the Steilacoom Lake Homeowners Association which does not provide minimum flows for fish in the ladder. This limits fish access to the lake and upstream into the Clover Creek watershed (Runge et al., 2003).

In the past, species such as sockeye, summer chum, early and late coho, and Chinook navigated through the lake and entered Clover Creek (Runge et al., 2003). In recent years anadromous fish have been unable to access their historic spawning or rearing areas due to barriers such as low and intermittent streamflow or alterations to the creek such as culverts and impoundments. Similarly, many resident species such as cutthroat trout also experience difficulties accessing their habitats (Runge et al., 2003). Today, cutthroat, steelhead and coho are known to use the watershed (Pierce County, 2011).

A variety of wildlife lives within the Clover Creek watershed. Wildlife presents a potential source of FC bacteria, biological oxygen demand (BOD), and nutrients. Open fields, riparian areas, and wetlands provide feeding and roosting grounds for some birds whose presence can increase fecal coliform counts, BOD, and nutrients in runoff. Usually these sources are dispersed and do not elevate FC counts or affect DO and pH in streams significantly enough to violate state water quality criteria.

Domestic animals such as house pets and livestock are potential sources of FC pollution. Waste from domestic animals may have greater potential to negatively impact water quality than wildlife in the Clover Creek watershed. This may be attributed to the highly urbanized characteristic of the watershed where increased human population density promotes an increase in the domestic animal population. Where there are people, there are pets; hence, potential for fecal matter generation.

Riparian vegetation

The majority of riparian and upland vegetation was initially removed for timber harvest and agriculture (Runge et al., 2003). The urbanization process also removed vegetation. This has altered the natural vegetative landscape substantially and promoted growth of many fast-growing invasive plants. For example, along several stream reaches, grasses or blackberries can fill a niche, hindering the reestablishing of native vegetation.

Native riparian vegetation commonly found in the Clover Creek watershed includes; Western red cedars, firs, spruce, pine, alders, maples, hazelnut, ash, dogwood, rose, raspberries, laurels, ocean spray, hawthorn, osoberry, ninebark, spiraea, snowberry, huckleberry, currant, thimbleberry, sweet gale, lilies, asters, edible thistle, nettles, cow-parsnip, grasses, Oregon grape, salal, elderberry, willows, cattails, ferns, and many other plants (Pojar and MacKinnon, 2004).

Stakeholders and tribes

Stakeholder involvement in the watershed comes from a variety of municipalities, governments, tribes, commissions, and non-governmental organizations. The following is a list of stakeholders and tribes that have expressed interest or taken action in the Clover Creek watershed (Pierce County, 2005):

Federal governments
- US Environmental Protection Agency
- US Department of Defense Joint Base Lewis-McChord

State governments
- Washington Department of Fish and Wildlife
- Washington State Department of Ecology

Local governments and districts
- City of Lakewood
- City of Tacoma
- Lakewood Water District
- Pierce County Conservation District
- Pierce County Department of Public Works and Utilities
- Pierce County Drainage Districts 14 and 19
- Tacoma-Pierce County Chamber of Commerce
- Tacoma-Pierce County Health Department

Tribes
- Muckleshoot Tribe
- Nisqually Indian Tribe

Educational organizations
- Bethel School District
- Clover Creek Elementary School
- Clover Park High School
- FP School District
- Pacific Lutheran University
- People’s Christian School

Interested parties, business organizations, and councils

- Building Industry Association
- Citizens for a Healthy Bay
- Clover Creek Council
- Conservation Northwest
- Crest Builders
- Elmhurst Mutual Power and Light
- Graham Advisory Commission
- Inner Focus
- Midland Residents Association
- Montevista Garden Club
- North Clover Creek-Collins Advisory Commission
- Parkland Area Advisory Commission
- Pierce County Council
- NW Forest Fiber Products
- NW Watershed
- River Network
- Soundwaves
- PSWQ Authority
- Spanaway Advisory Commission
- Spanaway Water Company
- Steilacoom Lake Improvement Club
- Summit Waller Association
- Tacoma-Pierce County Association of Realtors

Historical Data Review

Clover Creek has been documented and studied by various organizations, universities, and citizens. The following is a concise summary of information collected by Pierce County, USGS, and Ecology. Figure 5 shows the previous sampling locations represented in this data review.

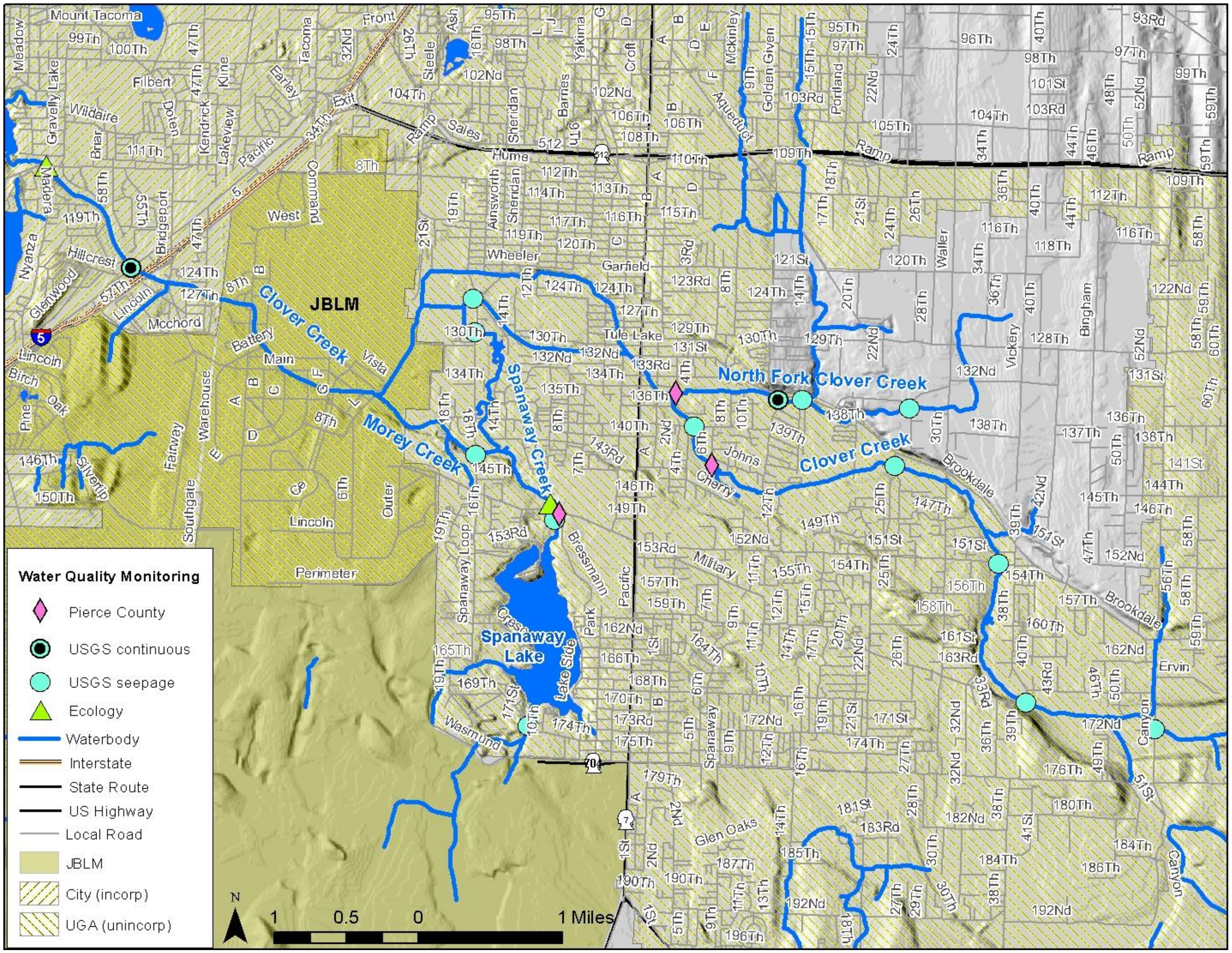

Figure 5. Historical and existing monitoring stations in the Clover Creek watershed.

Pierce County

Clover Creek Basin Plan

Pierce County developed a Clover Creek Basin Plan (Pierce County, 2005) providing a comprehensive guide to surface water management in unincorporated areas of the watershed. The plan acts as a more focused approach to watershed management and includes aspects of water quality, surface water management, flooding, and habitat. The plan identifies specific problems that lead to water quality degradation and develops solutions to these problems.

Water Quality Index

Pierce County developed a Water Quality Index (WQI) in order to generally assess, track, and score water quality conditions. The WQI has a range from 1 (poor quality) to 100 (good quality). Parameters that comprise the score are temperature, pH, fecal coliform bacteria, DO, total suspended sediment, turbidity, total phosphorus, and total nitrogen. These measurements are compared to water quality curves and standards provided by the Washington Department of Ecology, WAC 173-201A. The scores are combined and results are aggregated over time to produce a single yearly score for each sample station (Pierce County, WA - official website - water quality monitoring).

Annual data, WQI scores, and reports are produced to assess water quality condition over time and guide water quality improvement projects (Table 5; Figure 5) (Pierce County, 2011).

Table 5. Pierce County Water Quality Index (WQI).

Creek name	Water year	WQI
Clover Creek[1]	2010	52
	2011	63
	2012	54
North Fork Clover Creek[2]	2008	56
	2009	70
	2010	68
	2011	74
	2012	72
Spanaway Creek[3]	2008	68
	2009	62
	2010	76
	2011	78
	2012	89

[1] Clover Creek at 6th Avenue and Johns Road
[2] North Fork Clover Creek at 136th Street and B Street
[3] Spanaway Creek downstream of Spanaway Lake

Table 6 provides a summary of Pierce County FC data including annual and seasonal statistics and a comparison to water quality criteria. The seasonal data were grouped together based on precipitation patterns observed in the study area. The wet season spans from October through April, and the dry season spans from May through September as defined by this QA Project Plan.

Table 6. Pierce County fecal coliform data summary.

Water body name	Year	n	Fecal coliform (#/100mL)					
			Annual		Wet season		Dry season	
			Geo mean	10% criteria*	Geo mean	10% criteria*	Geo mean	10% criteria*
Clover Creek	2010	11	96	**27**	63	**16**	**160**	**40**
	2011	12	**134**	**33**	**103**	**43**	**194**	**20**
	2012	9	**131**	**20**	insufficient data		**159**	**40**
North Fork Clover Creek	2008	4	**596**	**100**	insufficient data		insufficient data	
	2009	6	**251**	**83**	**264**	**80**	insufficient data	
	2010	10	**76**	**50**	**79**	**43**	insufficient data	
	2011	8	**131**	**50**	**112**	**50**	insufficient data	
	2012	8	**167**	**63**	**167**	**67**	insufficient data	
Spanaway Creek	2008	10	74	**20**	62	**20**	89	**20**
	2009	12	27	8	13	**14**	77	0
	2010	12	25	8	14	**14**	56	0
	2011	12	19	0	14	0	32	0
	2012	9	14	9	insufficient data		24	0

Bold indicates water body possibly not meeting water quality criteria
* 10% of data not to exceed the water quality criteria expressed as a percentage
n is the number of samples collected for the indicated year that were used for analysis

North Fork Clover Creek has the highest FC concentrations followed by Clover Creek and Spanaway Creek (Table 6). Clover Creek and its north fork exceed the FC water quality criteria more frequently than Spanaway Creek (Table 3 describes the applicable criteria). Dry season results for Clover Creek are higher than wet season results. North Fork Clover Creek has insufficient data for the dry season statistical calculations where a minimum of five samples are recommended in order to characterize a single season (WAC 173-201A). During the wet season, Spanaway Creek has been below the water quality criteria over the last couple of years. Spanaway Creek has been below the criteria for the past four years both annually and during the dry season.

Figure 6 shows the distribution of single sample temperature data roughly from 2008 through 2012. The North Fork Clover Creek has the lowest temperatures followed by Clover Creek and Spanaway Creek. The time of day was not included in the analysis. Capturing the thermal diurnal fluctuation with continuous (time-series) data will characterize the system more thoroughly than single sample data.

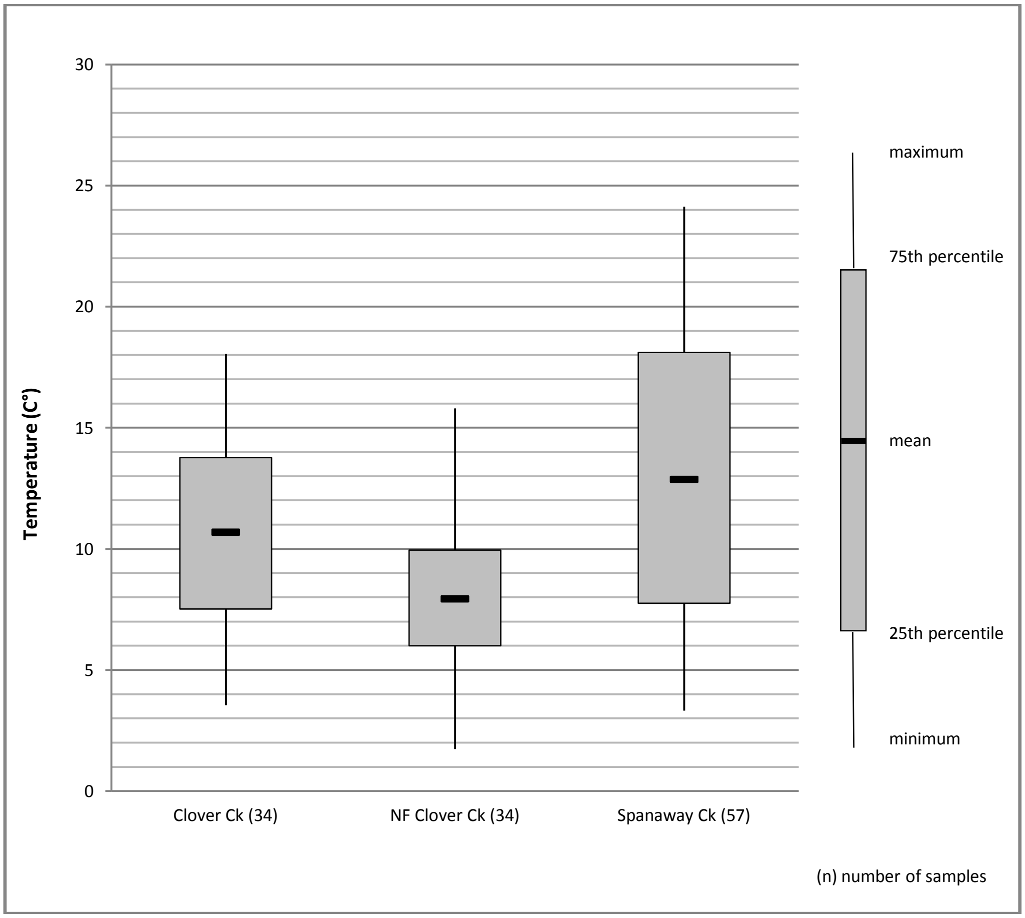

Figure 6. Pierce County single sample temperature data summary from 2008-2012.

Figure 7 shows the distribution of single sample DO data roughly from 2008 through 2012. The North Fork Clover Creek has the highest DO levels followed by Spanaway Creek and Clover Creek. The time of day was not included in the analysis. Capturing the diurnal fluctuation with continuous (time-series) data or sampling before sun rise and during the afternoon will characterize the system more thoroughly than single sample data taken once a day.

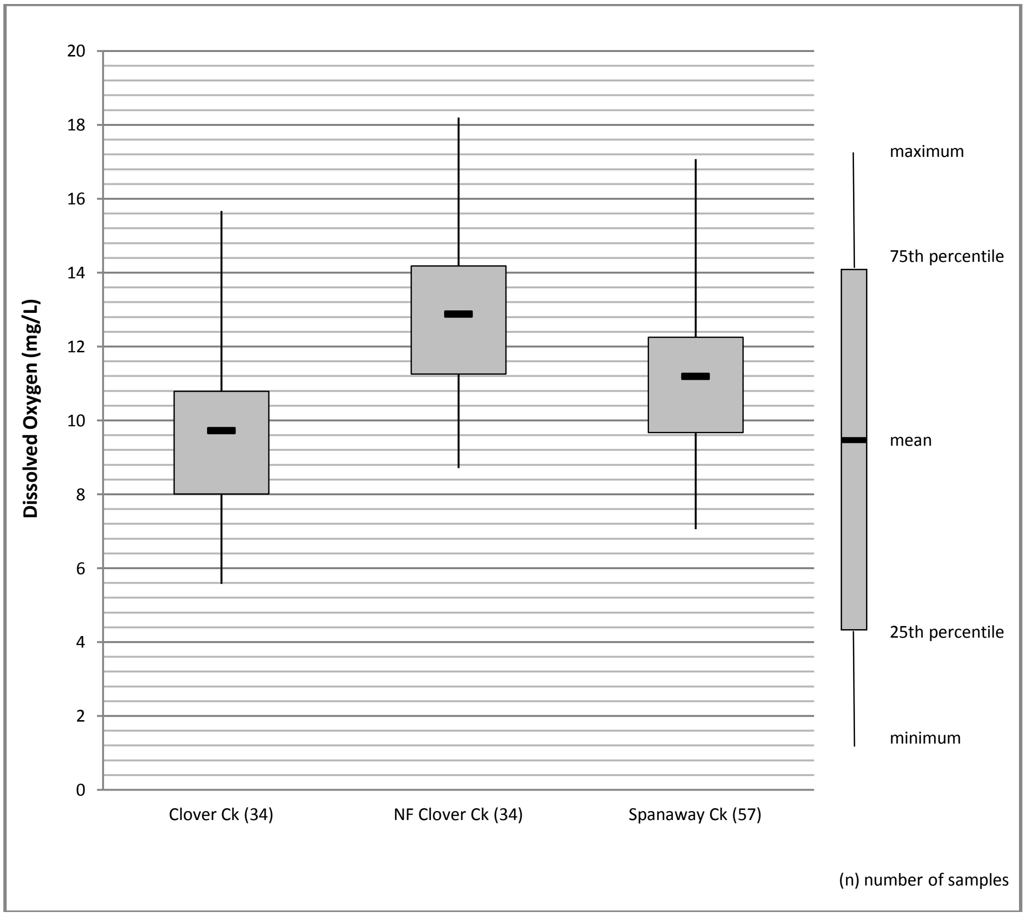

Figure 7. Pierce County single sample dissolved oxygen data summary from 2008-2012.

Figures 8 and 9 show the distribution of total phosphorus (TP) and total Kjeldahl nitrogen (TKN) data roughly from 2008 through 2012. In general Clover Creek has slightly lower nutrient concentrations than North Fork Clover Creek and Spanaway Creek.

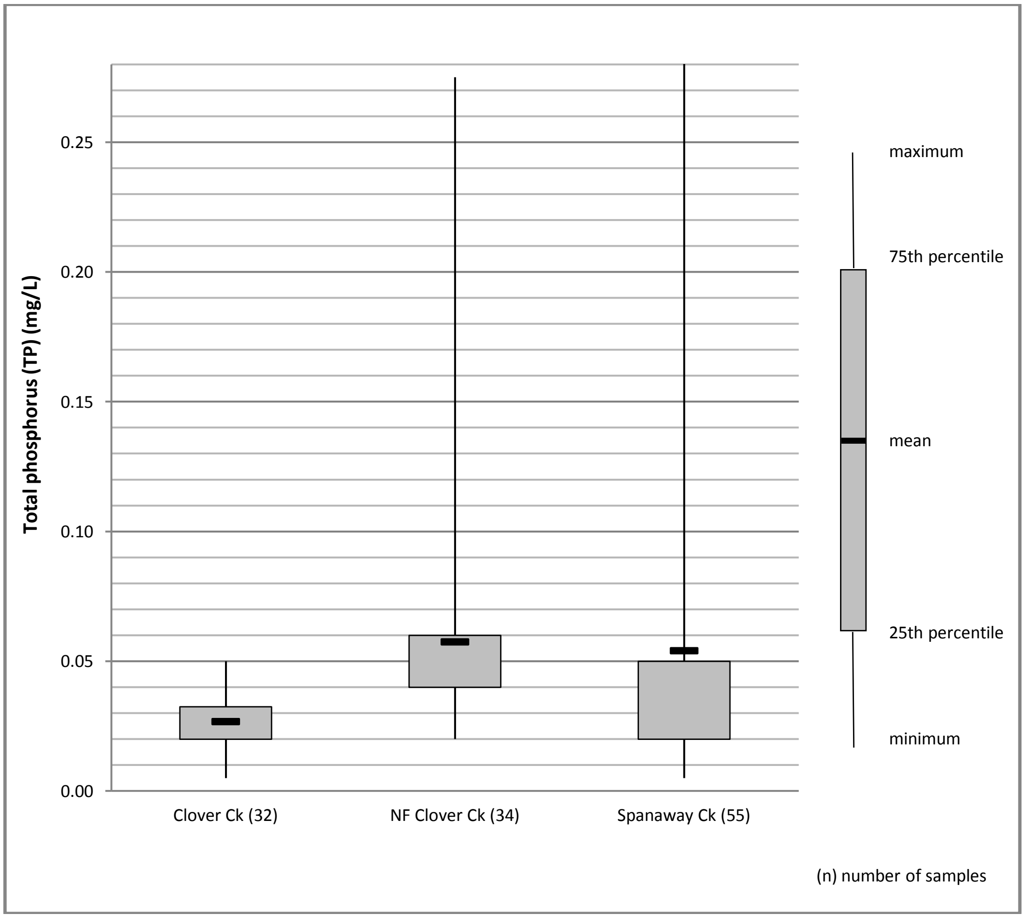

Figure 8. Pierce County single sample total phosphorus data distribution from 2008-2012.

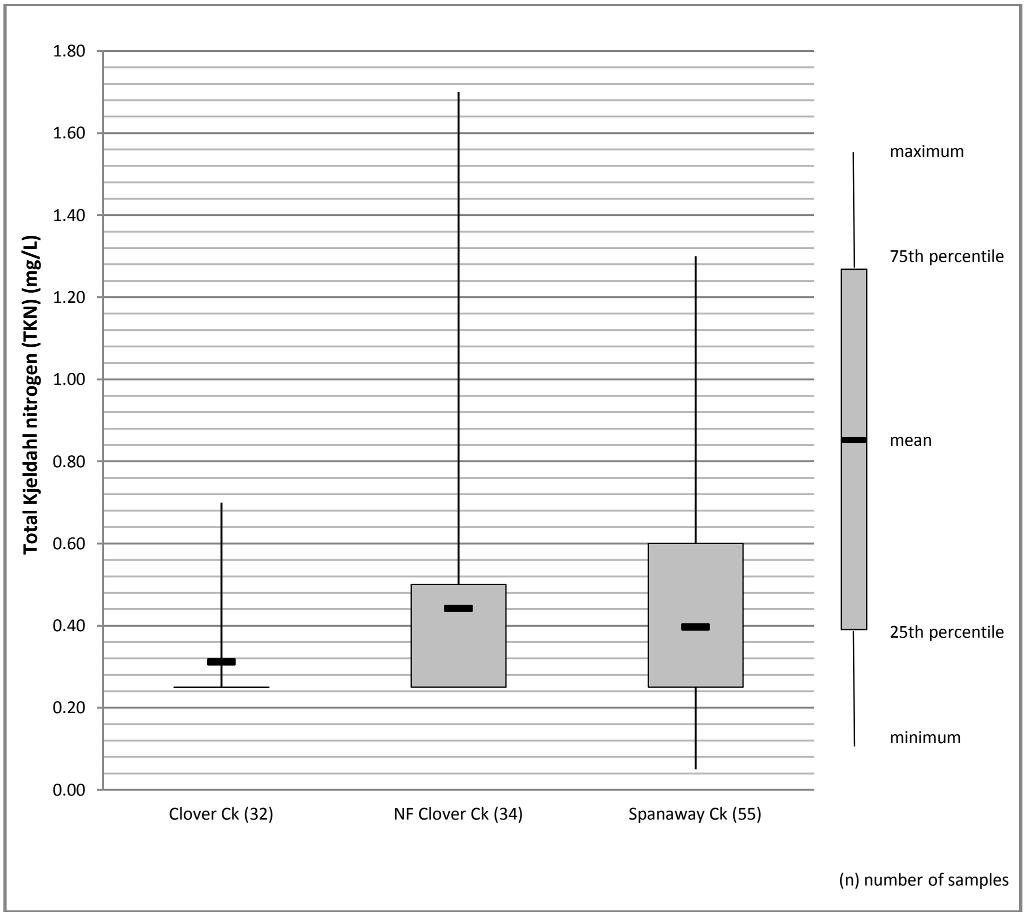

Figure 9. Pierce County single sample total Kjeldahl nitrogen data distribution from 2008-2012.

USGS

The Streamflow subsection of this Project Plan shows a summary of continuous stream discharge at Clover Creek and the North Fork Clover Creek provided by the USGS (Figures 3 and 4). The USGS also studies groundwater/surface water interactions of the Clover Creek watershed (Figure 5).

The in-depth predictive model estimates water movement and budget in the watershed (Johnson et al., 2011). In general, groundwater recharge is dominated by precipitation. The creeks are feed by groundwater during long periods of antecedent precipitation. In contrast, sufficient precipitation will dictate streamflows by causing direct surface water runoff and by raising the water table, thus increasing groundwater discharge to the system. The predictive model also shows complex groundwater/surface water interactions with lateral subsurface movement throughout the basin in both wet and dry stream reaches.

The assessment of groundwater/surface water interactions during baseflow conditions is included in Table 7 showing the results of synoptic streamflow measurements (Savoca et al., 2010). Areas of groundwater recharge and discharge occur throughout the watershed. Results slightly vary between the sampling events of September 2007 and July 2008. There were differences in discharge and gain/loss at some stream locations, possibly illustrating the complexity of the Clover Creek system or the effects of climatic conditions that vary from year to year. Zero surface water discharge occurred at several locations and was observed consistently during the years of the study. There are also reaches of low discharge that may cause increased error for the measurement.

Table 7. USGS Clover Creek basin instantaneous stream discharge results during baseflow conditions.

Water body name and location	Date	Discharge (ft^3/s)	Discharge rating*	Inflow (ft^3/s)	Gain (+) or loss (-) (ft^3/s)
Clover Creek at Canyon Rd. E	9/10/07	1.33	poor		1.33
	7/10/08	1.38	poor		1.38
Clover Creek at Military Rd. E	9/10/07	1.36	fair	1.33	*0.03*
	7/10/08	1.31	fair	1.38	*-0.07*
Clover Creek at 152nd St. E	9/10/07	6.17	fair	1.36	4.81
	7/10/08	6.11	fair	1.31	4.80
Clover Creek at 25th Ave. E	9/10/07	3.88	fair	6.17	-2.29
	7/10/08	5.47	fair	6.11	*-0.64*
Clover Creek at 138th St. E	9/10/07	0.25	poor	3.88	-3.63
	7/10/08	0.00		5.47	-5.47
NF Clover Creek at Waller Rd. E	9/10/07	0.00			
	7/10/08	0.10	poor		0.10
NF Clover Creek at 14th Ave. E	9/10/07	0.00		0.00	0.00
	7/10/08	0.10	poor	0.10	*0.00*
NF Clover Creek at Golden Given Rd. E	9/10/07	0.00		0.00	0.00
	7/10/08	0.00		0.10	-0.10
Clover Creek at Spanaway Loop Rd. S	9/10/07	0.00		0.25	-0.25
	7/10/08	0.00		0.00	0.00
Spanaway Creek at Spanaway Lake inlet	9/10/07	2.10	fair	2.10	2.10
	7/10/08	2.42	poor	2.42	2.42
Spanaway Creek at Spanaway Lake outlet	9/10/07	5.38	fair	2.10	3.28
	7/10/08	4.11	fair	2.42	1.69
Spanaway Creek at Spanaway Loop Rd. S	9/10/07	2.32	fair	2.76	-0.44
	7/10/08	2.25	fair	1.60	0.65
Morey Creek at Spanaway Loop Rd. S	9/10/07	1.72	fair		
	7/10/08	0.81	poor		
Clover Creek at Pacific Highway SW	9/10/07	2.50	fair	4.04	-1.54
	7/10/08	2.50	fair	3.06	-0.56

*Quality of measurement.
Italicized are measurements where uncertainty was too large to make defensible conclusions.

Washington State Department of Ecology

The Washington State Department of Ecology (Ecology) collects water quality samples throughout the state in order to monitor and assess existing conditions and trends in watershed health. In addition, Ecology's studies such as TMDLs and many others provide data sets characterizing water quality and water quantity.

Ambient Monitoring

As part of the long-term monitoring program (ambient monitoring), Ecology collects and analyzes water samples for parameters such as: pH, oxygen, fecal coliform bacteria, nutrients, and sediment. Routine monitoring data are compared to state water quality criteria and summarized by the WQI.

WQI results and data used for calculation at individual stations are available on Ecology's river and stream water quality monitoring webpage. The WQI ranges from 1 (poor quality) to 100 (good quality). The WQI summary does not include non-standard elements like metals or toxics. For temperature, pH, oxygen, and fecal coliform bacteria, the WQI is based on criteria in Washington's Water Quality Standards, WAC 173-201A. For nutrient and sediment measures where standards are not specific, results are based on expected conditions in a given region. Multiple constituents are combined and results aggregated over time to produce a single score for each station and each year. A brief overview of the index, detailed methodology, and a spreadsheet version that can be used to calculate index scores using your own data, are available on the above mentioned webpage.

Ecology collected samples from Clover Creek off Gravelly Lake Drive at the entrance of Clover Crest Estates 0.4 miles upstream of Lake Steilacoom (Station ID 12A110) (Figure 5). Sampling years include; 1963-65, 1976, 1996-99, and 2012.

Figure 10 shows a monthly summary of all single sample DO data collected by Ecology. The DO quality criterion of 8.0 mg/L is met in all but a few instances according to this data set.

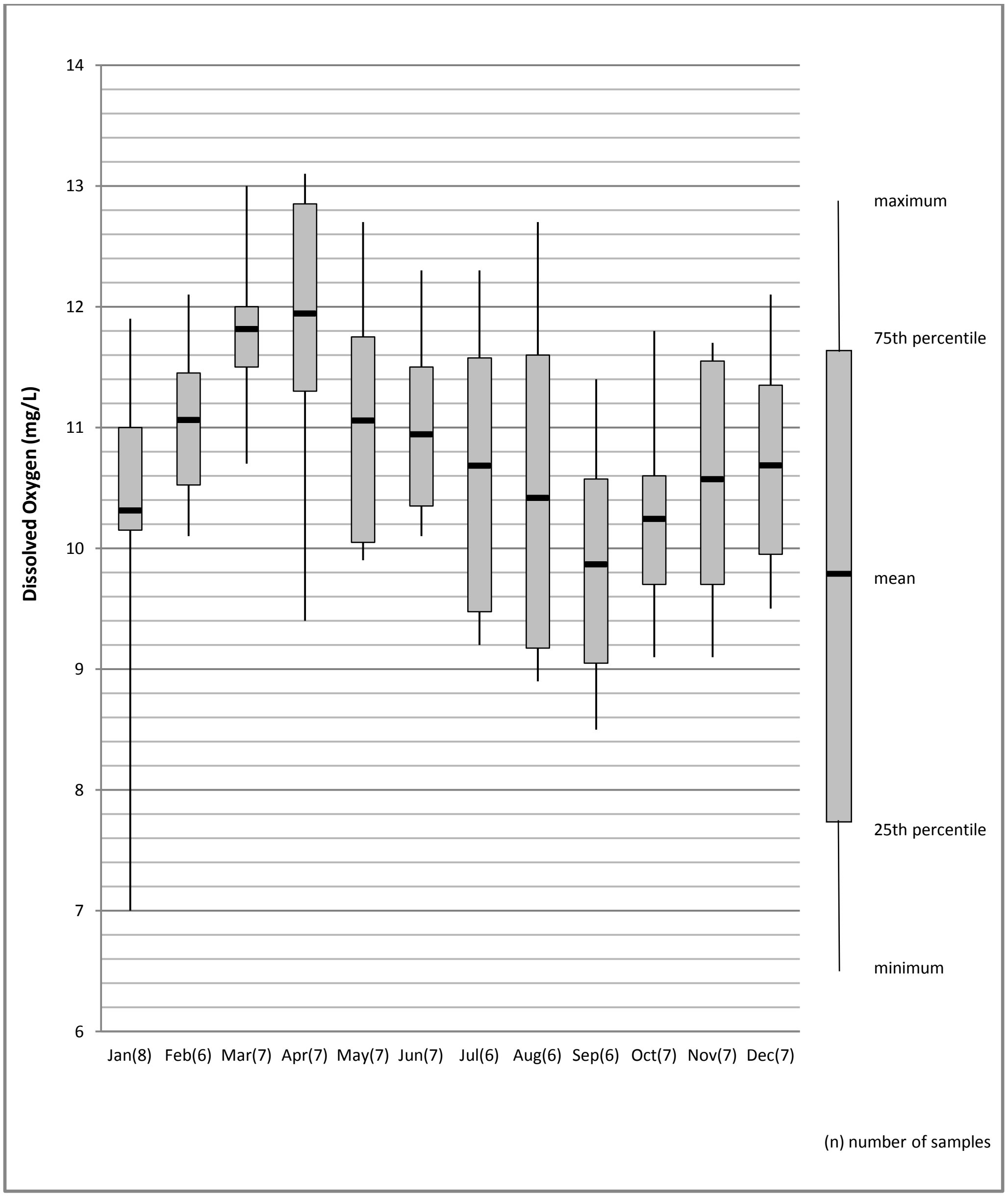

Figure 10. Ecology single sample dissolved oxygen data distribution.

Discrete temperature results of Clover Creek show that the summer temperatures are higher than those during winter (Figure 11).

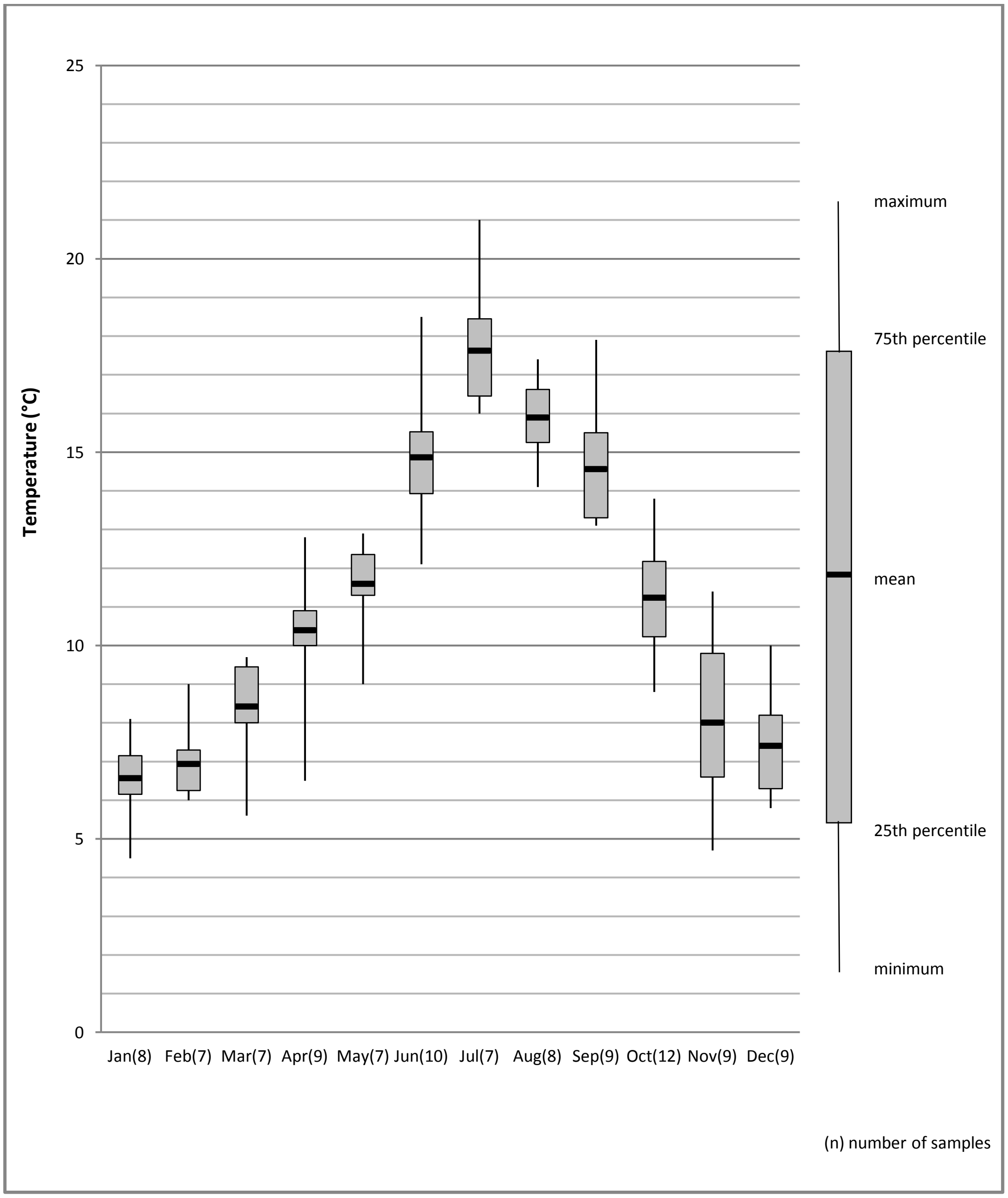

Figure 11. Ecology discrete temperature data distribution.

The overall WQI index score of Clover Creek is 57 (moderate) (Figure 12). This score is a result of all Ecology data collected up to 1996 (2012 data has not been analyzed yet).

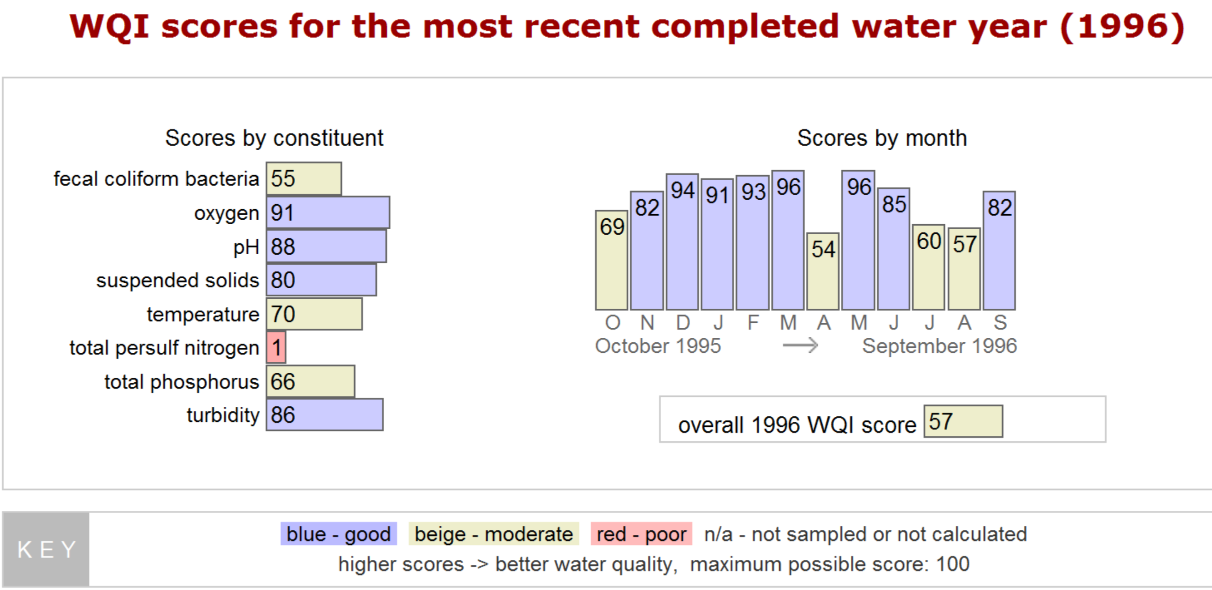

Figure 12. Ecology summary of the Clover Creek WQI score.

From October 2008 through September 2009 (water year 2009), Ecology collected 12 samples from Spanaway Creek at Old Military Road downstream of the outlet of Spanaway Lake (Station ID 12F090) (Figure 5). This station was near the same location of Pierce County's on Spanaway Creek. The purpose of data collection was to assess and verify water quality conditions. Sample parameters included: ammonia, arsenic, cadmium, chromium, copper, DO, fecal coliform, hardness as $CaCO_3$, lead, mercury, nickel, nitrate-nitrite as N, ortho-phosphate, pH, silver, specific conductivity, temperature, total persulfate nitrogen, total suspended solids, and zinc.

Table 8 shows FC results of Spanaway Creek including Pierce County data for comparison. The annual FC geometric mean of this data set was 34 cfu/100mL and only 8% of the data was above 200 cfu/100mL, meeting water quality criteria (Table 8). The dry season statistics were higher than the wet with a geometric mean of 75 cfu/100mL and 20% of samples were above the water quality criterion. The wet season data results show a geometric mean of 19 cfu/100mL and 0% above the water quality criterion. These results are similar to Pierce County data for water year 2009. Pierce County data (Table 6) are not segregated by water year.

Table 8. Ecology and Pierce County fecal coliform data summary comparison of Spanaway Creek.

Organization	Water year	n	Fecal coliform (#/100mL)					
			Annual		Wet season		Dry season	
			Geo mean	10% criteria*	Geo mean	10% criteria*	Geo mean	10% criteria*
Ecology	2009	12	34	8	19	0	75	**20**
Pierce Co.			26	0	12	0	77	0

Bold indicates water body possibly not meeting water quality criteria.
* 10% of data not to exceed the water quality criteria expressed as a percentage.
n is the number of samples collected for the indicated water year.

Single DO sample and temperature data from Spanaway Creek are presented in Figure 13. Temperature exceeds water quality criterion based on the available data and DO does not drop below criterion according to this data set. Summer and fall seasons show the highest temperatures and the lowest DO levels. There was no DO datum reported for June.

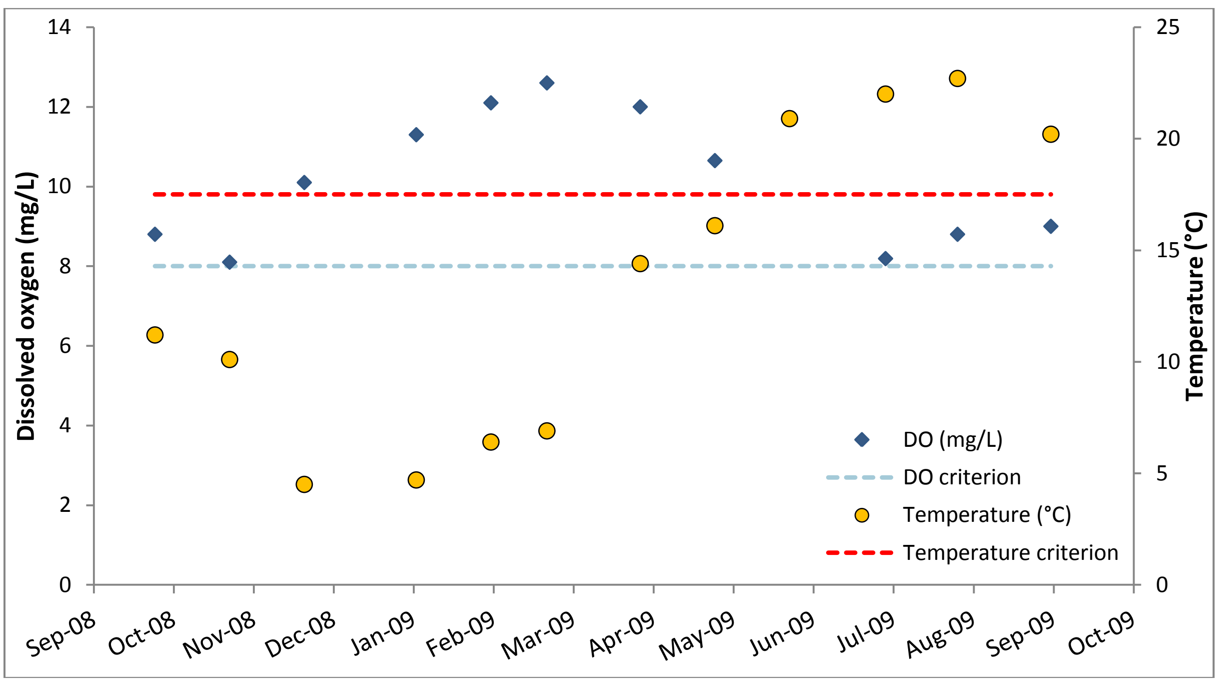

Figure 13. Ecology single sample data of dissolved oxygen and temperature of Spanaway Creek

Figure 14 shows the thermal 7-DADMax (7 day average of the daily maximum temperatures) during the summer months (thermal critical period). The 7-DADMax was calculated using continuous (time-series) data collected by a temperature data logger (thermistor). All data are above the water quality temperature criterion of 17.5 °C 7-DADMax.The WQI for Spanaway Creek is depicted in Figure 15 with an overall score of 67 (moderate).

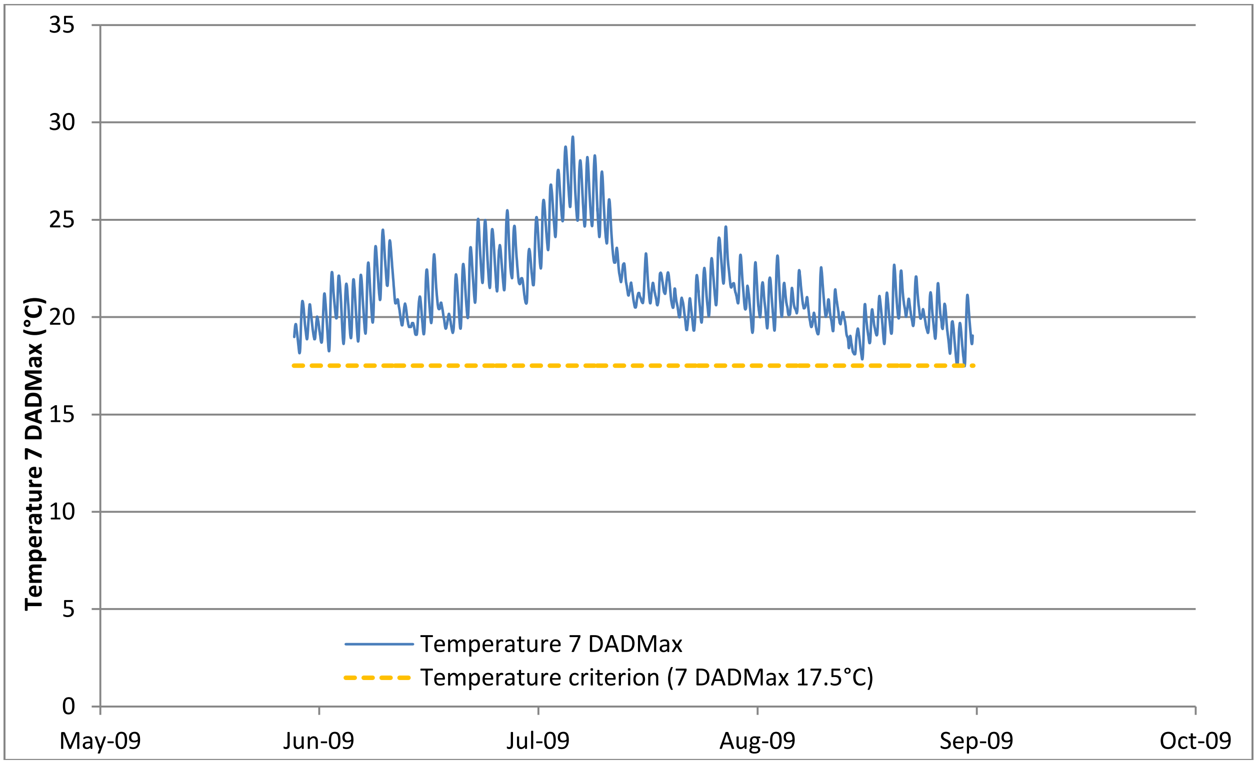

Figure 14. Ecology continuous temperature data at Spanaway Creek.

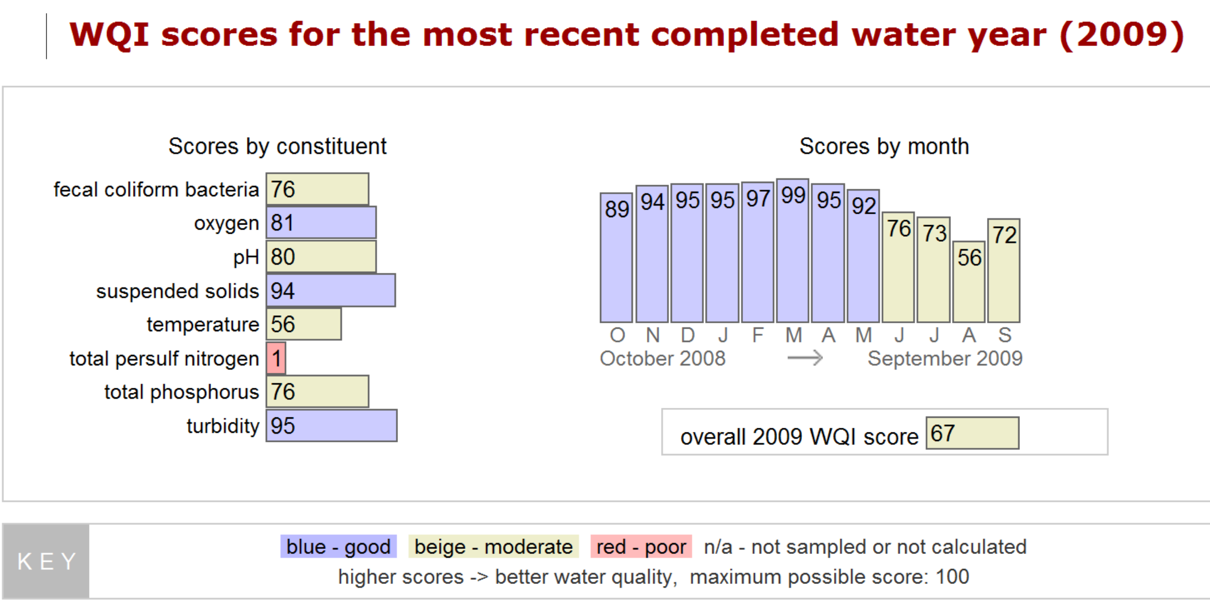

Figure 15. Ecology summary of the Spanaway Creek WQI score.

Seepage Study

Ecology conducted a synoptic streamflow assessment (seepage study) in the summer of 1984 during baseflow conditions (Figure 16) (Sinclair, 1986). The study showed areas of groundwater recharge and discharge. In many stream reaches the discharge values were significantly higher than those measured by the USGS. For example, in 1984 the discharge of Clover Creek at Pacific Highway was 10.5 cfs with a loss of -0.2 cfs between measuring points, while the average discharge during 2007 and 2008 was 2.5 cfs with an average net loss of -1.1 cfs (Table 7). However, in many areas of the watershed both studies show discharges of 0.0 cfs along North Fork Clover Creek and the middle reaches of Clover Creek.

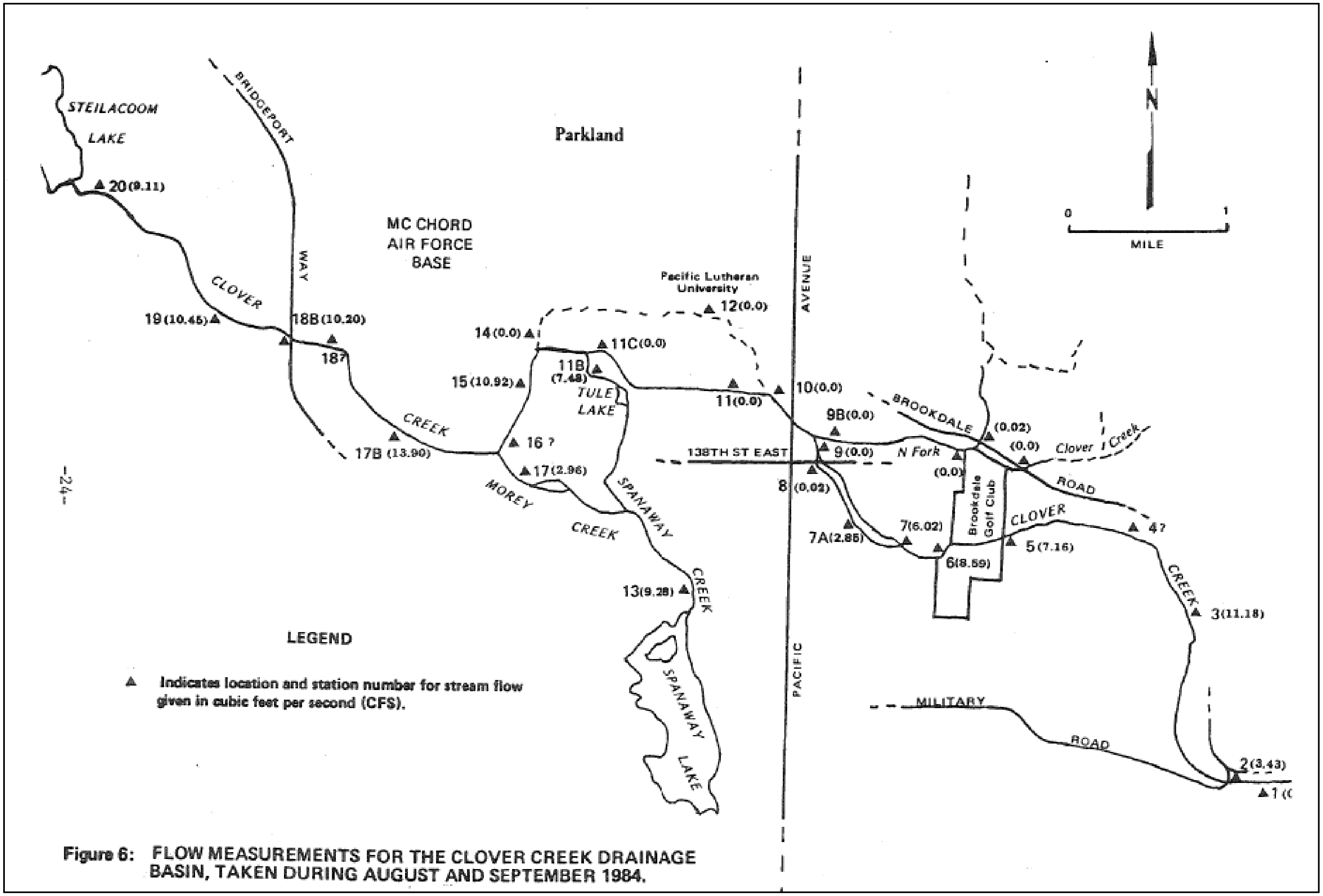

Figure 6: FLOW MEASUREMENTS FOR THE CLOVER CREEK DRAINAGE BASIN, TAKEN DURING AUGUST AND SEPTEMBER 1984.

Figure 16. Ecology 1984 synoptic stream discharge measurements.

Goals and Objectives

Project goals

The goal of this TMDL is to determine the total maximum daily load of pollutants that will allow the water bodies to meet water quality criteria.

Study objectives

Objectives of the study are as follows:

- Characterize FC bacteria concentrations and loads throughout the watershed under various seasonal or hydrological conditions including:
    - Comparison to WAC water quality criteria.
    - Assessment of FC concentrations during wet and dry seasons.
    - Recommend percent reductions in order to meet water quality criteria.
    - Identify relative contributions of FC loading to Clover Creek based on source areas so restoration activities can focus on the largest sources of pollution.
- Assess existing DO concentrations in Clover Creek and its major tributaries. Characterize processes potentially governing DO, including the possible influence of temperature and groundwater interactions.
- Assess existing temperatures in Clover Creek and its major tributaries. Characterize stream temperatures and processes potentially governing the thermal regime in the watershed and develop load allocations. The study will assess:
    - Existing thermal conditions.
    - Riparian shade.
    - Groundwater/surface water interactions using surface water discharge measurements.
    - Channel geometry and riparian vegetation heights and densities.
    - System-potential vegetation characteristics using tools such as soil surveys, historic records, and Light Distance and Ranging (LiDAR).
    - Shade needed to reduce stream temperatures using shade curves.
- Characterize stormwater runoff by sampling during storm events.
- Assess streamflow in the watershed using instantaneous and continuous data.
- Collect benthic macro-invertebrate and periphyton samples in order to assess biological characteristics and relate this information to water quality.
- Characterize hydromodifications throughout the watershed.

Study Design

Overview

To meet its objectives, this project will rely on data collected by Ecology during the 2013 – 2014 study period as well as existing data collected by other organizations. FC, DO, temperature, and associated water quality parameters will be monitored at a network of sampling sites. These sites will be located at the mouths of all tributaries, near the downstream end of catchments and specific watershed characteristics such as wet lands, and at significant drainage/discharges such as stormwater outfalls. Stream discharge will be measured when possible at all sites during the time of sampling.

This TMDL study will use a simple approach to develop load and wasteload allocations for temperature and FC. DO will be characterized and no load allocations will be developed. Complex modeling will not be used to predict and assess DO and temperature characteristics. Modeling and calibration for such parameters may not prove successful given the altered nature of the basin, intermittent discharge along some reaches, and the history of extensive wetlands.

Effective shade will be assessed and shade curves developed, including tree species, heights, and buffer widths, in order to characterize their potential influences on stream temperature. The statistical rollback method (Ott, 1995) will be applied to FC data distributions to determine target count reductions along key reaches of each water body during critical conditions.

Analytical Framework

Fixed-network sampling

Data from the fixed-network sampling will provide water quality information at each sampling location. As a result, the water quality can be characterized over time and comparisons can be made between sampling locations. Figure 17 and Table 9 show the fixed-network of sampling locations for the Clover Creek TMDL study. There are 18 proposed fixed-network sampling locations throughout the watershed.

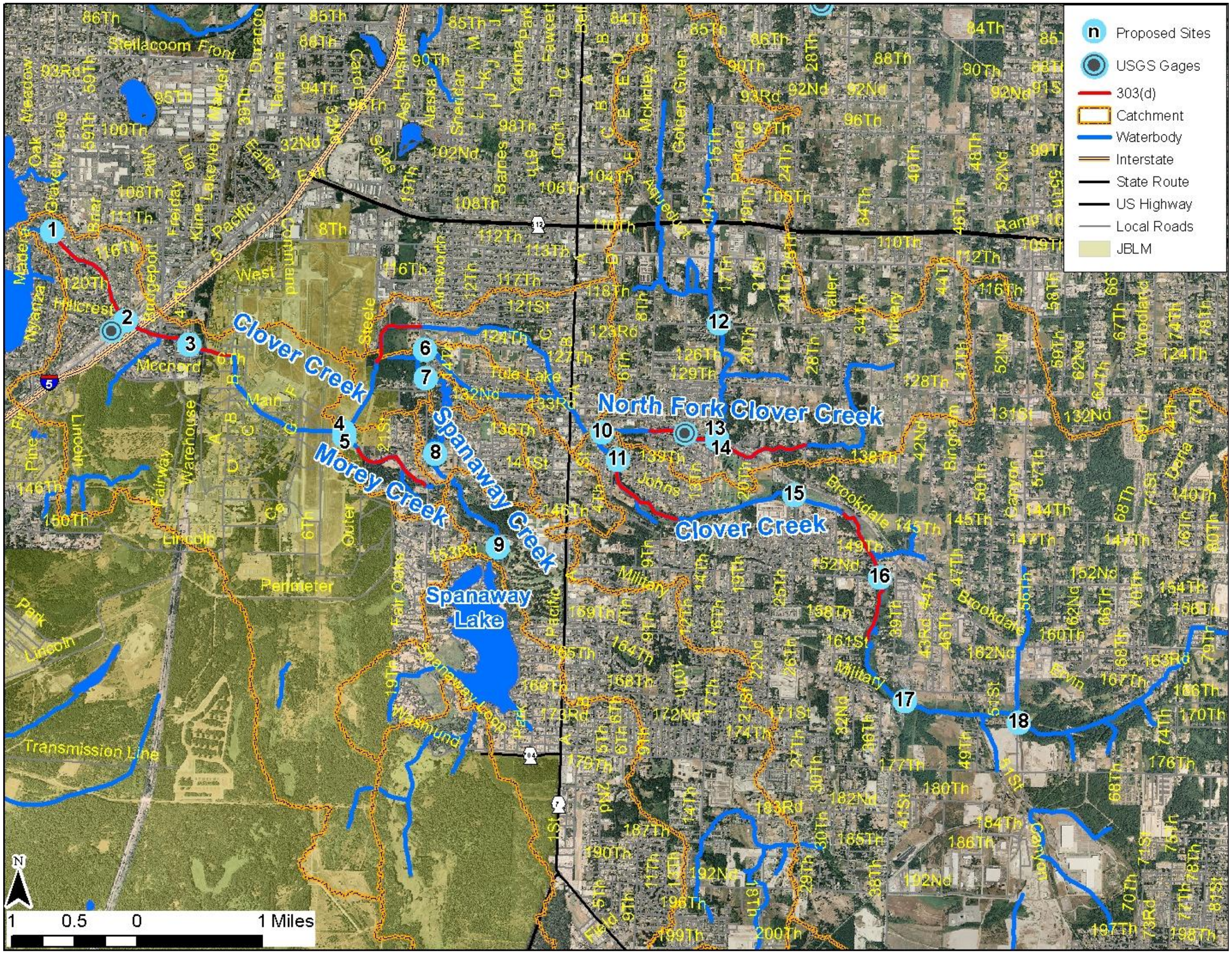

Figure 17. Proposed fixed-network sampling sites and 303(d) stream segments.

Table 9. Proposed fixed-network sampling sites in the Clover Creek watershed.

Map ID	Site ID	Site Description	Latitude	Longitude
1	12CLO0.4	Clover Ck at Gravelly Lk Dr SW	47.1560283	-122.5231217
2	12CLO1.4	Clover Ck at Pacific Hwy SW	47.1459917	-122.5103583
3	12CLO1.9	Clover Ck at 47th Ave SW	47.1433467	-122.4994567
4	12CLO3.5	Clover Ck 1980 ft. d/s of Perimeter Rd JBLM	47.13367305	-122.472765
5	12MOR0.1	Morey Pond outlet to bypass at JBLM	47.13326896	-122.4727272
6	12CLO4.6	Clover Ck at Spanaway Loop Rd S	47.14345922	-122.4594648
7	12SPA0.5	Spanaway Ck at Spanaway Loop Rd S	47.1401477	-122.4592428
8	12SPA1.4	Spanaway Ck at 138 St S	47.1315217	-122.4572317
9	12SPA1.8	Spanaway Ck at Spanaway Park	47.1209117	-122.446315
10	12NFC0.0	NF Clover Ck at B St S	47.13446094	-122.4291162
11	12CLO7.1	Clover Ck u/s of 138th St E	47.13128465	-122.4263154
12	12NFCB1.1	NF Clover Ck branch at 121st	47.14737659	-122.4098005
13	12NFCB0.0	NF Clover Ck branch at Brookdale Rd E	47.13409742	-122.4095695
14	12NFC1.0	NF Clover Ck u/s of USGS gage Brookdale Rd	47.13395347	-122.4095402
15	12CLO8.7	Clover Ck at 25th Ave E	47.1277317	-122.396245
16	12CLO9.8	Clover Ck at 152nd St E	47.1185067	-122.3814833
17	12CLO11.0	Clover Ck at Military Rd E	47.10428904	-122.3766933
18	12CLO12.0	Clover Ck at Canyon Rd E near headwaters	47.1021316	-122.3573064

Latitude and longitude datum: NAD 83 HARN

Sampling sites were selected based on spatial resolution, waterway confluences, catchment locations, historical discharge and water quality sampling locations, land uses, and 303(d) listed segments. 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.

Data from the fixed-network will provide information to meet the following needs:

- Characterize and compare stream, temperatures, DO concentrations, FC concentrations, macroinvertebrate communities, periphyton communities, potential upland pollution sources, effects of stormwater, and discharge using high resolution/frequency sampling.
- Provide detailed information about the thermal regime throughout the watershed using continuous temperature data-loggers.
- Provide an estimate of FC annual and seasonal geometric mean, 10% of data above water quality criteria, and 90th percentile statistics. The sampling schedule should provide approximately 24 samples per site to develop annual statistics, including 10 samples per site during the dry season (May – September) and 14 samples per site during the wet season (October – April).
- Provide reach-specific FC concentration comparisons in the watershed to define areas of increase or decrease. Loads also will be estimated using accurate streamflow monitoring.
- Determine if certain land uses and stream characteristics affect changes in temperature, DO concentrations, FC concentrations, and relative loads.

The fixed-network sites will be sampled twice monthly from March 2013 through February 2014. The detailed sampling schedule and techniques are provided in the *Sampling Procedures* section of this project plan.

Temperature analysis

The temperature assessment of Clover Creek will use effective shade as a surrogate measure of heat flux, allowing shade to be linked to temperature. Effective shade is defined as the fraction of the potential solar shortwave radiation that is blocked by vegetation and topography before it reaches the stream surface. Effective shade accounts for the interception of solar radiation by vegetation and topography. Shade curves will be developed to determine the shade prescription for a specific stream location.

Riparian canopy assessment will be done by:

- Analyzing hemispherical photography.
- Measuring vegetation heights and densities.
- Processing existing Light Distance and Ranging (LiDAR).
- Assessing and mapping soils.
- Measuring channel morphology including wetted width, bankfull width, near stream disturbance zone, and flood prone width.

Shade curves will be used to predict effective channel shade for Clover Creek. Shade curves are based on the estimated relationship between riparian shade, channel width, and stream aspect (Cummings et al., 2011, and Cristea and Janisch, 2007). Various shade curves including tree species, heights, and buffer widths for each water quality station will be developed and can be applied throughout the watershed.

Shade curves will be developed using four possible riparian zone buffer widths:

- 5 meters (15 feet)
- 15 meters (50 feet)
- 30 meters (100 feet)
- 46 meters (150 feet)

Hemispherical photography analysis generates site-specific information by taking 360° pictures of the sky to calculate the shade provided by vegetation and topography at the center of the stream. Digital photographs will be taken at each fixed-network site and at a few reference reaches to document and verify existing riparian vegetation compared to aerial photos. The digital images will be processed and analyzed using the HemiView© software program.

LiDAR produces accurate topographic surveys using an airborne scanning laser rangefinder. From these data, vegetation heights such as riparian tree canopy may be derived. The most recent data available through the Puget Sound LiDAR Consortium will be used to characterize riparian canopy throughout the watershed. On-the-ground measurements such as hemispherical photography, vegetation heights, and channel measurements will augment and verify LiDAR data.

Shade will be used as a surrogate to thermal load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR § 130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section.

Load allocations for effective shade will be based on the estimated relationship between channel width and stream aspect at the assumed maximum 100-year riparian vegetation condition. Effective shade corresponding to system-potential vegetation (100-year) will be estimated assuming mature vegetation, using historic records or Geographic Information System (GIS) soils data.

- **Maximum system-potential vegetation**
  System-potential mature riparian vegetation is defined as that vegetation which would have grown and reproduced naturally on a site, given: climate, elevation, soil properties, plant biology, and hydrologic processes. System-potential vegetation is determined through historic records or soils GIS databases and is generally provided by 180-foot wide buffers. *"A 180 feet buffer is the distance for which landowners enrolled in a Conservation Reserve Enhancement Program (CREP) can receive payment. Another often-used buffer width for analysis is one site-potential tree height. The justification is that because of geometry, one tree height is the maximum that can cast shade. Wider buffers, those greater than 150 feet, are necessary to provide microclimate and other water quality benefits (excerpt from Snoqualmie TMDL, Svrjcek et al., 2011)."* Additionally, research has shown that a 180-ft buffer protects more than just temperature with benefits such as removing nutrients and sediment, enhancing aquatic habitat, and increasing riparian plant and wildlife habitat, (Wenger, 1999).

Every temperature TMDL to date has established a load allocation target equal to maximum system-potential vegetation. Using data collected to develop predictive computer models, Ecology determined that the system would not meet temperature water quality criteria even if the load allocation was fully implemented. Therefore, the natural condition provision is in all of the temperature TMDLs (examples below).

- *Snoqualmie Temperature TMDL* (Svrjcek et al., 2011)
- *Hangman Creek Temperature TMDL* (Joy et al., 2009)
- *Upper Naches Temperature TMDL* (Brock, 2008)
- *Bear-Evan Temperature TMDL* (Mohamedali and Lee, 2008)
- *Green River Temperature TMDL* (Coffin et al., 2011)
- *Newaukum River Temperature TMDL* (Lee et al., 2011)
- *Tucannon and Pataha Temperature TMDL* (Bilhimer et al., 2010)
- *Wenatchee Temperature TMDL* (Cristea and Pelletier, 2005)
- *South Prairie Creek Temperature TMDL* (Roberts, 2003)
- *Pend Oreille River Temperature TMDL* (Baldwin et al., 2010)
- *Upper Chehalis River Temperature TMDL* (Water Quality Program, 1999)
- *Stillaguamish Temperature TMDL* (Pelletier and Bilhimer, 2004)
- *Wind River Temperature TMDL* (Pelletier, 2002)

The only exception is the *Willapa Temperature TMDL* (Stohr, 2004) which found that a less-than system-potential tree condition was sufficient to protect water quality.

Analysis in this TMDL will focus on determining system-potential vegetation and shade goals for the Clover Creek basin using soils and LIDAR data. This may lead to an earlier emphasis on restoration activities rather than an emphasis on determining specific water temperatures associated with system-potential vegetation.

Fecal coliform bacteria analysis

The statistical rollback method (Ott, 1995) will be applied to determine the necessary reduction for both the geometric mean value (GMV) and 90th percentile bacteria concentration to meet water quality criteria. For statistical purposes the 90th percentile will be used as a surrogate target for the 10% of data not to exceed water quality criterion. 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 90th percentile are set to the corresponding water quality standard. The reduction needed for each target value to be reached is determined. The rollback factor ($f_{rollback}$) is

$$f_{rollback} = \text{minimum} \{ (100/\text{sample GMV}), (200/\text{sample } 90^{th} \text{ percentile}) \}$$

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

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

This calculates 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. Application of this reduction factor to the study GMV yields a target GMV that is usually less (i.e., more restrictive) than the water quality criterion. The 90th percentile is used as an estimate expression to the “no more than 10%” criterion found in the second part of the water quality standards for FC bacteria.

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. 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.

FC loading will be estimated at each fixed-network sampling location in order to assess relative contributions throughout the watershed. Loading is the product of FC concentrations multiplied by stream discharge. Loading results may be used to prioritize water quality improvement projects. For example, areas or seasons experiencing relatively high loads may be considered top priority for restoration activities.

Dissolved oxygen analysis

Single DO samples will be measured throughout the watershed during each site visit. Continuous (time-series) DO data will also be collected at a sub-set of fixed-network monitoring locations. Two diurnal studies, one during summer and one during winter, will be conducted over a two- to three-day period. Continuous DO data will characterize diurnal patterns and make seasonal comparisons possible. DO loads will be estimated as a product of stream discharge and DO concentrations. DO concentrations will be compared to the water quality criteria.

Factors that influence DO concentrations include groundwater upwelling, stream temperatures, primary productivity and nutrients. However, the influence of these processes will not be quantified as potential mechanisms driving DO conditions during this study.

Groundwater is naturally low in DO and warmer water holds less DO than cooler water. Cooling the stream temperatures with effective shade may increase DO levels of the Clover Creek watershed. Cooler water can hold more DO that fish and other aquatic life need to breathe.

Temperature is the main determinant of metabolic rates and influences rates of primary production and respiration (Yuan et al., 2010). Well-shaded streams can limit primary productivity of phytoplankton and aquatic plants by reducing incoming solar light available for photosynthesis. Over-productive streams caused by increased nutrients (eutrophication) have the potential for low DO level during (1) photorespiration at night and (2) heterotrophic respiration, as organic matter from plants and algae are consumed by microbes and macroinvertebrates. Increased organic matter from increased primary productivity, combined with increased microbial activity, results in an increase in heterotrophic respiration, which consumes DO (Allan and Castillo, 2007).

Increased primary production may increase pH due to uptake of CO_2. When photosynthetic organisms decompose or reduce productivity, CO_2 is released or is no longer used, and pH may decrease. DO is also influenced by primary production. Primary production activity emits oxygen, thus temporarily increasing DO in aquatic systems. Primary production die-off is oxygen-demanding, as aquatic microbes and macroinvertebrates use oxygen while decomposing the carbon-based plant matter.

Diel (24-hr period) fluctuations may occur with pH and DO. Typically during daylight hours, an increase in DO and pH occurs as primary producers emit oxygen, and take in CO_2. At night, pH and DO levels decrease as primary producers engage in photo respiration by taking in oxygen. Excessive nutrients and biomass, and large diel chemical fluctuations, are characteristic of a eutrophic (nutrient-rich) condition.

Load duration curve

Hydrologists commonly characterize stream values such as flow and load, using a duration curve, which is the percentage of time during which the value of a given parameter is equaled or exceeded. Discharge rates are typically sorted from the highest value to the lowest. Using this convention, flow duration intervals are defined and expressed as a percentage, with zero corresponding to the highest stream discharge in the record (i.e., flood conditions) and 100 corresponding to the lowest (i.e., drought conditions) (Cleland, 2002).

Load duration curves (LDC) will be used to incorporate the assimilative capacity of the watershed as a function of flow and allows for the maximum allowable loading to vary with flow conditions (Cleland, 2003). The LDC is a useful tool for characterizing the pollutant problems over the entire flow regime. This study will assess FC using LDCs, whereas temperature and DO will not be assessed using this technique due to limits in it application. LDC analysis involves using: (1) measured or estimated/modeled flow data, (2) water quality criteria, and (3) concentration/load data to assess flow conditions when water quality criteria are not met. FC load reductions will be estimated for each monitoring station by calculating the percent reduction, using the difference between the existing loading and the LDC.

The development of LDCs requires the development of flow duration curves. Flow duration curves will be developed at each fixed-network monitoring location (Studley, 2001). Regression analysis will be used to assess the relationship between the USGS continuous discharge data and discharge measurements from all other instantaneous sampling locations. Pollutant loads are the product of two constituents; (1) water quality sample concentrations such as FC, and (2) stream discharge.

LDCs will be useful to characterize water quality and provide a visual display for people to better understand the problem and TMDL targets. LDCs and instantaneous discharge measurements will be used to estimate: (1) total FC loads, and (2) unit FC loads. Total loads will characterize annual and seasonal results. Unit loads will be used to estimate daily and storm results. As a result, the expected duration or percentage of time of load in any given year will be estimated.

Normalized ranked means

Calculations for normalized rank means (NRMs) for flow and FC data will be used for comparison between monitoring stations. This may be useful when setting implementation priorities for TMDL management actions. Each monitoring location will have a calculated NRM for flow and FC. Temperature and DO will not be assessed using this method due to limits of its application. NRMs are expressed in units of standard deviation from the mean,

$$\text{NRM} = (R_j - R_o)/(\text{SD})$$

Where R_j is the actual rank-sum of water quality at location j; R_o is the expected rank sum for a location where all locations are equal (null hypothesis); and SD is the standard deviation for the pooled ranks. The NRM is similar to the variously called C, Z, or z Wilcoxon-Mann-Whitney statistic (Stringfellow, 2008).

Using this method, drainages can be classified into one of four categories (quadrants) based on the relationship between stream discharge and FC NRMs without using pollutant loads. This method may be more comprehensive than using load analysis to set implementation priorities.

Landscape Development Intensity Index

The Landscape Development Intensity Index (LDI) is used to infer potential human disturbance based on the type of land use activity present in the landscape under examination (Brown and Vivas, 2005). LDI is an index calculated from defined coefficients (i.e., intensity factors) which are a function of energy use per unit area of land use. The LDI index is calculated using Geographic Information System (GIS) for the study area, influenced by land use activity (i.e., watershed scale). Generally, land-cover/land-use data can be obtained by orthophotos or by processed land use parcel data created by various federal, state and local agencies. LDI methods will be used to estimate the effects of land use activities on water quality in the Clover Creek watershed. As a result, the watershed will be assessed spatially by comparing areas subject to water quality degradation based on land use activities.

In terms of water quality, pathways of anthropogenic disturbance can create a variety of multiple impacts based on several physical, bio-geochemical, and hydrological characteristics of the watershed. Alterations to the landscape and river channels can cause contaminates (i.e., nutrients, bacteria, and toxins) to be transported at greater volume, frequency, and magnitude. This affects the biotic structure and integrity (biodiversity, community structure, and biomass variability of individual species) of aquatic ecosystems. The development of human disturbance gradient indices are necessary in order to infer which specific land use practices have the greatest or least impact on ecological systems. Then pollutant source identification, biological assessment or TMDL development activities within a watershed can begin.

Stormwater

Stormwater and water quality

Throughout the US there are thousands of waters listed for impairments from stormwater sources. The most common pollutants coming from stormwater sources include sediment, pathogens, nutrients, and metals. These listed impaired waters need a TMDL, which identifies the total pollutant loading that a water body can receive and still meet water quality standards (EPA, 2007).

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 potentially degrade water quality.

Human influences often reduce stormwater percolation with activities that include: (1) covering the soil (e.g., paving and building), (2) compacting the soil (e.g., holding livestock, building trails and roads, and trampling sensitive soils, and (3) limiting infiltration (e.g., reducing vegetation and filling wetlands). All of these human influences can be present in a wide range of intensities for any given land use category. Maintaining pervious surfaces is not only important for reducing flows. When impervious surfaces are minimized or regularly cleaned, pollutant export to sensitive environments such as riparian areas or waterways is minimized. Stormwater infiltration is one way to achieve natural treatment and reduce flow simultaneously (Lubliner, 2007).

Schueler (2000) defines impervious area as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces in the urban landscape. Most of the impervious area composition is from transport and rooftops. The transport component is predominant in the suburban environment, at 63-70% of the total impervious cover for residential, multi-family, and commercial areas (City of Olympia, 1995).

During typical rainfall runoff events, the hydrograph in sub-watersheds with impervious areas has become earlier and more intense, with a shorter overall life span. The effects of stormwater runoff into streams has increased the frequency and severity of flooding, accelerated channel erosion, altered streambed substrate-size composition, reduced baseflow, altered energy inputs to streams, and altered the natural temperature regime (Schueler, 2000). A one-acre parking lot impervious cover will increase the annual volume of stormwater runoff over a one-acre undeveloped meadow by up to 16 times (Schueler, 2000).

Over the long term, the hardened surfaces and shortened travel times for rainwater have had sustained impacts to stream hydrology, geomorphology, and water quality. Variability is due to several factors such as annual climate, historical uses, infiltration rates, soil types, human use influences, and population (Paul and Meyer, 2001).

Stormwater and TMDLs

In a TMDL, accurately characterizing stormwater pollutant concentrations across a large spatial scale is difficult with a limited lab budget. A high number of samples would be necessary to approximate the statistical population mean because of the complex nature and variability of pollutant concentrations in stormwater. However, sampling every outfall is not a realistic option. The scale of a drainage network and number of outfalls to be monitored becomes a critical design element that often is restricted by the budget. Laboratory sample analysis alone is one of the most expensive elements in many TMDL studies.

Common difficulties in studying stormwater pollution include the following (Lubliner, 2007);

- Limited resources, personnel, or equipment
- Selecting acceptable sites
- Mapping and sampling limitations on the physical conveyance systems
- Timing and logistics of catching stormwater samples
- Gathering representative samples of highly variable discharges
- Gathering existing data from multiple jurisdictional authorities
- Modeling the highly variable concentrations and discharge rates
- Statistical analysis, particularly with missed samples and non-detects

Stormwater samples will be collected at the fixed-network sampling locations and at nearby flowing outfalls (Table 4). Stormwater contributions will be characterized for each sampling location and catchment (Figure 17). Load duration curves will be used to assess and characterize water quality in relation to stormwater. The LDC has become widely used for nonpoint source pollution due to the ease of assessing water quality across a range of flow conditions (Lubliner, 2007).

At least two sampling teams will be necessary to sample a storm event in one day. Storms will be anticipated using meteorological forecasts. The timing of stormwater runoff will be plotted on a hydrograph as well as the time of sampling and the amount of precipitation. This will give an estimated comparison between sample time, precipitation, and stormwater runoff characteristics. For example the time of sampling may coincide with the rising limb of increased stream discharge where both may be plotted on the hydrograph for comparison.

Up to four storm events will be sampled, providing an estimate of stormwater contributions to the watershed. Practical constraints such as timing and magnitude of storm may reduce the chances of capturing all four storm events. A qualifying storm event is defined by: (1) a minimum 0.2-inch of rainfall in a 24-hour period preceded by no more than trace rainfall (< 0.02-inch) in the previous 24 hours, or (2) any rain event that results in an observable increase in stream discharge based on USGS continuous discharge data. Figure 18 shows the probability of 0.2 inches of precipitation within a 24-hour period at the Tacoma meteorological station (Western Regional Climate Center). Based on the past 29 years of record, rainfall of 0.2 inch or more in 24 hours occurs on average 54 times per year.

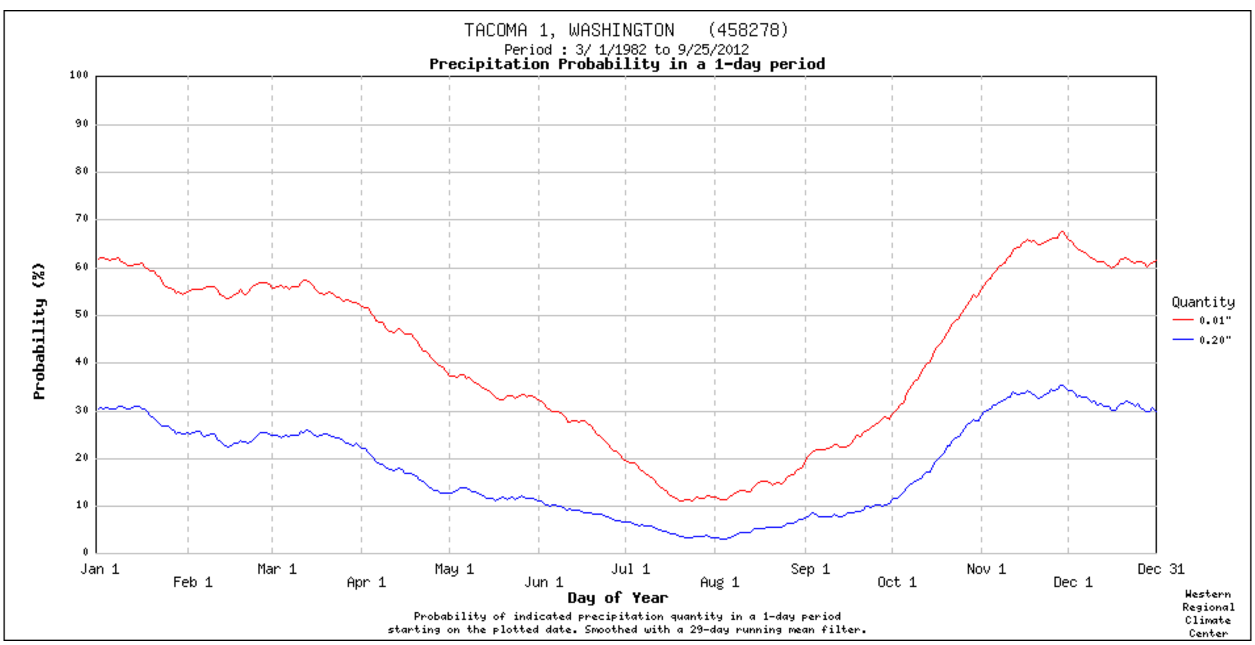

Figure 18. Probability of 0.01 and 0.2 inch of precipitation during a 24-hour period.

Streamflow will be measured or estimated using stage and rating curves or relationships with other monitoring locations when grab samples are collected. Daily rainfall data will be obtained from local sources including Tacoma 1 (station ID 458278) and Tacoma/McChord A (station ID KTCM).

Stormwater NPDES permits are required to have corresponding wasteload allocations (WLAs) set in TMDL studies. Therefore, this study will determine WLAs for each permit holder including: WSDOT (permit number WAR043000A), the City of Lakewood Phase II (permit number WAR045012), and Pierce County Phase I (permit number WAR044002). Load duration curves will be used to determine WLAs and characterize stormwater runoff.

Once field sampling begins, it may be necessary to adjust the storm monitoring schedule and site locations. It may be challenging to quickly and safely access some sites and obtain representative samples.

Streamflow monitoring

Instantaneous stream discharge data will be collected at the sampling locations. Data will also be collected from the existing USGS gage stations. Existing staff gages may be used to estimate stream discharge at certain locations if the established flow-rating curves are accurate. In addition, flow-rating curves may be developed using data collected during field activities.

During routine monitoring, seepage data will be collected under baseflow conditions in order to characterize exchanges of water between the groundwater flow system and streams. These results will also be compared to USGS results of September 2007, and July 2008 (Savoca et al., 2010), and Ecology's previously conducted seepage study (Sinclair, 1984).

Biological monitoring

Benthic macroinvertebrate and periphyton communities are used to assess stream condition. Macroinvertebrates and periphyton provide information about environmental conditions based on the range of tolerance individual taxa have to environmental conditions. Based on their unique tolerance levels, those taxa – either present or missing – indicate habitat conditions. Fish community evaluations are not used because relatively few taxa in western North America exist and harvests are restricted for several threatened or endangered species including salmon (Moyle et al., 1986).

Measurements of chemical and physical components alone do not provide enough information to fully address surface water problems. Biological assessments (Adams, 2010) enhance chemical and physical evaluation by:

- Capturing impacts of pollutants for which there are currently no criteria and no regulation by Washington's Water Quality Program.
- Directly measuring the most sensitive resources at risk.
- Measuring stream components that reflect natural variation over time.
- Providing a diagnostic tool that synthesizes chemical, physical, and biological perturbations (Hayslip, 1993).

Biological monitoring will be used as a supplement to routine chemical parameters collected for this TMDL. Physical habitat, water chemistry, and soil chemistry will be measured and biological samples will be collected and analyzed. These measurements and samples describe the environment at the time of sampling.

The primary tasks conducted by the biological monitoring staff include:

- Site reconnaissance and selection
- Collection of
  - Water quality data (temperature, pH, DO, and conductivity)
  - Benthic macroinvertebrate samples
  - Periphyton samples
  - Habitat data
- Data analysis

This data set will be analyzed using the developed empirical models for bioassessment of streams including:

- A multi-metric model similar to the Benthic Index of Biotic Integrity (BIBI) (Karr, 1991)
- A multi-variate model similar to the Riverine Invertebrate Prediction and Classification System (RIVPACS) (Wright, 1995)

RIVPACS type models are called O/E (observed/expected) models (Ostermiller and Hawkins, 2004). A multi-metric model was developed by Ecology for the Puget Lowlands and the Cascades (Wiseman, 2003) and multi-variate O/E models are currently being developed for the Cascades.

These models are built by correlating taxonomic composition and characteristics, such as life history traits and pollution tolerance, with the range of conditions found in each ecoregion from near pristine to highly disturbed sites. This creates a defined scale of community characteristics one would expect to find in reference and in disturbed stream conditions. Clover Creek is in the Puget Sound Lowlands ecoregion. As a result of modeling, the characteristics of the taxa at a site will be used to indicate the condition of the stream as good, fair, or poor. Modeled outputs will provide a basis for comparison between sampling sites within the Clover Creek watershed.

Hydromodifications Assessment

Hydromodification activities include channelization and channel modification, impoundments, and streambank and shoreline erosion. A frequent result of channelization and channel modification activities is a diminished suitability of instream and streamside habitat for fish and wildlife. They can also alter instream patterns of water temperature and sediment type, as well as the rates and paths of sediment erosion, transport and deposition. Hardening of banks along waterways has increased the movement of nonpoint source pollutants from the upper reaches of watersheds into coastal waters (EPA, 2013b).

The Clover Creek watershed has experienced significant modifications throughout its history as human development impacted the area. Hydromodifications will be characterized throughout the watershed using available GIS information, literature, and on-the-ground observations. As a result a hydromodifications map will be generated, showing spatially the type of modification.

Sampling Procedures

Field sampling and measurement procedures will follow Standard Operating Procedures (SOPs) developed by Ecology's Environmental Assessment Program including:

- EAP012 *Sampling Bacteria in Water*
- EAP015 *Grab Sampling – Fresh water*
- EAP023 *Winkler Determination of Dissolved Oxygen*
- EAP044 *Continuous Temperature Monitoring of Fresh Water Rivers and Streams Conducted in a Total Maximum Daily Load (TMDL) Study*
- EAP045 *Hemispherical Digital Photography Field Surveys Collected as part of a Temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit Technical Study*
- EAP046 *Computer Analysis of Hemispherical Digital Images Collected as part of a Temperature Total Maximum Daily Load (TMDL) or Forests and Fish Unit Technical Study*
- EAP033 *Hydrolab DataSonde and MiniSonde Multiprobes*
- EAP035 *Measurement of Dissolved Oxygen in Surface Water*
- EAP056 *Measuring and Calculating Stream Discharge*
- EAP071 *Minimizing the Spread of Aquatic Invasive Species from areas of Moderate Concern*
- EAP073 *Standard Operating Procedures and Minimum Requirements for the Collection of Freshwater Benthic Macroinvertebrate data in Wadeable Streams and Rivers*

SOP documents can be found on the web at: www.ecy.wa.gov/programs/eap/quality.html.

Laboratory samples

Sample specifications and holding times

FC grab samples will be collected directly into pre-cleaned containers supplied by the Manchester Environmental Laboratory (MEL) and described in the MEL *Lab Users Manual* (2008). FC samples for laboratory analysis will be stored on ice and delivered to MEL within 24 hours of collection. Invertebrate and periphyton samples will be delivered to a contracted laboratory within a few days after sampling. Specifications for sample containers, preservations, and holding times are presented in Table 10.

Table 10. Containers, preservation requirements, and holding times for samples collected.

Parameter	Sample matrix	Container	Preservative	Holding time
Fecal Coliform (FC)	Surface water and runoff	250 or 500 mL glass/poly autoclaved	Cool to 4ºC	24 hours
Dissolved Oxygen (DO)	Surface water and runoff	300 mL BOD[1] bottle & stopper	2 mL manganous sulfate reagent + 2 mL alkaline-azide reagent	4 days
Invertebrates	Surface water	Wide-mouth polyethylene jar (128 oz or 3.8 L)	95% Ethanol (add 3 parts by volume for each part sample)	Roughly 3 months
Periphyton	Surface water	Wide-mouth polyethylene jar (1 L)	95% Ethanol (add 3 parts by volume for each part sample)	Roughly 3 months

BOD[1] = Biochemical oxygen demand

Field sampling

Water quality samples will be collected from the stream thalweg (center of flow) whenever possible. Samples taken in freshwaters will be collected at approximately six inches below the surface of the water, with the sampler standing downstream from the collection point. Samplers will try to avoid stirring up sediment in streams with slow current velocities or shallow channels. Accessible flowing stormwater outfalls will be sampled carefully during storm sampling events. A minimum of 20% of FC will be field duplicates used to assess total (field and lab) variability.

Field logs will document each sampling event. Field logs will include information such as: project name, site identification, date, time, water quality parameters (listed in the "Measurement Procedures" section), general weather conditions, stream velocity measurements, and comments.

The proposed sampling frequency for FC, temperature, conductivity, pH, DO, and discharge will be once every two weeks at each fixed-network location (Table 11). Table 9 and Figure 17 show the fixed-network sampling locations. Storms will also be sampled once per calendar season (winter, spring, summer, and fall) and include the above mentioned parameters. Invertebrate and periphyton samples will be collected once during late September or early October at approximately six locations. Riparian photographs will be taken at each fixed-network location during late summer when the deciduous canopy cover is at an annual maximum of mature leaf growth. Diurnal surveys will occur at approximately five locations sometime during (1) late summer to early fall, and (2) late fall through winter.

Table 11. Sampling schedule.

Date	Water parameters	Stream discharge	Fecal coliform	Storm event	Biological	Riparian canopy	Diurnal survey
12-Mar-13	x	x	x				
26-Mar-13	x	x	x				
9-Apr-13	x	x	x				
23-Apr-13	x	x	x				
7-May-13	x	x	x	x			
21-May-13	x	x	x				
4-Jun-13	x	x	x				
18-Jun-13	x	x	x				
2-Jul-13	x	x	x				
16-Jul-13	x	x	x			x	
30-Jul-13	x	x	x				
13-Aug-13	x	x	x	x			
27-Aug-13	x	x	x				x
10-Sep-13	x	x	x				
24-Sep-13	x	x	x				
8-Oct-13	x	x	x		x		
22-Oct-13	x	x	x				
5-Nov-13	x	x	x	x			
19-Nov-13	x	x	x				
3-Dec-13	x	x	x				
17-Dec-13	x	x	x				
7-Jan-14	x	x	x				x
21-Jan-14	x	x	x	x			
4-Feb-14	x	x	x				

Chain-of-custody

Chain-of-custody forms and sample tags for each parameter will be prepared before each field study, adhering to MEL (2008) guidelines. Information on the sample tags includes: project name, sample identification number, site identification, date, time, and parameter. Samples will be collected in appropriate containers and delivered to the laboratory along with a chain-of-custody form. Date and time will be recorded on the sample tags at the time of field collection. Information on the sample tags will match with the information on the chain-of-custody form.

Temperature monitoring

Temperature data-loggers (thermistors) will be deployed at the fixed-network sites (Table 9 Figure 17) from May through September in order to assess the thermal critical period. Each site will have up to two thermistors; one to measure water temperature and another to measure air temperature. The thermistors will measure temperature at 30-minute intervals. Stream thermistors will be deployed in the thalweg of a stream such that they are suspended off the stream bottom and in a well-mixed portion of the stream, typically in riffles or swift glides.

Care will be taken to conceal the thermistor in order to reduce the risk of theft or vandalism. Temperature monitoring stations will be checked monthly to conduct field measurements/observations and to clear accumulated debris away from the instruments. Documentation of the temperature monitoring stations will include:

- GPS coordinates and a sketch of the site (during installation only).
- Depth of the stream temperature instrument (TI) under the water surface and height off the stream bottom.
- Stream temperature.
- Serial number of each instrument and the action taken with the instrument (i.e., downloaded data, replaced TI, or noted movement of the TI location to keep it submerged in the stream).
- The date and time before the data-loggers 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 instruments are still in place during the time change.

The temperature assessment of Clover 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. Effective shade accounts for the interception of solar radiation by vegetation and topography.

Shade will be used as a surrogate to thermal load as allowed under EPA regulations (defined as "other appropriate measure" in 40 CFR § 130.2(i)). A decrease in shade due to inadequate riparian vegetation causes an increase in solar radiation and thermal load upon the affected stream section. Effective shade will be linked to thermal loading by estimating the amount on incoming heat (solar radiation) absorbed by the water body. The amount of incoming heat will be estimated using canopy openness estimated by the canopy photos. The estimated incoming solar heat will be applied to each monitoring station.

Effective shade requires an estimate of the aerial density of vegetation shading the stream. Because direct confirmation of site conditions improves the quality of information, 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. Digital photographs will be taken at each fixed-network site and at a few reference reaches to compare existing riparian vegetation with aerial photos and LiDAR data. The digital hemispherical images will be processed and analyzed using the HemiView© software program.

Stream channel measurements will be taken at each fixed-network sampling location. Measurements include wetted depth, wetted width, bankfull width, flood prone width, and near stream disturbance zone. In addition vegetation heights will be measured using a laser range finder. This information will be used to develop shade curves and be compared with LiDAR data.

Dissolved oxygen

During each site visit, single DO samples will be measured at the fixed-network sites using a *Hydrolab DataSonde*® (Table 9; Figure 17). DO grab samples will be collected using BOD bottles at each fixed-network sampling location for field instrument QA/QC. The QA/QC grab samples will be analyzed for DO concentrations using the Winkler method. Roughly ten percent of the DO grab samples will have associated field replicates in order to assess Winkler method bias and precision.

Over a 24 to 48 hour period, continuous diurnal monitoring for pH, DO, conductivity, and temperature will be conducted at approximately five fixed-network sites using the *Hydrolab DataSonde*®. Continuous diurnal data collection will occur once during the summer months and once during the winter months.

Macrophytes, phytoplankton, and periphyton are photosynthetic primary producers in aquatic systems. Any combination of primary producers may dominate the water body, depending on watershed characteristics.

Stream discharge

Instantaneous streamflow measurements will be taken during each site visit whenever it is safe and practical. Continuous USGS stream gage data will also be collected and used for data analysis.

Stormwater

Stormwater will be sampled up to four times during the course of field data collection. The fixed-network sites (Table 9, Figure 17) and nearby flowing outfalls (Table 4) will be sampled. Grab samples include FC, temperature, pH, conductivity, and DO. Discharge will be measured at the sampling locations including accessible stormwater outfalls.

Invertebrates and periphyton

Benthic macroinvertebrates and periphyton will be sampled at approximate six locations throughout the watershed during early October. This timeframe was chosen for the following reasons:

- Adequate time has passed for the instream environment to stabilize after natural disturbances, e.g., spring floods.
- Many macroinvertebrates reach body sizes that can be readily identified.
- Representation of benthic macroinvertebrate species reaches a maximum, particularly during periods of pre-emergence, typically from mid-spring to late-summer
- Time is most available to schedule sampling efforts.

Both macroinvertebrate and periphyton samples collected will be transferred to the taxonomy lab for analysis. One sampling site will have replicate samples taken to quantify field/lab variability.

Invasive species management

It is Ecology's policy to eliminate the spread of invasive species accidentally caused by field sampling efforts. Environmental ethics and Washington law (RCW 77.15.290) prohibit the transportation of *any* plants or animals. While there are exceptions, such as for scientific study, field staff must ensure that sampling activities do not spread viable organisms from one sampling location to another.

Measurement Procedures

Field

Water quality grab samples will be taken during each site visit whenever it is safe and practical. Water quality parameters will be measured using a multi-probe/*DataSonde®* or *MiniSonde®*. Parameters measured by the *DataSonde/Hydrolab®* and recorded in the field log include: temperature (°C), DO (mg/L and % saturation), specific conductivity (µS/cm), and pH.

DO will also be collected and analyzed using the Winkler titration method. Temperature data loggers will be downloaded monthly or bi-monthly and the stream temperature checked using the *DataSonde/Hydrolab®*.

Instantaneous flow measurements will be taken during each site visit using the *Marsh McBirney* velocity meter. Flow volumes will be calculated from continuous stage height records and rating curves developed by the USGS. Staff gage or tape-down measurements will be established at other selected sites. When possible, flow rating curves will be developed for each site with a staff gage or tape-down reference point so gage readings can be converted to a discharge value.

All thermistors 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) a Department of Commerce agency, the National Institute of Standards and Technology (NIST) and (2) the U.S. Naval Observatory (military counterpart of NIST). All date and time stamps will be recorded in Pacific Daylight Savings Time.

Laboratory

All laboratory measurements will follow the MEL *Lab Users Manual* (2008). Laboratory measurement/analysis procedures are based on 'Standard Methods' (APHA, 2005)

Measurement quality objectives (MQOs) state the level of acceptable error in the measurement process. Precision is a measure of the variability in the results of replicate measurements due to random error (Lombard and Kirchmer, 2004). This random error includes error inherently associated with field sampling and laboratory analysis. Field and laboratory errors are minimized by adhering to strict protocols for sampling and analysis.

Quality Objectives

To meet the objectives of this study, all field sampling and lab analysis will follow strict protocols outlined in this QA Project Plan. This will ensure data credibility and usability, in compliance with the Water Quality Data Act (RCW 90.48.570-590) and Water Quality Program-Environmental Assessment Program Policy 1-11, Chapter 2: "Ensuring Credible Data for Water Quality Management".

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

Measurement quality objectives (MQO) state the acceptable accuracy for the data collected for a project. MQOs, sampling methods, protocols, and data analysis are discussed in following sections.

Quality objectives for analysis

Precision

Precision is defined as the measure of variability in the results of replicate measurements due to random error (Lombard and Kirchmer, 2004). Random error is imparted by the variation in concentrations of samples from the environment as well as other introduced sources of variation (e.g., field and laboratory procedures). Precision for replicates will be expressed as percentages using relative standard deviation (RSD) and relative percent difference (RPD). RSD will be applied to field replicates and RPD will be applied to lab duplicates.

RSD = (standard deviation of the sample population) × 100 / (mean of the sample population)

RPD = ((the absolute value of the difference between two samples) / (the sample mean)) × 100

Bias

RPD without absolute value may also be used to calculate bias. Bias is defined as the difference between the sample value and true value of the parameter being measured. Bias affecting measurement procedures can be inferred from the results of quality control (QC) procedures involving the use of blanks, check standards, and spiked samples. Bias in field measurements and samples will be minimized by strictly following measurement, sampling, and handling protocols. If laboratory samples are not meeting duplicate MQOs then bias will be estimated as follows (Lombard and Kirchmer, 2004):

An estimate of bias due to calibration is given by

$$B(\%) = \frac{\bar{x} - T}{T} \cdot 100$$

where *x* is the mean of the results of (at least 10) replicate analyses of the check standard, and *T* is the true concentration. If the confidence interval on the mean includes *T*, the difference is probably due to random error rather than bias. The analyst will monitor check standard results and recalibrate the instrument when the difference exceeds the laboratory's control limits.

For matrix spikes, the percent recovery (%R) is given by

$$\%R = \frac{x_s - x}{C_s} \cdot 100$$

where x_s is the result for the matrix spike, *x* is the result for the unspiked sample, and C_s is the concentration of the spike added to the sample.

Confidence interval

The confidence interval (CI) will be estimated based on the mean of several sample results given by

$$CI = \bar{x} \pm t_{(1-\alpha,\nu)} s_x / \sqrt{n}$$

where *t* is the appropriate value of Student's-t statistic for the desired level of confidence (1 - α) and the number of degrees of freedom (ν).

Confidence intervals may be assigned to individual results when the sample population is greater than ten. The confidence interval for a result, *x*, is given by

$$CI = x \pm t_{(1-\alpha,\nu)} s_x$$

Measurement quality objectives

The *Hydrolab*® multi-meter will be calibrated to standard solutions both before and after each sampling event. Field instrument calibration checks for DO and specific conductivity will be assessed for bias using RPD. Instrument calibration checks for pH will be assessed by taking the difference between the observed instrument value and the predicted value from the check standard solutions. Table 12 shows the MQO for the *Hydrolab*® post-field calibration.

Table 12. Field instrument calibration measurement quality objectives (MQO).

Measured field parameter	Units	Data qualifier and definition		
		Accept	Accept with qualifier	Review for acceptability
Specific Conductivity (SpCond)	uS/cm	≤ ± 5%	> ± 5% and ≤ ± 10%	> ± 10%
Dissolved Oxygen (DO)	% saturation	≤ ± 5%	> ± 5% and ≤ ± 15%	> ± 15%
pH	standard units	≤ ± 0.25	> ± 0.25 and ≤ ± 0.5	> ± 0.5

Microbiological and analytical methods, expected precision of sample replicates, and method reporting limits and resolution are given in Table 13. The targets for analytical precision of laboratory analyses are based on historical performance by MEL for environmental samples taken around the state by the Environmental Assessment Program (Mathieu, 2006). The reporting limits of the methods listed in the table are appropriate for the expected range of results and the required level of sensitivity to meet project objectives. The laboratory's measurement quality objectives and quality control procedures are documented in the MEL *Lab Users Manual* (MEL, 2008).

Table 13. Field and laboratory precision measurement quality objectives (MQO) for laboratory samples.

Analysis	Method	Field replicate MQO (RSD)	Lab duplicate MQO (RPD)	Reporting limit
Fecal Coliform MF (FC)	SM 9222D	50% of replicate pairs < 20% RSD 90% of replicate pairs < 50% RSD	40%	1 cfu/100 mL
Dissolved Oxygen (DO)	SM4500OC	10%	NA	0.1 mg/L
Periphyton	Barbour *and others* (1999)	20%	20%	NA
Macroinvertebrates	Plotnikoff and Wiseman (2001)	20%	20%	NA

FC replicate results with a mean of less than or equal 20 cfu/100 mL will be evaluated separately.
SM: Standard Methods for the Examination of Water and Wastewater, 21st Edition (APHA et al., 2005).
RSD: relative standard deviation
RPD: relative percent difference

Twenty percent of FC samples will be duplicated in the field in a side-by-side manner to assess field and lab variability. The higher percentages of variability in lower results limit the effectiveness of the relative standard deviation (RSD) and relative percent difference (RPD) statistics for evaluating precision of water quality data, especially with bacteria parameters. For example, replicate results of 2 and 5 mg/L yield an RSD of 61% and an RPD of 86%, whereas results of 22 and 25 yield an RSD of 9% and an RPD of 13%. Each replicate pair is only 3 mg/L apart; however, the RSD and RPD between the two pairs are dramatically different. For this reason, projects where the mean of replicate pairs is relatively low may have difficulty meeting precision standards and will be reviewed separately by the project manager (Mathieu, 2006). In this case, the root mean squared error (RMSE) may be calculated to estimate the precision of replicate samples less than 20 cfu/100mL.

Before each and after each sampling event, the field instruments will be assessed for proper function. Table 14 shows the specifications of field instruments used for this study. The *Marsh McBirney* velocity meter will be checked and adjusted according to factory specifications.

Table 14. Field instrument specifications.

Analysis	Instrument	Method	Range	Accuracy	Resolution
Stream velocity	Marsh McBirney Flowmate	EAP056	0.01 to 5.00 feet/second	± 0.05 ft/s	0.01 ft/s
Continuous temperature	Hobo Water Temperature Pro v2	EAP044	-40° to 50°C	± 0.21°C	0.01°C
Instantaneous temperature	Hydrolab Sonde®	SM2550B-F	-5C° to 50°C	± 0.10°C	0.01°C
Specific conductivity	Hydrolab Sonde®	EPA120.1M	1 to 100,000 uS/cm	± (0.5% of reading + 1 uS/cm)	0.1 to 1 µS/cm
Dissolved oxygen	Hydrolab Sonde®	Hach 10360	1 to 60 mg/L	± 0.1 mg/L at ≤ 8 mg/L, ± 0.2 mg/L at > 8 mg/L	0.01 mg/L
pH	Hydrolab Sonde®	EPA150.1M	0 to 14 pH units	± 0.2 units	0.01 units

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). Sample precision 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

All laboratory samples will be analyzed at MEL except for DO using the Winkler titration method. DO grab samples will be analyzed at Ecology's Environmental Assessment Program wet-lab. The MEL's measurement quality objectives and quality control (QC) procedures are documented in the *Lab Users Manual* (MEL, 2008). MEL staff will follow standard quality control procedures. 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 et al., 2005) 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 of 24 hours for microbiological samples (MEL, 2008). Standard Methods (APHA et al., 2005) 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 denoted by a 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 fecal coliform 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. Replicates were compared to the measurement procedures in Table 14.

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 Environmental Assessment Program TMDL studies using the MF method, suggesting that a longer (that is, 24-hour) holding time has little effect on fecal coliform results processed by MEL. Samples with longer holding times did not show a significant tendency towards higher or lower fecal coliform counts compared to the samples analyzed within 6-8 hours.

Field

Another type of QA/QC is the calibration check for thermistors. The Onset Hobo Water Temp Pro v2© instruments will have a calibration check both pre- and post-study. This check will be to document instrument bias or performance at representative temperatures. A NIST-certified reference thermometer will be used for the calibration check. The calibration check may show that the thermistor differs from the NIST-certified thermometer by more than the manufacturer-stated accuracy of the instrument (range greater than ±0.21°C).

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

Variation for field sampling of stream 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 near the end of September 2013. Air temperature data and stream temperature data for each site will be compared to determine if the stream thermistor was exposed to the air due to stream stage falling below the installed depth of the stream thermistor.

At each fix-network site, the *Hydrolab®* DO probe will be checked against Winkler samples (SM4500OC) for QA/QC as described in Ecology's SOP manuals (EAP023 and EAP035). The results from the titrations and *Hydrolab®* data will be compared using RSD. RSD values greater than 10% will be assigned a data qualifier fulfilling the precision MQOs for DO. Bias will be evaluated between *Hydrolab®* readings and Winkler titrations by calculating the average residual. *Hydrolab®* DO data will be corrected if significant bias is found.

Data Management Procedures

Field measurement data will be entered into a notebook of waterproof paper or a field computer and then carefully entered into EXCEL® spreadsheets. Data will be checked to ensure transfer accuracy. This database will be used for preliminary analyses and Quality Assurance/Quality Control (QA/QC). Data will be uploaded by the project manager into Ecology's Environmental Information Management (EIM) System after verification and validation.

Sample results received from MEL by Ecology's Laboratory Information Management System (LIMS) will be loaded into EIM, exported, 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. Final data statistical analysis will be done using WQHydro (Aroner, 2003) or statistical roll-back software (Ott, 1995).

An EIM user study code (JKAR0004) has been created for this TMDL study and all monitoring data will be available via the internet. The web address for this geospatial database is: www.ecy.wa.gov/eim/. All finalized data will be uploaded to EIM by the EIM data engineer.

All spreadsheet files, photos, paper field notes, and Geographic Information System (GIS) products created as part of the data analysis will be kept with the project data files. Data that do not meet acceptability requirements will be separated from data files and not used for analysis.

Audits and Reports

The project manager is responsible for verifying data completeness before use in the technical report and entry into the EIM. The project manager is also responsible for writing the final technical report to the Water Quality Program watershed lead. The final technical report will undergo the peer review process by staff with appropriate expertise.

The final report will include analyses of results that form the basis of conclusions and recommendations. Results will include site-specific information for FC, temperature, riparian canopy assessment, DO, stormwater characteristics, water quality parameters, stream/drainage discharge measurements, and seasonal summaries.

Data Verification and Validation

Both data verification and validation require adequate documentation of the process.

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 developed by MEL (MEL, 2005). 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 set of samples.

Field notebooks will be checked for missing or improbable measurements before leaving each site. The EXCEL® Workbook file containing field data will be labeled DRAFT until data verification and validation 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. Valid data will be moved to a separate file labeled FINAL.

As soon as fecal coliform data are verified by MEL, the laboratory microbiologist will notify the project manager about results that exceed water quality criteria. The project manager will then notify the Southwest Regional Office (SWRO) client staff contact and Water Quality Program section manager of these elevated counts in accordance with Environmental Assessment Program Policy 1-03. The TMDL coordinator will notify local authorities or permit managers as appropriate.

Data received from LIMS will be checked for omissions against the Request for Analysis forms by the project manager. 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 MQOs in Table 11. Data requiring additional qualifiers will be reviewed by the project manager.

Data for stream 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 stream 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.

Data validation is the next step following verification. Data validation involves a detailed examination of the data package to determine whether the method quality objectives (MQOs) have been met. The project manager examines the complete data package to determine compliance with procedures outlined in the QA Project Plan and SOPs. The project manager is also responsible for data validation by comparing all data to MQOs for precision, bias, and sensitivity to assess data quality.

After data verification and data entry tasks are completed, all field, laboratory, and flow data will be entered into final file and then into EIM. Ten percent of the project data in EIM will be independently reviewed by another Environmental Assessment Program employee for errors. If significant entry errors are discovered, a more intensive review will be undertaken.

During periods of active data collection, quarterly progress reports will be prepared and distributed by the project manager to the Technical Advisory Committee. At the end of the field study, the data will be compiled and analyzed.

Data Quality (Usability Assessment)

The project manager will verify that all measurement and data quality objectives have been met for each monitoring station. If the objectives have not been met, consideration will be given to qualify the data, how to use it in analysis, or whether data should be rejected. Documentation of the data quality and decisions on data usability will provide accuracy and transparency of the QA/QC procedures. The data quality assessment methods and results will be documented in individual project data files and summarized in the final technical report.

Project Organization

Table 15 lists the people involved in this project. All are employees of the Washington State Department of Ecology.

Table 15. Organization of project staff and responsibilities.

Staff	Title	Responsibilities
Cindy James Water Quality Program Southwest Regional Office Phone: 360- 407-6556	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 and approves the QAPP and technical report. Prepares and implements TMDL report for submittal to EPA.
Kim McKee Water Quality Program Southwest Regional Office Phone: 360- 407-6407	Unit Supervisor of Project Lead	Reviews and approves the QAPP and TMDL report for submittal to EPA.
James Kardouni Directed Studies Unit Western Operations Section, EAP Phone: 360- 407-6517	Project Manager	Writes the QAPP. Collects field samples and records field information, coordinates field surveys with regional staff, oversees field sampling and transportation of samples to the laboratory. Conducts QA review of data, analyzes and interprets data, and enters data into EIM. Writes the technical sections of the draft report and final TMDL report.
George Onwumere Directed Studies Unit Western Operations Section, 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 TMDL report.
Robert F. Cusimano Western Operations Section, EAP Phone: 360- 407-6596	Section Manager of Project Manager	Reviews and approves the QAPP and technical sections of the TMDL report.
Joel Bird Manchester Environmental Laboratory, 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. Reviews and approves the QAPP.
William R. Kammin Phone: 360-407-6964	Ecology Quality Assurance Officer	Provides technical assistance on QA/QC issues. Reviews the draft QAPP and approves the final QAPP.

EAP: Environmental Assessment Program
EIM: Environmental Information Management system
QAPP: Quality Assurance Project Plan

Project Schedule

Table 16. Proposed schedule for completing field and laboratory work, data entry into EIM, and reports.

Field and laboratory work	Due date	Lead staff
Field work completed	February 2014	James Kardouni
Laboratory analyses completed	March 2014	
Environmental Information System (EIM) database		
EIM user study ID	jkar0004	
Product	Due date	Lead staff
EIM data loaded	July 2015	James Kardouni
EIM quality assurance	August 2015	
EIM complete	October 2015	
Quarterly reports		
Author lead	James Kardouni	
Schedule		
1st quarterly report	May 2013	
2nd quarterly report	August 2013	
3rd quarterly report	December 2013	
4th quarterly report	March 2014	
Final TMDL (WQIR) report		
EAP Author lead	James Kardouni	
EAP technical report sections -- Draft due to EAP supervisor.	March 2015 (Project Tracker)	
EAP technical report sections -- Draft due to WQP TMDL lead and technical peer reviewer. Policy review if warranted	April 2015 (Project Tracker)	
Optional (at WQP TMDL Lead discretion): Implementation sections added.		
Report draft due to external reviewer(s) (includes at a minimum the EAP technical sections).	June 2015 (Project Tracker)	
Draft WQIR due to Joan (all reviews and author revisions complete). Allow 4 to 6 wks for Joan to plain talk/edit report.	August 2015	
Joan transmits WQIR to WQP; report marked as complete in Project Tracker.	October 2015 (Project Tracker)	
Final WQIR posted on web by WQP.	October 2015	

Laboratory Budget

Table 17 shows the estimated lab budget for this study based on 18 sampling sites. The budget includes a 50% discount through MEL for FC analysis. The lab budget also includes an additional 10% for unexpected costs. For example, Table 9 lists 18 potential sampling locations that may be established in order to achieve the project objectives. However, some sampling locations may be removed from the list due to temporal lack of flowing water (stagnation or dry), limited accessibility, or lack of contribution to the project's primary goal. In either case, the lab budget is projected to cover expenses to the maximum extent necessary for this study.

Table 17. Estimated laboratory budget.

Parameter	Cost/ sample	Number of samples (including field QA)	Number of surveys	Total number of samples	Total cost
Fecal Coliform (FC)	24.93[1]	22	24	528	$13,163
Periphyton	300.00	7	1	7	$2,100
Macroinvertebrates	300.00	7	1	7	$2,100
4 storm sampling events (FC)					$3,590
Additional samples (e.g., for unknown sources)					$868
				Total:	$21,821

[1]Sample costs include a 50% discount through MEL

References

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

Allan, J.D., and M.M. Castillo, 2007. Stream Ecology: Structures and Function of Running Waters. 2nd Edition. Springer.

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

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

Baldwin, K., A. Whiley, P. Pickett and D. Moore, 2010. Pend Oreille River Temperature Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Spokane, WA. Publication No. 10-10-065.
https://fortress.wa.gov/ecy/publications/SummaryPages/1010065.html

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling, 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates, and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency, Office of Water, Washington, D.C.

Bilhimer, D., D. Gray and J. Jones, 2010. Tucannon River and Pataha Creek Temperature Total Maximum Daily Load: Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Spokane, WA. Publication No. 10-10-019.
https://fortress.wa.gov/ecy/publications/SummaryPages/1010019.html

Britsch, S., and J. Ratcliff, 2012. Washington's 2020 Clean Waters Plan A Plan to Re-invigorate the Federal Clean Water Act Polluted Waters Cleanup Program for Washington State. FACT sheet.

Brock, S., 2008. Upper Naches River Temperature Total Maximum Daily Load: Volume 1, Water Quality Study Findings. Washington State Department of Ecology, Yakima, WA. Publication No. 08-03-036.
https://fortress.wa.gov/ecy/publications/SummaryPages/0803036.html

Brown, M. T. and B. Vivas, 2005. Landscape development intensity index. Environmental Monitoring and Assessment 101: 289-309.

Casola, J.H., J.E. Kay, A.K. Snover, R.A. Norheim, and L.C. Whitely Binder, 2005. The Climate Impacts Group. 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).

City of Olympia, 1995. Impervious Surface Reduction Study: Final Report. Public Works Department, Water Resources Program, Olympia, WA.

Cleland, B., 2002. TMDL Development from the "Bottom Up" – Part II: Using Duration Curves to Connect the Pieces. America's Clean Water Foundation, Washington, DC 20002. www.tmdls.net/tipstools/docs/BottomUp.pdf

Cleland, B., 2003. TMDL Development from the "Bottom Up" – Part III: Duration Curves and Wet-Weather Assessments. America's Clean Water Foundation, Washington, DC 20002. http://www.tmdls.net/tipstools/docs/TMDLsCleland.pdf

Coffin, C., S. Lee and C. DeGasperi, 2011. Green River Temperature Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Bellevue, WA. Publication No. 11-10-046.
https://fortress.wa.gov/ecy/publications/SummaryPages/1110046.html

Cristea, N. and G. Pelletier, 2005. Wenatchee River Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 05-03-011. https://fortress.wa.gov/ecy/publications/SummaryPages/0503011.html

Cristea, N. and J. Janisch, 2007. Modeling the Effects of Riparian Buffer Width on Effective Shade and Stream Temperature. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-028.
https://fortress.wa.gov/ecy/publications/SummaryPages/0703028.html

Cummings, T., K. McKee, and A. Stohr, 2011. Salmon Creek Temperature Total Maximum Daily Load: Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Olympia, WA. Publication No. 11-10-044.
https://fortress.wa.gov/ecy/publications/SummaryPages/1110044.html

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

Ecology, 2012. Focus on Water Availability: Chambers-Clover Watershed, WRIA 12 (revised). Washington State Department of Ecology, Olympia, WA. Publication number 11-11-017. https://fortress.wa.gov/ecy/publications/SummaryPages/1111017.html

EPA, 2000. Nutrient Criteria Technical Guidance Manual Rivers and Streams. U.S. Environmental Protection Agency, Washington DC. EPA-822-B-00-002. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/guidance_index.cfm

EPA, 2007. Total Maximum Daily Loads with Stormwater Sources: A Summary of 17 TMDLs. United States Environmental Protection Agency (EPA), Washington DC. EPA-841-R-07-002 http://www.epa.gov/owow/tmdl/techsupp.html

EPA, 2013a. EPA's proposed stormwater permit for JBLM incorporates low impact development to protect Puget Sound. http://yosemite.epa.gov/opa/admpress.nsf/3881d73f4d4aaa0b85257359003f5348/4369eb5d47c94c1385257997007f1c09!OpenDocument

EPA, 2013b. Hydromodification and Habitat Alteration. http://water.epa.gov/polwaste/nps/hydromod.cfm

Hamlet, A.F. and D.P. Lettenmaier, 1999. Effects of climate change on hydrology and water resources in the Columbia River Basin. Journal of the American Water Resources Association, 35(6):1597- 1623.

Hayslip, G.A. (Ed.), 1993. EPA Region 10 In-Stream Biological Monitoring Handbook: for Wadable Streams in the Pacific Northwest. U.S. Environmental Protection Agency- Region 10, Environmental Services Division, Seattle, WA. 75 pp.

Johnson, K.H., Savoca, M.E., and Clothier, Burt, 2011, Numerical simulation of the groundwater-flow system in the Chambers-Clover Creek Watershed and Vicinity, Pierce County, Washington: U.S. Geological Survey Scientific Investigations Report 2011–5086, 108 p. http://pubs.usgs.gov/sir/2011/5086/

Joy, J., R. Noll, and E. Snouwaert, 2009. Hangman (Latah) Creek Watershed Fecal Coliform, Temperature, and Turbidity Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Spokane, WA. Publication No. 09-10-030. https://fortress.wa.gov/ecy/publications/SummaryPages/0910030.html

Karr, J.R., 1991. Biological Integrity: A long-neglected aspect of water resource management. Ecological Applications, 1:66-84.

Lee, S., D. Garland, and J. Burkey, 2011. Newaukum Creek Temperature Total Maximum Daily Load: Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Bellevue, WA. Publication No. 11-10-047. https://fortress.wa.gov/ecy/publications/SummaryPages/1110047.html

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. https://fortress.wa.gov/ecy/publications/SummaryPages/0403030.html

Lubliner, B., 2007. Characterizing Stormwater for Total Maximum Daily Load Studies: A Review of Current Approaches. Washington State Department of Ecology, Olympia, WA. Publication No. 07-03-006. https://fortress.wa.gov/ecy/publications/SummaryPages/0703006.html

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 Twelve Total Maximum Daily Load (TMDL) Studies and Recommendations for Precision Measurement Quality Objectives for Water Quality Parameters. Washington State Department of Ecology, Olympia, WA. Publication No. 06-03-044. https://fortress.wa.gov/ecy/publications/SummaryPages/0603044.html

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.

Mohamedali, T. and S. Lee, 2008. Bear-Evans Watershed Temperature and Dissolved Oxygen Total Maximum Daily Load: Water Quality Improvement Report. Washington State Department of Ecology, Bellevue, WA. Publication No. 08-10-058. https://fortress.wa.gov/ecy/publications/summarypages/0810058.html

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.

Moyle, P.B., L.R. Brown, and B. Herbold, 1986. Final report on development and preliminary tests of indices of indices of biotic integrity for California. Final report to the U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR.

Ostermiller, J.D. and C.P. Hawkins, 2004. Effects of sampling error on bioassessments of stream ecosystems: application to RIVPACS-type models. Journal of the North American Benthological Society 23(2):363–382.

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

Paul, M.J. and J.L. Meyer, 2001. Streams in the Urban Landscape. Annual Review of Ecology and Systematics. Institute of Ecology, University of Georgia, Athens, GA. 30602. Vol. 32: 333-365.

Pelletier, G., 2002. Wind River Watershed Temperature Total Maximum Daily Load. Washington State Department of Ecology, Olympia, WA. Publication No. 02-03-010. https://fortress.wa.gov/ecy/publications/summarypages/0203010.html

Pelletier, G. and D. Bilhimer, 2004. Stillaguamish River Watershed Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-010. https://fortress.wa.gov/ecy/publications/SummaryPages/0403010.html

Pierce County, 2005. Clover Creek Basin Plan, Volumes 1 and 2. Pierce County Public Works and Utilities Water Programs Division. Tacoma, WA.

Pierce County, 2011. 2011 Water Quality Index. Pierce County Public Works and Utilities. Tacoma, WA. https://www.co.pierce.wa.us/Archive.aspx?AMID=146

Plotnikoff, R.W. and C. Wiseman, 2001. Macroinvertebrate Biological Monitoring Protocols for Rivers and Streams: 2001 Revision. Washington State Department of Ecology, Olympia, WA. Publication No. 01-03-028. http://www.ecy.wa.gov/biblio/0103028.html

Pojar, J., and A. MacKinnon, 2004. Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia and Alaska. Lone Pine Publishing, ISBN: 9781551055305

Roberts, M., 2003. South Prairie Creek Bacteria and Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-021. https://fortress.wa.gov/ecy/publications/SummaryPages/0303021.html

Runge, J., M. Marcantonio, and M. Mahan, 2003. Salmon Habitat Limiting Factors Analysis Chamber-Clover Creek Watershed (Including Sequalitchew Creek and Independent Tributaries) Water Resource Inventory Area 12. Pierce Conservation District. http://www-stage.scc.wa.gov/wp-content/tmp/2012/04/WRIA_12_LFA_Final.pdf

Savoca, M.E., Welch, W.B., Johnson, K.H., Lane, R.C., Clothier, B.G., and Fasser, E.T., 2010. Hydrogeologic framework, groundwater movement, and water budget in the Chambers-Clover Creek Watershed and vicinity, Pierce County, Washington: U.S. Geological Survey Scientific Investigations Report 2010-5055, 46 p.

Schueler, T.R., 2000. The Importance of Imperviousness. Watershed Protection Techniques 1(3):100-111.

Sinclair, Kirk, 1986. Intermittent Flow on Clover Creek: Causes and Possible Solutions. Washington State Department of Ecology, Olympia, WA.

Stohr, A., 2004. Willapa River Watershed Temperature Total Maximum Daily Load Study. Washington State Department of Ecology, Olympia, WA. Publication No. 04-03-024. https://fortress.wa.gov/ecy/publications/SummaryPages/0403024.html

Stringfellow, W.T., 2008. Ranking Methods to Set Restoration and Remediation Priorities on a Watershed Scale. Water Science and Technology, 58.10. IWA publishing.

Studley, S., 2001. Estimated flow-duration curves for selected ungaged sites in Kansas. USGS Water-Resources Investigations Report: 2001-4142. http://pubs.er.usgs.gov/publication/wri014142

Svrjcek, R., A. Stohr, and J. Kardouni, 2011. Snoqualmie River Basin Temperature Total Maximum Daily Load - Water Quality Improvement Report and Implementation Plan. Washington State Department of Ecology, Olympia, WA. Publication No. 11-10-041 https://fortress.wa.gov/ecy/publications/SummaryPages/1110041.html

Tobiason, F., 2003. Historic Flows, Flow Problems and Fish Presence in Clover Creek---1924-1942: Interviews with Early Residents. Tacoma, WA. http://www.piercecountywa.org/archives/100/CCHistoricFlows.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

Water Quality Program, 1999. Upper Chehalis River Temperature Total Maximum Daily Load. Washington State Department of Ecology, Olympia, WA. Publication No. 99-52. https://fortress.wa.gov/ecy/publications/summarypages/9952.html

Wenger, S., 1999. A review of the scientific literature on riparian buffer width, extent, and vegetation. Office of Public Service and Outreach, Institute of Ecology, University of Georgia, Athens, GA.

Wiseman, C.D., 2003. Multimetric index development for biological monitoring in Washington State Streams. Washington State Department of Ecology, Olympia, WA. Publication No. 03-03-035. 48 pp. http://www.ecy.wa.gov/biblio/0303035.html

Wright, J.F., 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. Australian Journal of Ecology 20: 181- 197.

Yuan, L., D. Thomas, J. Paul, M. Paul, and M. Kenney, 2010. Using Stressor-response Relationships to Derive Numeric Nutrient Criteria. United States Environmental Protection Agency (EPA). Washington, DC. EPA-820-S-10-001. http://water.epa.gov/scitech/swguidance/standards/criteria/nutrients/guidance_index.cfm

Appendix. Glossary, Acronyms, and Abbreviations

Glossary

1-DMax or 1-day maximum temperature: The highest water temperature reached on any given day. This measure can be obtained using calibrated maximum/minimum thermometers or continuous monitoring probes having sampling intervals of thirty minutes or less.

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.

90th percentile: An estimated portion of a sample population based on a statistical determination of distribution characteristics. The 90th percentile value is a statistically derived estimate of the division between 90% of samples, which should be less than the value, and 10% of samples, which are expected to exceed the value.

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.

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.

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.

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

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

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

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 water's loading capacity attributed to one or more of its existing or future sources of nonpoint pollution or to natural background sources.

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

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

Municipal separate storm sewer systems (MS4): A conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, manmade 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, stormwater, 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, 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.

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

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

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.

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

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

Stormwater: The portion of precipitation that does not naturally percolate into the ground or evaporate but instead runs off roads, pavement, and roofs during rainfall or 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 mature riparian vegetation: Vegetation which can grow and reproduce on a site, given climate, elevation, soil properties, plant biology, and hydrologic processes.

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

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

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

Acronyms and Abbreviations

BOD	Biochemical oxygen demand
BMP	Best management practice
DO	Dissolved oxygen
Ecology	Washington State Department of Ecology
FC	Fecal coliform bacteria
EPA	United States Environmental Protection Agency
GIS	Geographic Information System software
JBLM	Joint Base Lewis-McChord
LiDAR	Light Distance and Ranging
NAF	New Approximation Flow
QA/QC	Quality Assurance/Quality Control
RM	River mile
TMDL	Total Maxim Daily Load
USGS	United States Geological Survey
WAC	Washington Administrative Code
WQA	Water Quality Assessment
WRIA	Water Resource Inventory Area
WSDOT	Washington State Department of Transportation

Units of Measurement

°C	degrees centigrade
cfs	cubic feet per second
ft	feet
g	gram, a unit of mass
km	kilometer, a unit of length equal to 1,000 meters
l/s	liters per second (0.03531 cubic foot per second)
m	meter
mg	milligrams
mg/L	milligrams per liter (parts per million)
mL	milliliters
ug/L	micrograms per liter (parts per billion)
uS/cm	microsiemens per centimeter, a unit of conductivity